

Reviewing Resource Leveled Schedules Using P6™

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Abstract

Standard CPM schedule review techniques are insufficient to review automatically resource leveled schedules. When faced with the task of reviewing resource leveling, most reviewers try to pretend that it does not exist and ignore this facet of the schedule submittal.

This paper provides a guide to effective review of resource leveling that can be used on construction projects utilizing an Oracle/Primavera P6 Professional™ CPM schedule. This paper also discusses a large number of issues and guidelines to be considered when evaluating an automatically resource leveled CPM schedule.

Beginning with issues such as how to identify if resource leveling has been used, this paper delves into the analysis of the root causes of resource delay and techniques for separating reality from error. Causes for rejection of a resource leveling procedure are covered. Methods for validating how well the plan was executed are explained. Using these procedures, the reviewer can potentially know more about the resource leveled schedule than the person who submitted it.

Introduction

A useful schedule must take resource constraints into consideration.[9] The Oracle/Primavera P6 Professional™ (P6) built-in function for automatic resource leveling (resource leveling) is one method to perform this task. When preformed transparently and correctly, the schedule should be able to show an adequate representation of the actual scheduling plan, including resource considerations.

For the purposes of context, this paper assumes that an owner of a project (Owner) has contracted with a second party (Contractor) to construct or otherwise create, build, or revise a project. The Contractor's supervisor who will direct the work (foreman) explains his or her workplan to the person responsible for modeling this workplan (scheduler.) Thus, the Contractor communicates their time-based work plan to the Owner using a CPM schedule created by a scheduler. The Owner's representative (reviewer) is responsible for evaluating the quality and usability of that submitted schedule.

Most schedules have similar activities performed by the same skill group of workers that cannot all realistically be accomplished at the same time. Without using resource leveling, schedulers must sequence activities that are using the same skilled resources by adding date constraints (which is discouraged) or sequencing the work activities by

adding preferential 'soft' logic (which is better.) However, as the project progresses the original soft logic must be modified to reflect the ever-changing resource assignments. This process becomes a lot of work for the scheduler to perform and is error-prone.[1][2][3]

Modifying soft logic to reflect resource constraints becomes even more difficult if project Owners are resistive to allowing logic changes in the schedule updates. In fact, it might be argued that using resource leveling is the only allowable method to sequence resource constrained activities on projects that put up high barriers to adding constraints and modifying logic.

Using resource leveling can be a much simpler method to employ and will normally produce much better results than manual logic revisions. Despite this fact, Project Owners may not be amenable to receiving schedules employing resource leveling as the submitted contract schedule. This hesitancy is due in part to the fact that 'standard' schedule review techniques do not necessarily apply to automatically resource leveled schedules. When faced with the task of reviewing a resource leveled schedule, most reviewers try to pretend that resource leveling was not used and ignore this facet of the schedule submittal. Ignoring parts of the schedule submittal can be a very dangerous practice.

What is Resource Leveling?

Resource leveling is used to identify excessive daily staffing levels. The software then re-sequences those overstaffed activities to reduce or eliminate these staffing excesses. In addition to preventing the scheduling of an impossible or difficult level of work at the same time, it also can provide a much more economic staffing plan.[1] Therefore, the reviewer of a resource leveling plan should have a good understanding of defining task resources and the resource-leveling process employed.[6][18]

A simple example of P6 resource leveling will quickly show the benefits of using this process for activity sequencing. Figure 1 displays a simple schedule fragment displaying a typical mechanical installation sequence. Activities C1010 through C1040 can be performed in any order but because there is only one crew (limited resources,) only one of the four activities can be performed at the same time.

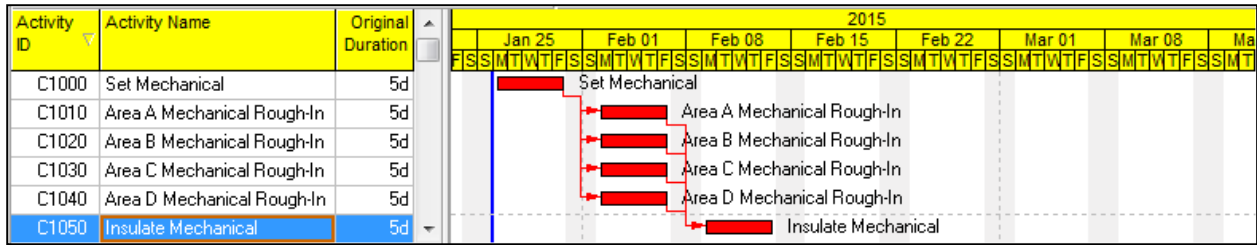


Figure 1, Schedule Example before Resource Leveling

Figure 2 displays the effects of using the resource leveling process. Activity C1010 was executed immediately and the other three Mechanical Rough-In activities were delayed to prevent resource over-staffing. The last activity in the fragnet, Activity C1050 is also delayed as a secondary result of the logical relationship with Activity C1040.

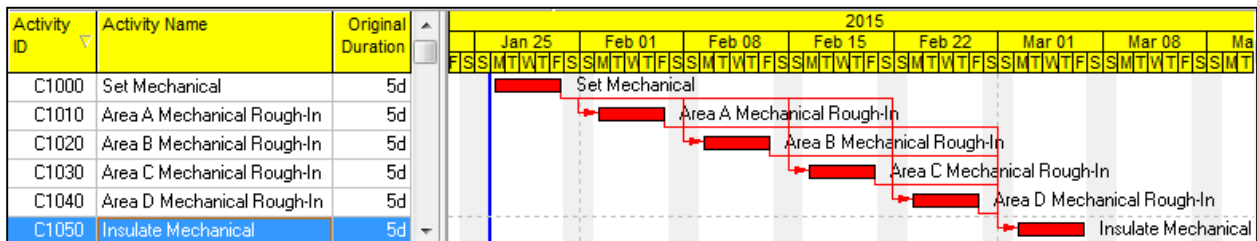


Figure 2, Schedule Example after Resource Leveling

Because of the inherent complexity of resource-constrained scheduling algorithms, the project durations of resource leveled schedules can be 10, 20, or 50 percent longer than needed.[7] Even if a resource leveled baseline schedule meets the required project completion date, small activity delays during the project can be greatly magnified when the resource leveling process is imposed.[1] If a resource leveling plan is to be accepted, it is crucial that it be sufficient and robust enough to also provide reasonable results if and when an unexpected activity delay occurs.

Since resource leveling is expected to delay some activities and schedule others immediately, there must be some criteria on which to base these planning decisions. The resource leveling process, in part employs a user-configurable resource priority plan. The priorities should mimic the foreman's intent of how they intend to deploy the resources.[2] The goal of this leveling process is to reduce daily overstaffing while also minimizing the impact of those delayed activities on the overall project completion date.

The formal description of the resource algorithm used by P6 is Nondeterministic, Polynomial-Time-Complete.[8] Mathematically, these type of processes have no known optimal solution. The resource priority process is a part of the pre-determined set of rules (heuristics) used to reschedule activities that are resource leveled. Heuristics are just 'rules of thumb' and cannot guarantee an optimal resource leveling plan.

The first step of the resource leveling process considers activity logic. No activity can be considered for resource leveling until all predecessors have first been resource leveled. If more than one activity has no outstanding predecessors needing to be resource leveled, then the user-customized priority plan is considered to decide which activity goes next.[18]

There is no such thing as an optimum resource priority leveling plan, so both the scheduler and reviewer should try several different 'best guesses' to see which one delivers the best plan (i.e. shortest project.) The P6 resource leveling process can use any combination of the following properties as resource leveling priorities,

- Activity ID
- Activity Priority
- Early Finish
- Early Start
- Free Float
- Late Finish
- Late Start
- Original Duration
- Planned Finish
- Project Planned Start
- Project Priority
- Remaining Duration
- Total Float
- (any defined activity code)

Finally, if a tie still exists between activities in determining the next activity to be considered for resource leveling, P6 simply chooses the oldest activity. There cannot be a tie in this last test. This last condition is not reported on in the log.

By using first logic and then the priority list options to select the next resourced activity to be scheduled, the activity's computed early scheduled dates are considered to see if the activity will 'fit' in the time slot and not exceed the remaining allowable maximum daily resource tally for each day. If each day's resource requirement for that activity is under the remaining maximum for each day, then that activity is scheduled for that time slot and each day's remaining daily allowable maximum is reduced by that amount.

Each subsequent activity on the priority list is similarly reviewed and if that activity does not meet the requirements for any given day, then that activity is delayed until it can

meet the maximum resource totals for each day scheduled. All logical successor activities to the delayed activity are then re-scheduled using CPM rules to adjust their early dates.

This 'secondary delay' may even delay activities yet to be resource leveled, delaying the starting point where the process will start looking for their available time slots. Even though the logical successor activities to the delayed activities have new dates recomputed, P6 does not re-calculate the activity's Total Float values which remain the same as before resource leveling. It does update the Remaining Total Float column.

Prioritizing resources based upon the activity's Total Float is typically amongst the better priority options to use to create shorter duration resource leveled schedules. In general, this means that you should try to schedule the critical activities first and let the activities with more float be delayed, using up some or all of their Total Float.

Another resource priority should be to promote project continuity. Sadly, P6 does not appear to have a resource property option that would give priority to activities that have already started. The lack of this ability to prioritize just started activities often causes the P6 resource leveling process to suspend the work and delay these activities due to resource constraints. Actual Start or Percent Complete would be useful options for this purpose but are not currently available in the P6 options list.

Resource Leveling by Activity Codes

Schedules can also be resource leveled using activity codes instead of resources. By setting the activity code hierarchy to match the priorities as described by the foreman responsible for directing the work, P6 will resource level then in that order, provided your resource leveling priorities list is set to sort activity codes using hierarchical sort order. Changing the priorities is merely a matter of adjusting an activity code up or down in the activity code hierarchy list.[2]

This process of resource leveling on activity codes instead of resources can be extended to more than scheduling repetitive series of activities; schedulers can also solve issues like separating work in elevated portions of a large workspace from work occurring below. For example, the elevated work activities can be coded as Upper-Area and those below coded as Lower-Area. Then limit the schedule to only resource level work on one area at a time and resource leveling has seamlessly guaranteed that this construction restriction is observed while performing normal CPM scheduling.

Issues in Reviewing a Resource Levelled Schedule

Resource levelled schedules are both difficult to properly create and to review. Many schedulers have tried to use this technique on projects and have failed. Some of the problems with actually employing resource leveling on an actual project include,

- Total Float values may not reflect the true 'resource float.' Resource leveling overrides pure CPM logic and duration calculations. A resource-levelled activity can delay the project and still indicate positive total float in P6. A high-float activity may 'tie-up' a resource that is needed by a low-float activity in order for the work to proceed. For this reason, a resource levelled schedule is not a 'true' CPM schedule in the traditional sense.[9]
- Lack of transparency. It is often difficult to understand the process involved in resource leveling as well as difficult to observe the results. The P6 software provides very little information or explanation about the operation of the process or results.
- There is no one optimum solution. Subsequent schedule updates may reflect large swings in the planned project completion date using the same resource leveling parameters, necessitating priority changes.
- Large variations. The resource leveling process requires trial and error and can produce large variation in the outcomes from minor input changes.

Although there are issues to be overcome, the result of properly employing resource leveling provides a robust and responsive model for project planning. Resource leveling adds 'real-world' considerations into schedule planning that previously was only resolved at the last minute in the field. When a resource levelled schedule is submitted, the reviewer must be able to analyze and understand the plan and its ramifications.

Does the Owner have a Right to Review Resource Leveling Plans?

Most construction contracts do not specifically specify whether the Owner has the right to review the Contractor's resource leveling plan. In the absence of specific language, some contractors have argued that resource leveling represents the Contractor's means and methods and is thus not subject to Owner's review.[4] Since the resource leveling plan represents their internal sequencing of planned work, Contractors may reason that it is not subject to the Owner's review and approval.

The P6 resource leveling plan is generally inferior to the process implemented by the project foreman in the actual work place. For example, P6 resource leveling does not have the ability to smooth out the potential fluctuations in required manpower. P6

resource leveling does have the ability to increase the resource maximum by a started percentage if resources cannot be leveled within the activity's float but this is not real 'smoothing.' [5] The process does not intentionally try to bridge gaps in manpower usage. This means that a foreman's manpower management is more complex than what an automatic resource leveling software function can perform. In this respect, a P6 resource leveled schedule does not meet the working definition of traditional 'means and methods.'

Because a resource leveling output may represent the foreman's desired staffing plan does not mean that any resource leveling output is correct or that it must be accepted by the Owner without review. It is therefore unacceptable to say that an improperly configured resource leveling computation using bad inputs and unreasonable limitations represents the Contractor's 'Means and Methods.'

Ultimately, a resource staffing plan that was generated by a computer with little input from field personnel and that will not be followed in the field is not a representation of the contractor means and methods. The staffing plan and the execution must closely align for this to be a consideration. Just as any CPM schedule must be transparent and shown to be reasonably and correctly designed before the calculated dates and float can be valid and used as a basis of control, the same thing holds true for computer-generated resource leveling.

The conclusion to be drawn is that the Owner has the right to review resource leveling plans before resource leveling can be considered as a legitimate part of the scheduling discussion. Certain resource leveled plans may be found to be incomplete and inaccurate and should normally be rejected as a basis of planning, monitoring, and controlling the project.

Determining if Resource Leveling Has Been Used

It is very difficult to know if resource leveling has been accomplished for any given schedule with most scheduling software packages. Scheduling packages like P6 do not have a 'flag' or indicator saying that the submitted schedule has been resource leveled. Therefore, when receiving a schedule submittal, the reviewer should resist the impulse to first recalculate the schedule dates. This process is often the first step taken during a CPM schedule review.

Before recalculating the CPM, the schedule reviewer must first determine if resource leveling was used in the submitted schedule. If this step is ignored, re-scheduling will

remove all resource leveling effects and cause the reviewer to analyze a different schedule from that which was submitted.

For P6 schedules, one quick check for resource leveling can be made by looking to see if the Project Early Finish date does not equal the Project Forecasted Finish date. If they do not match then resource leveling has been used and the project has been extended. Project Forecasted Finish is created by resource leveling. This check does not produce different dates in cases where the project end date was not extended due to resource leveling.

A better indication of resource leveling is if the Early Start date does not equal the Remaining Early Start date for any activity.[10] To be effective, this check requires that the P6 resource leveling option “Preserve scheduled early and late dates” be selected or checked (so that resource leveling does not overwrite the Early Start date.)

Remaining Early Start dates are created by resource leveling, as shown in Figure 3 below. Reviewers will need to export these dates to a spreadsheet in order to spot which activities have mismatched Early Start dates and Remaining Early Start dates. This is a sure sign that the activity was delayed due to resource leveling.[11]

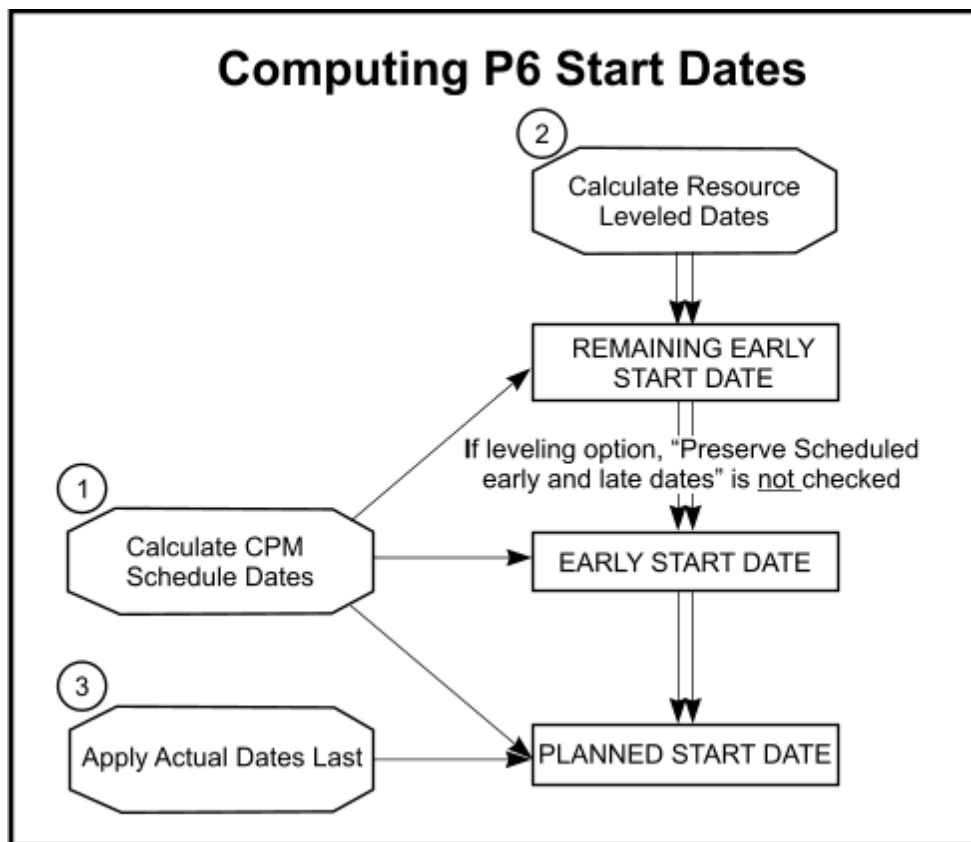


Figure 3, Computing P6 Start Dates

Calculating the CPM scheduling dates overrides all three of the early dates. Resource leveling will then overwrite the Remaining Early Start Date and potentially the Early and Planned Start Dates if the resource leveling option allows. Actual Dates will always override any Planned Start Date entries, regardless of other processes.

The P6 resource leveling process also creates the Remaining Early Finish dates. A similar chart may be created for determining the computation of Remaining Early Finish, Early Finish, and Planned Finish Dates as show in Figure 4,

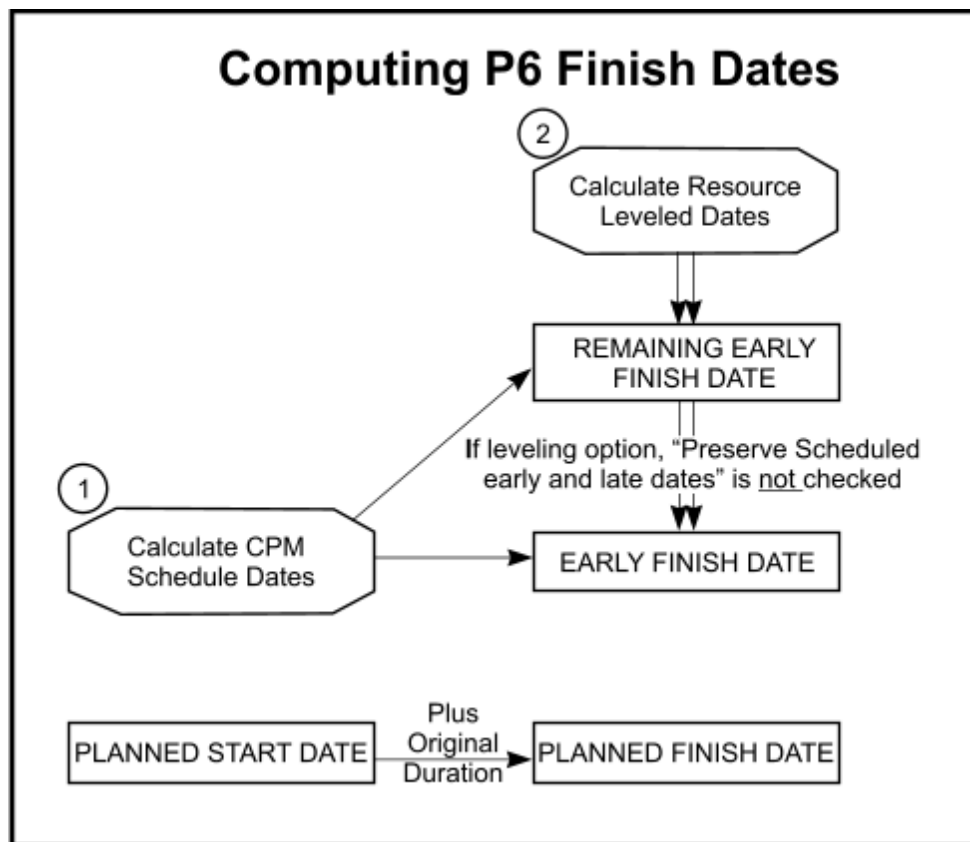


Figure 4, Computing P6 Finish Dates

A third indicator that P6 resource leveling has been performed is to check the column, Remaining Float. Remaining Float is calculated as the difference between Late Finish and Remaining Early Finish. Remaining Float will be equal to Total Float when the activity is unstarted and resource leveling is not used. When Total Float is not equal to Remaining Total Float, then this is an indication that the activity as delayed due to resource leveling.

If resource leveling is used, then the Remaining Early Finish might be different than Early Finish date. In this case, Remaining Total Float will have a different value than

Total Float. In other words, Remaining Float is a resource-dependent float. Figure 5 demonstrates this by displaying early bars in green and remaining bars in red.

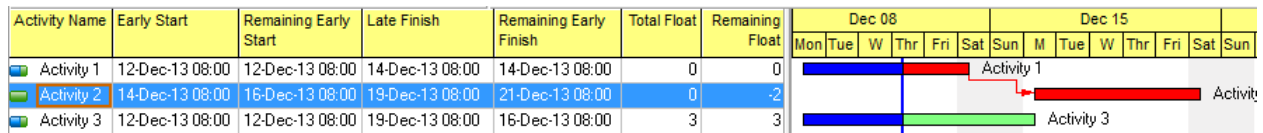


Figure 5, Remaining Total Float after Resource Leveling

Of course, the scheduler should not make the reviewer ‘guess’ as to whether resource leveling was used on the submitted schedule. A Schedule Narrative should be submitted with any schedule submittal clearly stating this.

The narrative should state that resource leveling has been employed and exactly what settings and priority list was used. The level of abstraction for resource definition should be explained. It should state what resource limits were used and what those limits represent. The Narrative should also clarify whether or not the Contractor planned to use any overtime during the project in excess of the maximum limits set. The schedule submittal should also include a copy of the P6 resource leveling log and it should list which resources were used for resource leveling and which activities were delayed.

Review Issues

Several general issues should be considered before a detailed resource leveling review is performed.

Resource Definition. All resource types are an abstract description of labor, material, or expenses used on a project. The level of that abstraction is an important consideration. The definition should only be a detailed as needed to model that resource in the schedule.

Resource definition is an important issue for useful resource leveling. The level of detail should not be too specific or too general. Resources should not be named, “George” or “Mary” because you cannot resource level a ‘George.’ There is also the issue of what is an equivalent for a missing ‘George?’

Constraints. The schedule should not mix constraints, soft logic, and resource leveling for any given resource, especially for critical resources. A resource leveled schedule can be turned into a CPM schedule by adding date constraints or soft logic but this is not recommended. Mixing the methods at the same time reduces transparency and accuracy. It can be very difficult to discern if the soft logic used is interfering with the optimum solution for resource leveling.

All assigned activity constraints are considered during the resource leveling process except for As Late As Possible and Expected Finish constraints. Those two constraints are ignored by the resource leveling process. Activities with mandatory constraints are leveled first, regardless of logic or leveling priorities.[18] After resource leveling activities with mandatory constraints, then logic is considered, followed by priorities.

Longest Path. After resource leveling, the CPM Scheduling log can list longest path activities that later fail to show up using the Longest Path filter. Resource leveling can 'hide' the longest path. Using resource leveling to delay the start of an activity originally on the longest path disrupts the backward-looking controlling logic process used. Even critical activities with zero total float that are delayed due to resource leveling may drop from the longest path list. The total float values will remain the same as before the activities were delayed even though they may no longer be a part of the computed longest path.

Total Float. One of the problems with resource leveling is that P6 does not automatically adjust float after manually moving the activity. Both Total Float and Free Float remain at the original CPM-calculated settings.

Remaining Total Float. To better reflect a picture of the resource float, one needs to refer to the Remaining Total Float field. Remaining Float is calculated as the difference between Late Finish and Remaining Early Finish. Even this is somewhat misleading as float adjustments that simply subtract the number of working days delayed from the CPM calculated values would still not accurately reflect the real float values of resource-leveled activities.[10]

Suspended Activities. The P6 Suspend Activity function is another source of potential error. Resources assigned to a suspended activity are considered available for assignment to other activities until the resume date of the suspended activity. [12]

LOE and WBS Summary Activities. It is problematic to apply resources to Level of Effort (LOE) or WBS summary activities. This type of activity summarizes the time durations of associated activities and can stretch or shrink in duration as the project progresses. Some of the reasons for LOE and resource conflicts are, [5]

- The percent complete on LOEs can increase and can even decrease unexpectedly, each time you update based on the predecessor and successor activities of the LOE. If you are calculating actuals based on percent complete, your actuals may not be consistent each month.

- Many software packages update and compute Earned Value and other cost metrics differently, depending upon software settings used. It can be very difficult to troubleshoot the cause for Earned Value differences on the same schedule as seen on different computers.
- Earned value of a LOE is computed differently than earned value on an activity and can vary wildly.
- Resource curves to a resource on a LOE activity can constantly change because the duration of a LOE activity can constantly change.
- Resources on LOE and WBS Summary activities are not taken into account during resource leveling in P6. To be fair, it would be very complicated to include these two types of activities into the resource leveling process. If P6 were to delay a LOE activity due to resource leveling, then it would also need to delay all activities being summarized. Unlike Microsoft Project, P6 is not designed to let summary activities control the timing of activities being summarized.

LOE and WBS Summary activities should not have critical resources assigned to them. It is preferable that no resources be assigned to these types of activities.

Identifying Critical Resources

Not every type of resource used in a schedule needs to be resource leveled. Typically, only critical resources in the schedule should be resource leveled. A critical resource is any resource that causes any activity to be delayed during resource leveling. All critical resources should be identified in the Schedule Narrative submittal that accompanies the electronic schedule submittal. A review of the resource leveling plan should include a detailed review of all critical resource availability, assignment, and maximum limits.

The reviewer should check the list of critical resources for completion by selecting all resources for resource leveling, de-selecting any listed critical resources, and then activating resource leveling using the remaining resources. Any activities identified as being resource delayed in the resulting log should be investigated and the resource causing this delay should be added to the list of critical resources.

All critical resources should be considered for reasonableness. It would be unusual for generic resources such as “General Labor” to be a critical resource unless the project involves highly constrained areas or work in a remote location. Just as with critical activities, critical resources should get special attention and more in-depth study.

Resource leveling is typically only performed for ‘critical’ resources that are likely to result in staffing problems. Resource leveling ‘minor’ resources that are unlikely to be

involved in critical work and not in short supply just adds to the complexity of the process, reducing transparency and increasing chances for error.

Resource Leveled Schedules Review Procedures

The resource leveling issues listed above must be first considered in general while performing a review. Once understood, then specific procedures listed below should be considered.

Confirm Settings. The reviewer should confirm that the provided electronic schedule produces the same resource leveling plan as that which was submitted by the Contractor by referring to a listing of activity dates. Both the non-leveled and the resource leveled schedule should be reviewed and compared. It is not necessary to receive two schedules from the Contractor (the non-leveled one and the resource leveled one) as the reviewer can re-create the non-leveled schedule by just making a copy of the resource leveled schedule and then having the software re-calculate the CPM of the copied schedule.[18]

Reviewers should confirm the resource leveling procedure inputs by replicating the results using the review copy of the schedule. See the Figure 6 below to view the P6 resource leveling options. The resource leveling option, "Log to file" should be checked and log file name and location should be confirmed. The log file has an odd quirk when reporting resource leveling options; when many of the options are activated, it reports the fact but when those same options are set to, "No" then the notice on the option is missing from the log. A missing notice of a resource option setting indicates that the option was not used.

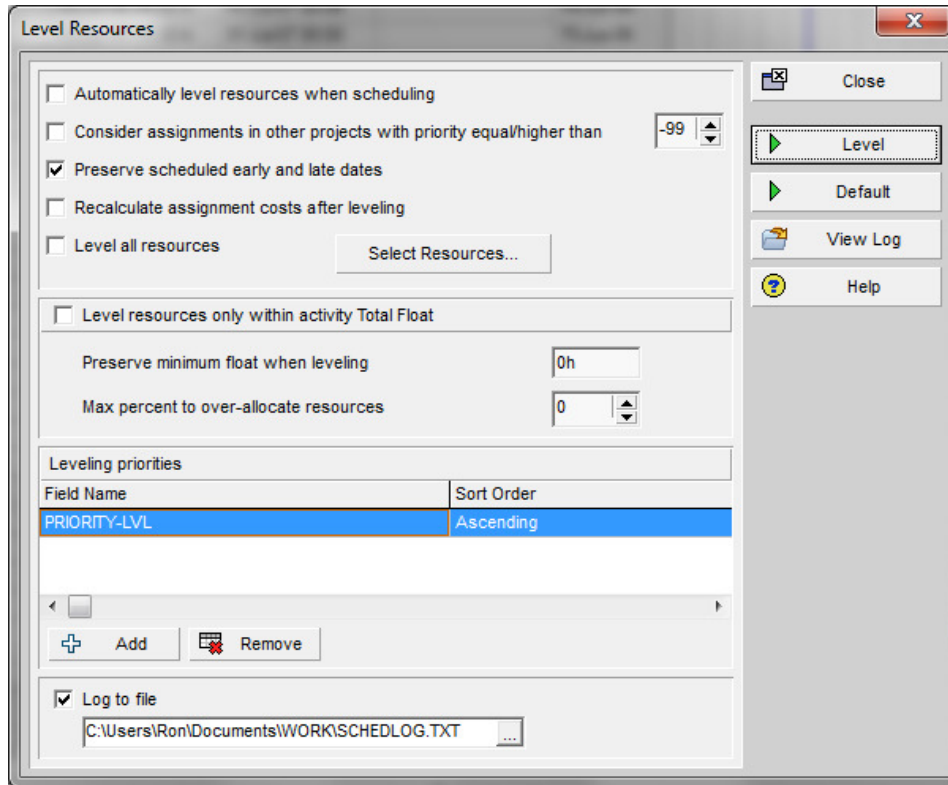


Figure 6, P6 Level Resources Screen

The reviewer should look to see if the published results of resource leveling match the copy of the schedule. The Contractor’s scheduler may have incorrectly included other outside projects during resource leveling, thus using up resources meant for the project being reviewed. Confirm that the setup is not accommodating resource needs from other schedules by listing all activities using a particular resource for each day. Activities from separate projects will be grouped by project.

The reviewer may even find that a restored Baseline Schedule is also using the needed resource. While resources in archived baseline schedules should not be counted as part of the required work, this erroneous condition has occurred in earlier versions of P6.

In addition to confirming that the settings are the same as used by the Contractor’s scheduler, the reviewer must determine if the correct or appropriate settings were used. Various entry fields in the Level Resources screen must be analyzed.

Separate Scheduling from Resource Leveling. It is best to schedule the CPM without automatic resource leveling set to occur at the same time. Separating the two functions allows the reviewer to isolate CPM scheduling issues from resource leveling issues. Always check the log after scheduling and after resource leveling. P6 uses the

same log file for both functions so the reviewer must save a copy of the log file after scheduling and before resource leveling.

Consider assignments from other projects with priority equal/higher than. P6 resource leveling always levels all activities in all open schedules. It will additionally consider assigned resources in closed projects if they have a project priority number equal to or smaller (higher is smaller numbers) than the listed priority number.

The 'consideration' process does not resource level the closed projects but uses their current daily assignments and first reduces the daily availability totals by this amount before performing resource leveling. The closed projects get 'first dibs' on the assignment slots, potentially delaying currently open activities and the project.

Preserve scheduled early and late dates. As stated earlier, selecting this option prevents P6 from over-writing the calculated early and late dates for the activity with the resource leveled dates. This provides an indicator that resource leveling was used. It also means that only forward resource leveling was employed.

When the Preserve scheduled early and late dates option is turned off, P6 resource leveling also performs a backward resource leveling process. Instead of starting at the beginning of the project and predicting the earliest finish date of the project, it starts at the project earliest finish date and calculates when each activity should have started and, in effect calculates when the project should have started in order to complete on time when activities are resource leveled. This process can create negative total float values.

Resource Leveling More than One Resource at a Time. P6 uses a complicated set of rules when resource leveling more than one resource at a time. If you resource level a Task dependent activity with driving and nondriving resource assignments, P6 Professional requires that all resources be available in order to place the activity.

There are different rules used when resource leveling Resource Dependent activity types,[17]

- If the activity has driving and nondriving resource assignments, P6 requires that all driving resources assigned to the activity be available in order to place the activity. All nondriving resources will be resource leveled on or after the activity dates, which are driven by the driving resources.

- If the activity has nondriving resource assignments, P6 will place the resources on or after the earliest possible start date of the activity. These resources can be placed any time in the future after this candidate date.
- If the activity has a combination of driving and nondriving resources, and the driving resource succeeds in finding availability, while the nondriving resource fails, the nondriving assignment dates will be delayed based on where the driving resources are placed.

For practical purposes, it is important to only resource level one P6 resource at a time. One reason for this restriction is that P6 does not list the name of the resource that caused the activity to be delayed. If more than one resource is resource leveled at the same time, the reviewer cannot determine which resource(s) caused the delay. Figure 7 below shows a typical P6 resource leveling log's list of resources that were resource leveled at the same time,

Resources to be leveled.....	4
Resource: Finisher	Finisher
Resource: FOREMAN	Foreman
Resource: LABOR-G	General Laborer
Resource: VIBRATOR	Gas Engine Vibrator

Figure 7, P6 Resource Leveling Report Excerpt: Resources to be Leveled

The only way to know what resource caused the delay is to level on one resource at a time and analyze the results after each run. The resource-delaying process is accumulative and will not negate previous adjustments due to other resource leveling runs against other resources. To prevent errors, do not re-calculate the CPM after each resource leveling run.

Limited Resource Leveling. P6 has an optional resource leveling setting that stops it from delaying an activity beyond its available float called, “Level resources only within activity Total Float.” It is important to note that according to P6 documentation, [18] this function only works if the other option, “Preserve scheduled early and late dates” is also checked.

If the limit is set to 0, then this option usually prevents the schedule from being delayed past normal CPM early completion. In this situation, the activity may end up being scheduled in a time period that exceeds the maximum resource availability. If this setting was used for a previously approved schedule, then it would be incorrect to change this setting in later submittals.

There is a potential for error in the entry of the Total Float value in this field. P6 automatically converts the daily float value entered into hours. This conversion uses the single Administrative setting or the Default Calendar's setting for days to hours. Entries other than 0 may be incorrectly interpreted by activities using different calendars and different number of hours per day settings when converting back to days.

There is a second potential for error; incorrect activity float values.[9] If the activity being investigated has already been delayed by a previous resource-leveled activity, then the activity's listed Total Float is likely to already be higher than it should be before resource leveling. The Total Float of the delayed activity is not lowered to reflect the previous delay. The delayed activity started off missing some of its CPM-computed float when the predecessor activity delayed it. In this case, the delayed activity does not have the entire computed Total Float to 'lose' and the project may be unintentionally extended even though this setting should have prevented that situation.

Over-Allocation of Resources. Should P6 resource leveling fail to schedule an activity after using up its float limit, the reviewer may have it repeat the search process using an expanded maximum resource limit by specifying an expanded limit as a percentage of the original limit. This process can be used to prevent the 'barely too much' issue of just missing the resource limit. This option is not the same thing as "resource smoothing" but can deliver some of the benefits.

It is important to understand that one cannot over-allocate resources unless the option to limit resource leveling is also selected.[18] This odd dependency is not obvious to the standard P6 user.

Another P6 'oddity' is that notification in the log that over-allocation of resources was used is only given if the option was selected. If used, the activities directly affected by this are listed. If the option is not selected, then nothing concerning this setting is entered into the log. One is to infer that the option was not set if the notice is missing.

It is more difficult to note exactly how much each activity was over-allocated. The reviewer should turn off this setting and see if the resource leveling results match the submitted schedule. If it does not, a slow increase (say by 5% each time) should be made until the results compare. To prevent errors, the reviewer should re-calculate the CPM after each resource leveling over-allocation run before increasing the over-allocation percentage.

Directly Delayed Activities

All activities that were directly delayed due to resource leveling need to be individually analyzed so that the reviewer understands exactly why they were delayed. Many people call the resource leveling function, a 'black box' because the program performing this function offers very little feedback as to the problems and results. Primavera P3 software used to produce a fairly detailed resource leveling report. The Oracle/Primavera P6 resource leveling log provides the barest minimum of information on the process.

P6 only lists the names of the activities that were delayed beyond their CPM-scheduled early start date by the resource leveling function. It does not list how much the activity was delayed. It does not indicate which resource caused the delay or by how much. Because of this reporting limitation, resources must be resource leveled one at a time to allow identification of the delaying resource. A list of such activities can be found using P6 in the Resource Leveling log under the section title, "Activities delayed due to resource leveling" as shown in the Figure 8,

Activities delayed due to resource leveling.....6		
Project: HwyNorth	Activity: P2N3110	REMOVE TEMP. PAVEMENT
Project: HwySouth	Activity: P1N2230	CONSTRUCT RETAINING WALL
Project: HwySouth	Activity: P1N2270	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth	Activity: P1N2300	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth	Activity: P1N2320	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth	Activity: P1N3200	CONSTRUCT CONCRETE BARRIER AGAINST WALL

Figure 8, P6 Resource Leveling Report Excerpt: Activities Delayed due to Resource Leveling

The following questions should be answered for each activity on the, "Activities delayed due to resource leveling" list,

- What resource was responsible for the delay? This can be problematic to determine if more than one resource is assigned to the delayed task. The only way a P6 reviewer can answer this question is by re-calculating the CPM and then resource leveling by each task resource one at a time until the delay is observed.
- Is it reasonable that this resource could delay the activity? Things such as General Laborer should not be the delaying resource unless the work is space constrained or very remote. Usually general laborers can be increased in number without difficulty.
- What is the maximum threshold used? What percent of over-allocation was employed? Is that threshold being staffed at that level right now? If the staffing level was higher, then what would that higher level do to the resource leveling

results? If lower, then are the thresholds reasonable and accurate? Resource requirements and maximum availability should have a basis in fact.

If a critical activity is resourced to use 3 crews and only 1 was employed, then the resource leveling plan was not executed and the schedule predictions based on that plan may be invalid. If more than the maximum level of a particular resource is employed, then the maximums listed in the schedule may be incorrectly stated.

- What threshold or over-allocation would free the activity from delay? How far apart is the difference between required and maximum? An activity should not be delayed for exceeding the threshold by a trivial amount. Displaying a daily resource histogram will help make this analysis much easier to perform such as shown in Figure 9 below.[7]
- If the threshold is exceeded by a significant amount, could the Contractor more effectively work overtime to overcome the limit as opposed to delaying the activity/project? Did they consider it? What would that cost? If justification is needed to pursue this line of thinking, then consider the question as if the Owner is asking for the cost of acceleration.
- Were any earlier resource availability slots overlooked simply because the slot was a couple of minutes or hours too small? This is an inherent problem when scheduling activities that are measured in durations down to the exact minute. This sort of resource leveling 'fumble' is not reported or even traceable using current P6 software. If you shorten the duration of the delayed activity, is it still delayed?

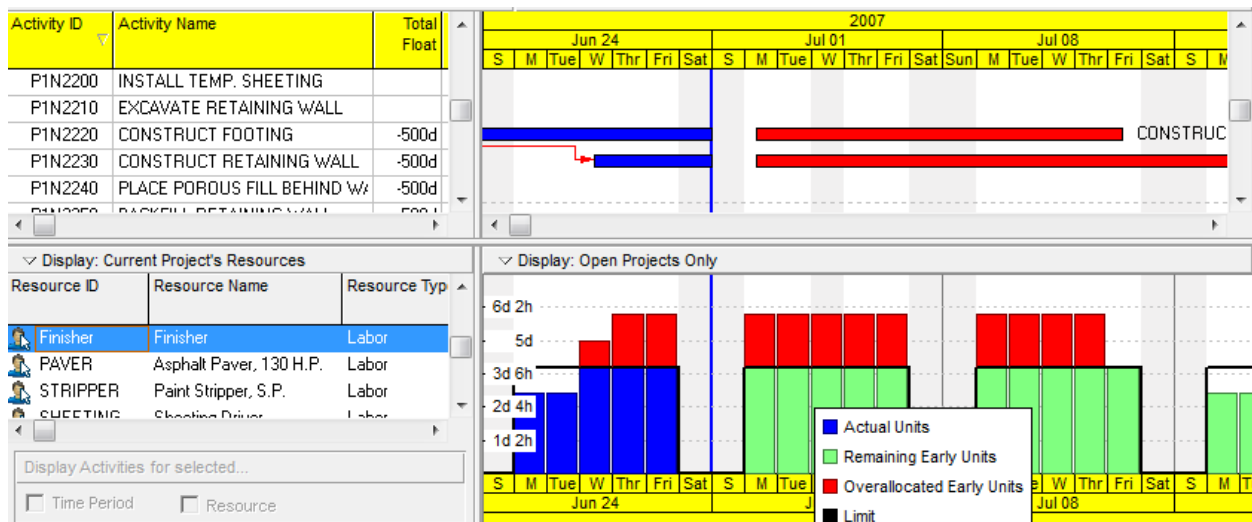


Figure 9, Resource Daily Use Histogram before Resource Leveling

Indirectly Delayed Activities

Next, the reviewer should analyze the indirectly delayed activities (those logically delayed by predecessor activities which in turn were delayed due to resource leveling.) P6 lists these activities in the report section titled, “Activities delayed due to predecessor delay” like the Figure 10 shown below,

Activities delayed due to predecessor delay.....7		
Project: HwyNorth	Activity: P2G600	PROJECT COMPLETE
Project: HwyNorth	Activity: P2N3120	REGRADE AREA
Project: HwySouth	Activity: P1N2240	PLACE POROUS FILL BEHIND WALL
Project: HwySouth	Activity: P1N2250	BACKFILL RETAINING WALL
Project: HwySouth	Activity: P1N2260	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth	Activity: P1N3220	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth	Activity: P1N3225B	CONSTRUCT CONCRETE BARRIER AGAINST WALL

Figure 10, P6 Resource Leveling Report Excerpt: Activities Delayed due to Predecessor Delay

These activities were not delayed directly by the resource leveling process but indirectly delayed because they logically followed an activity that was delayed by resource leveling. The following questions should be answered for each activity found in the above list,

- Is this really hard (physically-constrained) logic or a case of preferential soft logic that should be re-evaluated and left for resource leveling to resolve?
- Is the hard logic still valid or can it be reevaluated and modified in light of the current situation in ways that would mitigate the resource-induced delay?
- When evaluating a resource leveled schedule, the Contractor usually does not have the ‘right’ to insist on using the soft logic coded into the schedule. That is what the resource leveling was for. If work is available, then they should shift to that work (as normal.) If this change would result in disruption, then that is what should be addressed, not enforcing initial guesses at soft logic.

The secondary interaction of CPM scheduled activities with resource leveled activities is an extremely important part of the review process.

Activities that Cannot be Leveled

The P6 resource leveling log will sometimes list activities that cannot be resource leveled. Any activities found in this list were passed-over by the resource leveling routine and were not delayed at all. See Figure 11 for an example of the report section notifying the reviewer of such activities. Various conditions can be responsible for this error message.

```
Activities that cannot be leveled.....1
Project: HwyNorth Activity: P2N2196 STRIPE ROADWAY
```

Figure 11, P6 Resource Leveling Report Excerpt: Activities that cannot be Leveled

P6 does not 'break-up' a resource-leveled activity. It does not support interruptible activities that could have filled two or more time slots. The P6 resource leveling routine delays an activity until the entire activity can be completed using that resource without interruption.

This issue of the activity not 'fitting' the available time slot is further exasperated by P6's ultra time accuracy. If the time slot of resource availability is even one minute too small, P6 will pass that slot over and look for a later one that can completely meet the resource requirements. Changing calendars sometimes creates this interface issue. P6 does not report on this condition of, 'barely not fitting.' Overlooking an available time slot for a minor discrepancy does not reflect what would have been done manually by a foreman and is thus, 'wrong'.

In addition, P6 can only resource level resources shared by two or more activities. If the activity has more resource requirement than specified as the limit, it can never be resource leveled. Moving the activity to a later date does not solve the problem. [13] P6 will not stretch out the activity until the daily resource need matches the resource availability level. The resource leveling report will just state that it cannot level this activity.

Activities with multiple resources assigned must meet the resource availability of all leveled resources for the entire time the activity is active. A resource that works just at the start or end of an activity is required to meet availability requirements for the entire activity duration. P6 does not consider resource usage curves when resource leveling.[12]

Another reason for an activity not being able to be resource leveled is the condition where labor and non-labor resources are resource leveled together.[13] The object of most resource leveling exercises is labor resources. This is the resource type that is typically in limited supply. The availability of non-labor (material) resources are usually not subject to limits. Most schedulers and reviewers do not focus on the maximums of these non-labor resource settings but when they are resource leveled along with a labor resource, it can be the non-labor resource that cannot be accommodated. Resource leveling poorly defined non-critical resources may be a reason for inclusion in the 'unable to level' section of the resource leveling log.

If any activities are listed in the 'unable to level' section of the report, then the resource leveling plan has failed. Just as a Baseline Schedule is invalid with any activity showing negative float, a resource leveling submittal with activities that cannot be resource leveled is invalid unless the contract says otherwise or a case can be made for acceptance.

Review Critical Resources

Just as with activities on the critical path, the resource leveled schedule reviewer should concentrate on activity resources that delay the project. Resources that cause resource leveling to delay the project are called critical resources. This means that every critical resource should be checked for,

1. **Resource limits.** Look for obvious errors in the maximum resources list like that as shown in Figure 12 below. Limits should not be shockingly low, certainly never zero. Confirm the unit of measurement. Perhaps the resource requirement was assigned in hours but the limits were set using crew days. Resource limits should be set to a fraction above required to allow for 'barely too much' requirement that would have been accommodated by overtime, weekend work, or some other on-site technique. The over-allocation parameter may be used for this purpose.

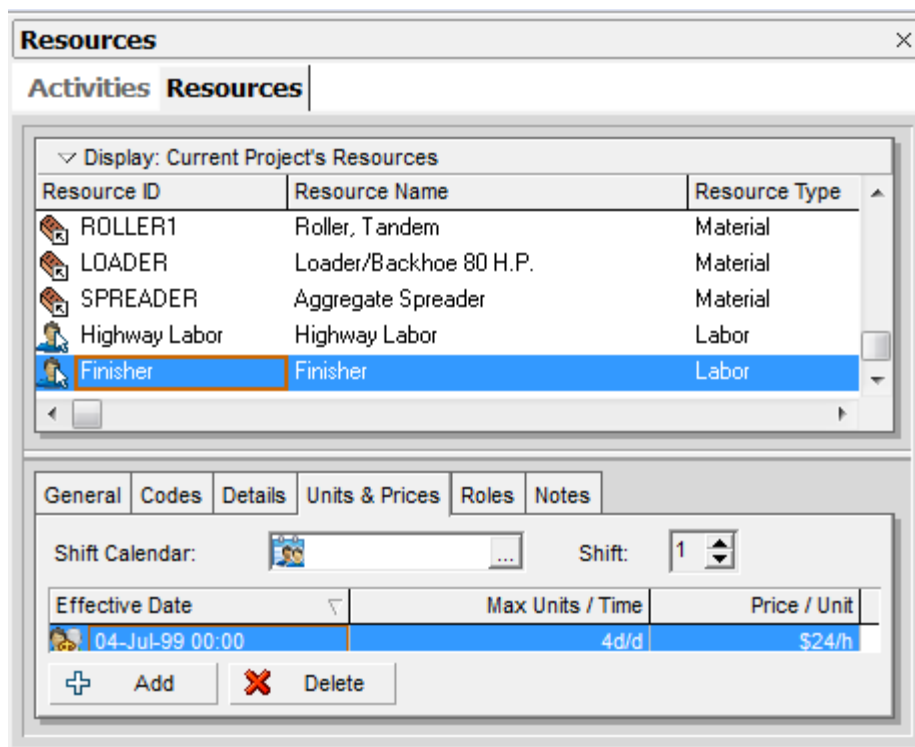


Figure 12, Maximum Resource Assignment Settings

2. Consistency in resource assignment. Similar activities should use similar resources and resource requirement levels. Look for assignment irregularities. Do any activities with duplicate descriptions have different resources? Check to see if activities with very similar titles have the same crew make-up. Drywall 4th floor should resemble the drywall installation activity for the 3rd floor, especially if one or the other is a critical resource-delayed activity.

3. Resource Calendars. P6 allows the user to assign calendars to the various task resources in addition to the calendar assigned to the activity. Calendars permit the user to dictate its standard resource working schedule, and any exceptions that resource might have. These may include yearly holidays or one-time events. Having both an activity calendar and a resource calendar allows the modeling of the intersection of the activity's daytime calendar and the resource's shift calendar.

Do resource calendars match the activity calendar? If not, what percent of the time do they conflict? Are there holidays in either that exacerbate the scheduling problem? What is a resource holiday? What is the effective active percentage of work time overlap?[7]

4. Resource Curves. The scheduler can use P6 to define how to allocate the resource utilization over the duration of the activity. This is normally not a resource leveling issue because P6 resource leveling does not currently consider resource curves when resource leveling. P6 just uses an even daily distribution for resource leveling.[12]

5. Primary Resource. Activities should have a primary resource responsible for progress. This makes tracking a resource such as crew more effective than multiple sub-crew designations such as Foreman and Laborer.[15]

6. Driving Resources. A P6 Driving Resource is a resource that determines the duration of the activity to which it is assigned. When this feature is used, P6 automatically calculates the activity duration based on the quantity to complete and the units per time period of the driving resource. While there is a default setting when adding a task resource, each task resource can have a unique setting for this property. To confirm if resources are driving the activity dates, add the column, "Drive Activity Dates" to the resource assignment tab or add this to the resource report.[16]

If the activity has any driving resource assignments, P6 calculates the early start date of the activity as the earliest Early Start date of all driving resource assignments. Once the Early Start of the activity is calculated from the driving assignments and relationships,

all non-driving resources are scheduled on or after this date using its assignment duration. The Early Finish dates of the non-driving assignments can fall earlier or later than the Early Finish of the activity.[17]

7. **Resource lags.** Are resource lags used? Schedulers can configure P6 to delay the start of resource usage after an activity begins by assigning a resource lag period. This can create hard-to-find scheduling conflicts. Is there an explanation for the use of resource lags in the Schedule Narrative?

8. **Actual dates.** Activity resources have actual start and actual finish dates as well as for the defined activity. Resource actual dates can be different from the activity actual dates. Resourced activities can have their resources unintentionally modify activity dates, even with activities set to fixed durations. When assigning an actual start to an activity resource that is earlier than the activity's actual start date, P6 will change the activity's actual start date to match. The same applies to the early finish of an activity being extended because the resource had a late actual start.

Resource actual dates may be automatically assigned by setting the activity dates or may be manually set. Automatically set dates may call into question the accuracy of the resource dates when performing forensic analysis.

Actual progress can also give insight as to the foreman's resource plan. Figure 9 above shows two activities sharing the same resource, "Finisher." The second activity, P1N2230 shows that it was started even though a shared resource is over the listed maximum. Resource leveling shown in Figure 13 below will halt progress in Activity P1N2230 until the resource in Activity P1N2220 is complete, delaying the project. While logical, delaying this activity now just because the status was taken is clearly not the intent of the supervising foreman. Active activities should not be halted simply because resource leveling was used.

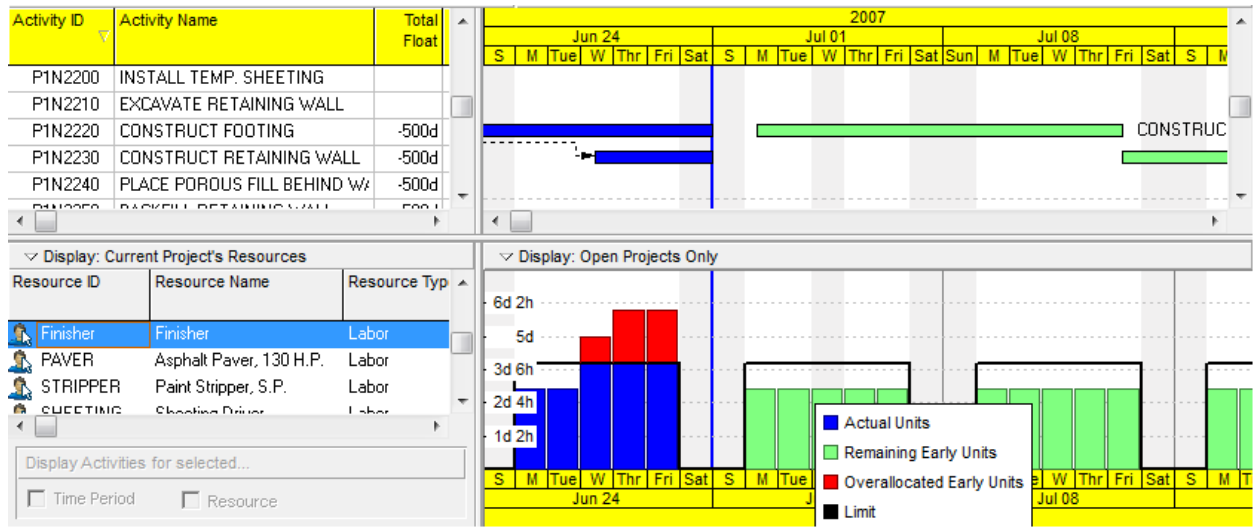


Figure 13, Resource Daily Use Histogram after Resource Leveling

As a side note, the keen observer will notice that the two activities in Figure 9 were on the longest path (bars in red) but are no longer on the longest path in Figure 13. The only difference is that resource leveling was accomplished. Also note that resource leveling did not change the float value of Activity P1N2230, even though it was delayed by 9 days.

Consistency of Application

Resource leveling results are only useable as long as the process is used throughout the schedule.

- Is this schedule using a combination of resource leveled activities, hard-coded soft logic, and date constraints? This condition is probably reviewable and confuses the resource leveling issue, perhaps invalidating the entire process.
- It may be permissible to 'mix' these techniques if all of the critical resources are being resource leveled and minor ones were handled in other ways.
- It is most likely not permissible to mix these resource-constraining techniques with different activities that are all using the same critical resource.

Was a Near-Optimum Solution Found?

The reviewer must determine if the submitted resource leveled schedule is using a near-optimum solution. This can only be answered through a trial process.

Perform resource leveling using alternate resource leveling priorities. Does the new priority option produce a schedule with less resource disruption and earlier project

completion? If a better plan can be found, why would you not want to use it? In most cases, the contractor is required to mitigate delays if they can do so without incurring additional expenses. This implies that they should be open to changing the priority plan if this would improve the project's completion date.

This trial of alternate strategies should also take place on later updates. Just because one priority plan worked well once does not mean that others might not be a better fit at a later date.[14] Unless otherwise specified by contract, an approved priority plan in one update should not be automatically approved for use in later updates.

Verify Planned versus Actual

The resource leveled schedule only represents the Contractor's means and methods if they were actually followed. It is a simple thing to create a resource leveled schedule without any real inputs from field personnel and claim that this is the work plan. It is only a meaningful plan if it was actually followed. Reviewers should determine,

- How well has the Contractor followed their 'means and method' resource leveled schedules?
- What percentage of the time did the resource plan follow the actual?
- Were the staffing levels greater than the maximums listed in the schedule?
- Were they lower than the activity requirements suggested?

Very few projects are ever executed exactly as planned, but the actual work should at least initially parallel the plan if the plan was actually used.

Document Your Resource Leveling Review

The resource leveling review should be documented and transmitted to both the Owner and the Contractor. Suggestions for improvements should be made, as appropriate. The reviewer should document the methods to improve the resource leveling plan, not the actual settings used. In this way, the Contractor will still be responsible for the results.[15] Consider having a joint meeting with the Contractor and Owner to review and resolve any resource leveling questions or issues.

Resource Leveled Schedules Delay Analyses

Accepting a resource leveled baseline schedule has potentially large ramifications with later events. The reviewer must be cognizant of the fact that if resource leveling was

accepted as part of the baseline plan, then such processes might also be employed to resolve the predicted affects of project delays.[1]

Once an activity is delayed (say by a hypothetical 5 days,) the resources necessary to re-start that activity might not be available when the 5-day delay period is over. The work crew may have 'moved on' to other work and are perhaps not even on the project site. It is possible that by including resource leveling along with a standard Time Impact Analysis (TIA,) a 5-day delay could analytically result in a 15-day project delay along with proportionate compensation. This result might even be achieved if the delayed activity had sufficient total float to accommodate the delay.

This 'magnified delay' potential aspect of resource leveling troubles many project owners. The review techniques listed here may be employed on a resource-constrained TIA as a counter-balancing analysis. If the resource leveling process was employed properly, then the results should follow reality.

Certain steps should be taken to ensure proper TIA results.

- The delayed activity should be suspended to allow the designated activity resources to be 'freed-up' for other activities. Activities are suspended when the scheduler assigns a Suspend date to that activity.
- For every Suspend date assigned, a projected Resume date should also be assigned. P6 ignores Suspend dates if it is not accompanied by a finishing Resume date.
- Because resource leveling can delay project completion even if no delay exists, a pre-delay resource leveled baseline must be established and compared to the post-delay analysis. The pre-delay analysis should have a data date as close to the start of the delay as possible. The difference between the two projected project completion dates is the time being investigated and not just the delay indicated by the impacted resource leveled schedule.

The TIA reviewer must be aware that it is possible to demonstrate project delay using resource leveling even if no delay is being modeled. A TIA should only reflect the changes and impacts of the delay being modeled.

P6 Automatic Resource Leveling Limitations

While the automatic resource leveling routines used by Oracle/Primavera P6 Professional software are generally considered to be quite reliable and robust, there are

limitations in its use when considering real-world conditions. Some currently missing features include,

- The P6 resource leveling report log does not completely explain what happened during the resource leveling process. In particular, it does not identify the delaying, critical resource.
- P6 does not have an interruptible activity setting. This means that the schedule cannot split activities and their resource requirements to allow for more precise resource allocations.
- The resource leveling process cannot adjust activity durations, thereby adjusting the daily resource requirement.
- Even though P6 has the setting to over-allocate resources, P6 lacks the ability to smooth resource requirements and reduce resource level fluctuations within the availability envelope.
- Failing to use the over-allocate resources feature, the resource leveling algorithm will not 'round up' to allow for minor allocation overlaps. Over-allocation is only employed if the option, "Preserve scheduled early and late dates" is also selected.
- There is no simple method to give resource leveling priority to ongoing, active activities and prevent disruptions.
- The process does not allow P6 to automatically substitute one resource for another.
- P6 cannot automatically convert one type of resource into another (say two Journeymen for one Expert.)
- The activity Total Float and Free Float values displayed are incorrect for resource leveled delayed activities and their successors. A better reference is found in the Remaining Total Float column but even this does not fully reflect 'resource float.'
- Resource leveling can 'hide' the P6 longest path.
- P6 does not consider resource usage curves when resource leveling.
- The P6 resource leveling process does not consider resources assigned to Level Of Effort (LOE) and WBS Summary type activities.

The above list is provided only as a summary of current resource leveling features and is not intended to provide an assessment of the quality or usability of the Oracle/Primavera P6 Professional software product.

In Conclusion

The guidelines presented in this paper provide the reviewer the information necessary to perform and verify the cause and effect of resource leveling a schedule. This can

also serve the resource leveling interests of all parties. Owners are generally more willing to accept transparent, simple resource leveling plans rather than opaque 'black boxes' that they do not understand.

While the reviewer may not be in the position to argue nuances of resource requirement or resource availability, a resource leveled schedule can still be reviewed for quality and obvious errors. The reviewer can gain insights as to the conflicting demands upon project resources. The reviewer can identify and document areas where errors have occurred in the process or if certain activities could not be resource leveled. A reviewer can note if the stated resource requirements and limits have been observed.

Just like a flawed CPM schedule submittal, a flawed resource leveling plan can be rejected if such errors are serious enough to invalidate the plan. At the very least, the analysis of a resource leveled schedule can give the reviewer new insight into the risks and constraints affecting successful project completion.

Resource leveling clarifies the Contractor's staffing plans and can be verified in the field, relieving the Owner from needless concerns and allowing the Owner to have confidence in the results of resource leveling. This situation is a win for the Contractor because it permits them to fully realize resource constraints in their CPM schedule without resorting to time-intensive logic modifications. It is a win for the Owner by facilitating understanding of the Contractor's resource issues.

Definitions

Critical Resource: A critical resource is an activity resource on a project that is available in limited supply and causes any activity to be delayed due to required daily staffing or material totals exceeding maximum available levels during automatic resource leveling.

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