

Proper Implementation of Resource Leveling

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ABSTRACT

Automated Resource Leveling has been available in software to Schedulers everywhere for more than 20 years. Although the benefits of using resource-leveled schedules are well known, its use on major projects has largely been unsuccessful. While some technical issues are involved, the major problem has been in the implementation of this technique.

This paper will outline the pitfalls and best procedures for implementing resource leveled schedules on a major project. The techniques involve using the resource-leveling report to establish a small number of control points to manage the leveling plan 'on the field.' This simple technique will allow for both control and validation that the plan was actually executed. We also will overview new technologies designed to respond to the remaining criticisms of using resource leveling.

INTRODUCTION

CPM activities use resources such as workhours and equipment in order to accomplish their task. Sometimes this fact is implicit and other times the resources are quantified and documented. The reason for performing the extra work of documenting the resources needed is that resources are both limited and expensive. There may not be enough resources to accomplish your intended plan or the non-optimum expenditure of that resource tends to drive the cost of the project higher. Both issues are of great concern to builders executing fixed-price contracts.

The AGC CPM manual states, "The schedule produced for a project assumes that enough manpower and equipment is available to get the activities done as scheduled. This is not always the case, and in a large or complex project, it might not be obvious that a deficiency exists." [1]

Other research has shown, "The basic assumption of the CPM, however, is that resources required by activities are unlimited, while some resources are highly limited in practice. In most real construction projects, scheduling without considering resource limitations may result in a non-credible schedule, since the start-ability of activities is affected by resource availability." [2]

Once resources are defined and assigned to the individual activities, you are able to analyze the daily accumulative effect of resources in your plan. After this, the next step is controlling and optimizing your accumulative resource plan. To do this, you need to modify your schedule to keep the peak manpower requirements

below your availability limit and to reduce the peak requirements such that a more optimum, level utilization occurs. This is called “resource leveling.”

Available research into resource leveling concerns itself with what is resource leveling and why it is needed[3][4][5]. This paper assumes the knowledge of what and why and proceeds directly to the HOW of properly implementing successful resource leveling on a typical construction project.

IMPLEMENTING RESOURCE LEVELING

It is not enough to just plan your resource usage; you also have to implement your plan. This is where most projects using resource leveling fail. They define their resource leveling plan at the beginning of a project and then expect it to be valid throughout the project without adjustment. Just like a CPM Baseline Schedule, you must monitor and correct your plan as you understand the environment better and as conditions change.

The implementation steps suggested here are from the collimation of a series of studies of two different construction projects. These projects used automatic resource leveling (or tried to use) in the determination of the effects of delays on a stated resource usage plan. As an Owner’s Scheduling Representative, it was left to me to determine if resource leveling was being properly implemented.

Not just any resource leveling plan is acceptable. It is safe to assume that if the resource leveling plan is not properly drawn-up and implemented, then the results returned for such calculations do not reflect reality and may not be relied upon for decision making. An inaccurate depiction of a resource leveling plan may not be relied upon as the basis for a delay settlement. For this very reason, it behooves the builder to properly design and implement their resource leveling.

Implementing a resource leveled schedule on a project is done in three steps; Design, Execution, and Reevaluation. You must create a resource leveling plan that you and the Owner can believe in. Then you need to see that the plan is actually carried out. Finally, you must evaluate how well you adhered to the actual plan and make adjustments as needed.

RESOURCE LEVELING DESIGN

BUILDING THE CPM SCHEDULE

A good resource leveling plan first requires a good CPM schedule. This must be a balanced schedule with all contract work described. Your Work Breakdown Structure (WBS) must be defined as this must also be the basis for resource assignment. This baseline schedule must be based upon your understanding of the project at the time your bid was submitted.

Finally, there must be no resource considerations in the logic used. This is sometimes called, “soft logic.” You do not want to codify resource timing considerations into your schedule if you are also going to later resource level your schedule. The two different procedures used together will only produce erroneous results. Finally, be sure to document all assumptions.

RESOURCE-LOADING YOUR CONTRACT SCHEDULE

Once your CPM schedule is properly created, you are able to assign your resources to the various activities. This occurs in two phases; definition of the resources to be tracked and then the actual assignment of the resources and required amounts to each activity. [7]

Caution and experience must be exercised here. Do not track and document every resource, no matter how trivial. You will most likely not have the luxury of time and money to completely describe every detail and then later maintain that detail. We are not trying to create a ‘little world’ inside of your computer; we are interested in obtaining a reasonable answer to our resource usage problem.

Only track those resources that you believe will be crucial to describing the manpower levels. Try to generalize the type of worker or equipment to the highest level possible that still reflects availability and interchangeability. For instance, it is generally acceptable to only track “Carpenters” as opposed to the various skill levels within the trade. For simpler projects without specialty trades, even just using one category called, “Workers” may suffice.

Investigate your local conditions. Check the Union Halls for both quantity and quality or available workers. Read the plans and specifications to identify special equipment and specialty trades. Look at long-lead items to see if late delivery will cause a trade overload.

Finally, document all assumptions made. This is always good advice but is more so for resources. The generalizations and abstractions that are necessary for the builder to use must be fully documented so that other people relying on the results of the leveling analysis may have confidence in the quality of the inputs. In addition, you may need to make modifications to your plan later and it must be clear whether your changes were already factored into the original inputs.

Some of the assumptions to be documented include your supervisory span of control; what is your planned ratio of overhead personnel to workers. Will you be using working foremen on each team or a pure supervisor? What percentage of the work is contract work with their lower supervisory requirements (at least from your viewpoint.) Are there area-stacking limitations?

RESOURCE LEVELING YOUR CONTRACT SCHEDULE

Before you can begin the leveling process, you must first understand everything there is to know about your available options. If you do not understand an option, then why would you expect someone to have confidence in the results produced?

There is not enough room in this paper to talk about all possible settings. A single note about the Primavera factor, "Smoothing: It does not mean what you inherently think that it means. It simply defines the maximum level to be considered, nothing more. Real smoothing is not implemented in Primavera software products. Also, most contractors haven't a clue about 'splitting,' 'stretching,' and 'crunching' or they wouldn't accept the default settings.

Assuming that a contractor is performing the scheduling, the method of resource leveling selected should be based on "entitlement" in terms of a potential time adjustment. If the contractor has not experienced an excusable delay, time-constrained leveling should be used in order to maintain the contractual completion date. However, if the contractor has been delayed for reasons "outside of their control," resource-constrained leveling will prevent the occurrence of resource over-allocations and most likely will result in a delay to project completion. The period of time between the contractual completion date and the delayed completion date will then be the amount of time extension that the contractor should ultimately seek from the owner. [web author unknown]

Do you use the defaults or custom settings? There is less of a possibility of a challenge using defaults. On the other hand, changing defaults shows that all issues were reviewed. To repeat, you can't expect others to believe in your resource leveling plan if you do not understand the analysis settings.

Resource leveling is an integrative process[6]. You must level, resolve inconsistencies, and then level again. This process is not complete until all obvious errors are resolved. Are you going to level the entire project or only out to a certain time limit? Were all activities leveled or just some? How sensitive is the schedule to your maximum resource availability limit?

Finally, document this process as well. Remember, resource leveling is a heuristics process. That means that there is no one single optimum answer. Be prepared to demonstrate how you tried several plausible settings. If you cannot, then you cannot prove that the later claim is based upon the best possible reaction to the problem.

RESOURCE LEVELING EXECUTION

There is a fair amount of existing documentation to show you how to properly create a resource-leveled schedule. What has been lacking is information on how to implement your resource leveling in the field.

Past experiences have shown me that there is a large 'disconnect' between the plan and the schedule with foremen assigning work as they intend without thought to the resource leveling plan. This may be due to the unreasonableness of just handing the foreman a list of 1,000 activities and telling them to "just follow the schedule." Even creating a three-week 'look-ahead' barchart from the resource-leveled schedule does not produce the correct results.

A 'look-ahead' barchart only shows the work without giving a clue about resource leveling. This information is crucial for the foreman to consider when an opportunity to perform work presents itself. If a task is completed earlier than planned (or conversely disrupted,) should the foreman wait and do nothing until the plan is correct? Which activity is he or she start early? Conversely, if delayed, what will this do to the plan and which activity should be delayed? The inflexibility of mapping a monthly plan onto a daily work schedule may be the major reason for the failure to use the resource-leveled plan.

Past experiences with implementing resource leveling have led some to declare that they are following the plan, even if they didn't use the schedule provided. The reasoning is that the plan is based on current conditions and the foremen were considering the same conditions, so the plan and execution should just naturally be the same.

While I am skeptical about this, this just may be true in certain instances. If this is the case, then all we need to do is to evaluate how well we executed our resource leveling plan. Should our results match conditions closely, then perhaps this is true. This evaluation is the topic of the next section of the paper. Until then, I will describe a better way to execute the resource-leveling plan.

A Better Way

The first issue to executing a resource-leveling plan is obvious; concentrate on the near-term work and don't confuse people with resource considerations months into the future (except for hiring and staffing considerations.)

The real trick to implementing your resource leveling plan is to identify the upcoming resource-delayed activities. Find which activities were purposefully and directly delayed by the leveling process. These activities are the ones you need to watch in the coming weeks. I call these resource-leveling "control points." Don't follow every activity that was delayed during leveling. Many will be delayed because their predecessor had been delayed by resource leveling. Only

identify the activities that would have started earlier except for the fact that the leveling process did not have resources for them at the earliest time they were ready to start.

Luckily for us, this identification is easy (if you know where to look.) Primavera P3[8] and Primavera P3e/c software both produce an optional report detailing the resource-leveling process as it is performed. The smart Scheduler will configure the programs to create a unique file name for the report and retrieve it to document the process. Figure 1 shows P3 displaying the appropriate screen where you designate the report. The sub-settings should be set as desired, but all options will give you the needed information.

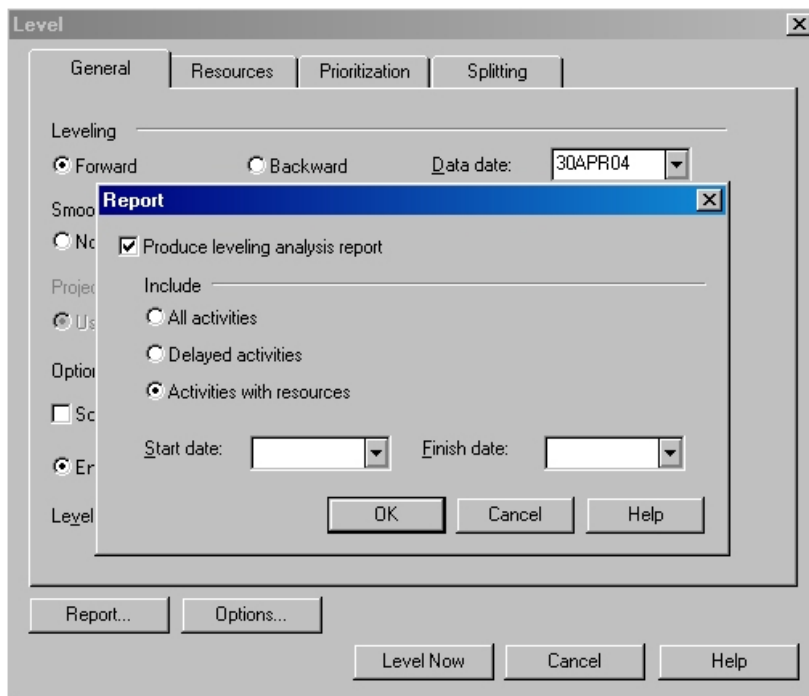


Figure 1 - Designating Resource-Leveling Report Option

The sort for this report is based upon the priority settings used during leveling. Leveling Priority is just another way of saying that the activities were sorted by these values and then 'leveled' by assigning the activity in the sort order. Activities that were sorted to the top of the list are assigned slots first, making them most likely to be assigned at their early start date. Later activities in this list have lower priority and must use whatever slots are still available or 'slip' until a slot is available.

A special note needs to be added before proceeding. Be sure to calculate the CPM just prior to performing resource leveling or your report will be incomplete. The leveling process assumes the current condition and will not note changes made during an earlier resource leveling run.

The report produced has a wealth of information that will not be completely covered here. The important thing is to recognize which columns indicate the needed information. Unfortunately, there is almost nothing in the P3 help files or manuals describing this report so you will need to rely on my interpretation. Figure 2 shows a portion of a typical resource-leveling report.

Ron Winter Consulting				Primavera Project Planner								Sample Resource-Leveling Schedule									
Report Date 29JUL04 14:28				Forward Resource Leveling Analysis Report								Start Date 09FEB04 Fin Date 17FEB06									
												Data Date 31MAY04				Page no. 2					
Activity Id	Cal Resource	Daily Res Usage	Res Lag	Rem Dur	-----Early Start-----	Date	Tf	Norm	Max	-----Delayed by Pred-----	Date	Tf	Norm	Max	-----Delayed by Res.-----	Date	Tf	Norm	Max	Early Start	Leveled Finish
030COPC100	1 FPS SOG @ IPS CAR	3.00		14 14	01JUN04 01JUN04	0		0.10	0.10						11JUN04 11JUN04	-8		16.91	16.91	11JUN04 11JUN04	30JUN04 30JUN04
030COPC110	1 FPS Walls East o CAR	5.00		20 20	21JUN04 21JUN04	0		21.00	21.00	01JUL04 01JUL04	-8		24.00	24.00						01JUL04 01JUL04	29JUL04 29JUL04
070COPC230	1 FPS SOG Clarifie CAR	2.00		20 20	03JUN04 03JUN04	26		0.10	0.10						11JUN04 11JUN04	20		13.91	13.91	11JUN04 11JUN04	09JUL04 09JUL04
030COPC120	1 1st Soffit (EL 1 CAR	4.00		20 20	20JUL04 20JUL04	0		19.00	19.00	30JUL04 30JUL04	-8		24.00	24.00						30JUL04 30JUL04	26AUG04 26AUG04
030COPC140	1 FPS Walls West o CAR	5.00		20 20	20JUL04 20JUL04	0		19.00	19.00	30JUL04 30JUL04	-8		20.00	20.00						30JUL04 30JUL04	26AUG04 26AUG04
030COHT120	2 Hydrottest (EL -1			7 7	17AUG04	0				27AUG04	-10									27AUG04	02SEP04
060COPC170	1 FPS AB 6 and 7 W CAR	4.00		20 20	01JUN04 01JUN04	46		0.10	0.10						11JUN04 11JUN04	38		11.91	11.91	11JUN04 11JUN04	09JUL04 09JUL04

Figure 2 – A Typical P3 Resource Leveling Report

Understanding this report is crucial toward properly implementing resource leveling, so we will describe each column and how to read the report. Each resource assignment consists of two or more lines of information, followed by a blank line. The first line describes the activity and each subsequent line describes the leveled resources, one per line.

First Line of P3 Resource Leveling Report

Activity Id - Activities are listed in the order that they are assigned during leveling. You may recall that you had the option of selecting “all activities,” “only delayed activities,” or “activities with resources” when you requested a report in Figure 1.

Activity Calendar – The resource calendar might have been more appropriate to show here, but that is not the case.

Activity Description (truncated) – The first 16 characters in the activity description are displayed on the first line.

Activity Remaining Duration – Activity remaining duration may be different from resource remaining duration.

Early Start – The section of the report lists the CPM calculated information unaltered by resource leveling.

Date – CPM early start date

Total Float – CPM total float for this activity before resource leveling.

Remember that if this activity is delayed by resource leveling, then this value is no longer correct (see, “Phantom Float”[3][4]). This author has proposed an automated system where resource leveling does show correct float values.[8]

Delayed by Predecessor – This report section is used when an activity was not actually delayed because the resource was lacking, but because some other predecessor activity was delayed by resource leveling and this activity was delayed by logic. This column is blank if this sort of ‘secondary’ delaying did not occur.

Date – The new early start date for this activity.

Total Float – The new total float once the delay was taken into consideration.

Look to Activity 030COPC110 in Figure 2 above. Notice how the original total float was ‘0’ but this value was reduced to ‘-8’ due to being delayed by a predecessor?

Delayed by Resource – Here is the ‘best’ part of the resource leveling report. If information is included here, then P3 delayed this activity from starting due to a resource availability issue. If blank, then this issue did not occur for the activity in question.

Date – The new resourced-leveled early start date. Look to Activity 030COPC100 in Figure 2 above. Notice how the original CPM early start date was 01JUN04 but this date was delayed to 11JUN04 due to a scarce resource and resource leveling? Remember this spot, as we will revisit all such dates that we find in this column.

Total Float – The resultant float due to being delayed by resource leveling.

Early Leveled – This is a summary, re-cap section that shows which date was actually used to schedule the activity.

Activity Start – Early start date.

Activity Finish – Early finish date.

Second (and Subsequent) Line(s) Immediately following the activity line will be one or more resource lines. Each leveled resource that is assigned to that activity will be displayed, one line for each.

Activity ID (blank)

Resource Short Name – Resource code name.

Daily Usage – This is the daily amount of resource needed in order to be able to schedule the activity.

Resource Lag – P3 allows you to delay the start of a resource until a set time after the activity starts. I strongly suggest that you do not use this feature. Explaining resource leveling is difficult enough without using this advanced feature.

Resource Remaining Duration - The number of days of resource requirement may be less than the total activity remaining duration. It is best if you just spread the resource usage over the entire activity duration.

Early Start – Resource early start will be the same as activity early start unless a resource lag was used.

Date – Early scheduled date for the start of the resource

Normal Limit – This column is very important for understanding why something was delayed. Here is listed the normal daily availability of that particular resource using the CPM early start date.

Maximum Limit - Maximum daily availability of that particular resource using the CPM early start date. Look to Activity 030COPC100 in Figure 2 above. Notice how the availability of resource CAR for the CPM dates was 0.10? The required 3.00 CAR was not available. That is the reason that it was delayed.

Delayed by Predecessor – In this section, the resource date should always be the same as the activity date.

Date – Date resource was scheduled to occur after being delayed by a preceding activity.

Normal Limit – Normal resource availability amount.

Maximum Limit – Maximum resource availability amount.

Delayed by Resource – Information in this section will explain which resource was responsible for delaying the activity.

Date – An activity can only have a single delayed date. This single activity may have several resources, each with availability limits. Looking down this list may indicate one resource being available earlier but a second being the deciding factor and deciding the actual scheduled date.

Normal Limit – Normal resource availability amount.

Maximum Limit – Maximum resource availability amount.

Early Leveled - This is the summary section that clarifies the actual dates used.

Resource Start – Actual early start date used.

Resource Finish – Actual early finish date used.

So now that we know how to read the results of a P3 resource leveling session, we can begin to say that we understand what was done to the schedule. It is not such a ‘black box’ anymore. With understanding comes confidence.

As far as documenting resource leveling is concerned, the newer P3ec software[9] is a huge step backward. Figure 3 shows the section of the scheduling report that explains the process used,

Activities delayed due to predecessor delay.....20		
Project: HwyNorth Activity:	P2G600	PROJECT COMPLETE
Project: HwyNorth Activity:	P2N2115B	REMOVE GUIDE RAIL
Project: HwyNorth Activity:	P2N2125A	EXCAVATE FOR ELECTRICAL
Project: HwyNorth Activity:	P2N2125B	INSTALL TEMP. ELECTRICS
Project: HwyNorth Activity:	P2N2130	INSTALL ELECTRIC CONDUITS & STRUCTURES
Project: HwyNorth Activity:	P2N2140	INSTALL POWER & LIGHTING
Project: HwyNorth Activity:	P2N3110	REMOVE TEMP. PAVEMENT
Project: HwySouth Activity:	P1N2210	EXCAVATE RETAINING WALL
Project: HwySouth Activity:	P1N2220	CONSTRUCT FOOTING
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
Activities delayed due to resource leveling.....10		
Project: HwyNorth Activity:	P2N3100	PLACE TEMP. CONST. BARRIER
Project: HwyNorth Activity:	P2N3120	REGRADE AREA
Project: HwyNorth Activity:	P2N3225A	REMOVE TEMP. CONST. BARRIER
Project: HwySouth Activity:	P1N2320	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Project: HwySouth Activity:	P1N3200	CONSTRUCT CONCRETE BARRIER AGAINST WALL
Activities that cannot be leveled.....3		
Project: HwyNorth Activity:	P2N2196	STRIPE ROADWAY
Project: HwySouth Activity:	P1N2105B	INSTALL EROSION CONTROL DEVICES

Figure 3 – P3e/c Resource Leveling Report (edited)

The report is easier to read but definitely gives the reader much less information. For the purposes of implementing a resource leveling project, the major piece of missing information is what resource actually delayed the activity.

Microsoft Project[10] does not report on the leveling process, other than to provide a Gantt Chart view that includes a column that tells you how many days each activity was delayed due to resource leveling. We are going to use the more complete information from the P3 report to continue our implementation.

The P3 resource leveling report identified the ‘control points’ that I mentioned earlier; those activities identified with a date in the “Delayed by Resource” column. In addition, we have another piece of useful information; the name of the resource (or resources) that actually caused the delay. We now only need one more piece of information to implement our plan; the delaying activity.

Identifying the activity that actually delayed the “delayed by resource” activity is a little difficult because even P3 does not know this information. When it leveled the activity, the program just kept scheduling the activity forward in time until a resource ‘slot’ opened for it. We are interested in identifying the activity using the

same restricted resource that ended immediately just before the open 'slot' began. Identifying the precursor to the delayed activity will allow us to translate the resource leveling process into a construction process description. I will describe how to do this after we identify this resource-delaying activity.

The resource-delaying activity is the activity that we are waiting to complete so that our resource slot will open and allow us to execute the leveling-delayed activity (or 'control point.')

To accomplish this, sort your resource-leveled schedule by early (resource leveled) finish and look for the activities that finish immediately before the control point activity starts. With that list, look to see which ones use the same resource that delayed your control point. This is our resource-delaying activity!

Now we have three things for every control point:

1. The activity that was purposely delayed by the resource leveling process due to a scarce resource (out control point,)
2. The resource that caused the delay, and
3. The activity using that same resource that is delaying the start of your control point (the resource-delaying activity.)

With the above information, we are ready to implement the resource leveling plan.

Starting with the earliest control point, document any of the activities occurring in the next three-weeks and educate your foreman as to how you want the resource leveling plan to be executed. We call this document, your Resource Deployment Orders.

Instead of saying,

1. ***"Here is the schedule, follow it."***

or even,

2. ***"Start plaster work on the fourth floor on two Tuesday's from now."***

you will now be able to say,

3. ***"Hold-up on the plastering work on the fourth floor until after you finish the plaster work on the sixth floor."***

Which one of the above instructions do you think will be carried out correctly? Obviously, instructions given explaining the order of work is more effective than relying on a date. You have now properly implemented resource leveling in the field.

I have written a program that reads the P3 resource leveling report and automates the identification of the control points and the search for the resource-delaying activity. It is called "Resource Planner"[11] and is included in my Schedule Analyzer software series. A sample report from Resource Planner is shown in Figure 4 below,

```
RESOURCE PLANNER REPORT

Resource Leveling Report = C:\P3WIN\P3OUT\M-RW06.OUT
Schedule: RW06

04AUG04: Activity 060ELCD120, Install Control Conduit and Wire (6-10) delayed waiting
for resource,
    ELEC with Activity 060ELCD100, Install Power Conduits (6-10) to complete.

04AUG04: Activity 030ELCD120, Install Control Conduit/Wire (EL-15 to 8) delayed
waiting for resource,
    ELEC with Activity 060ELCD100, Install Power Conduits (6-10) to complete.

06AUG04: Activity 040ELCD100, Install Power Conduits @ Primary Sed Basin delayed
waiting for resource,
    ELEC with Activity 060ELCD120, Install Control Conduit and Wire (6-10) to
complete.

09AUG04: Activity 040ELCD110, Install Branch Conduits @ Primary Sed Basin delayed
waiting for resource,
    ELEC with Activity 030ELCD100, Install Power Conduits (EL -15 to 8) to complete.
```

Figure 4 – Sample Resource Planner Report.

Why is it important to follow the resource leveling plan? The reason is fairly clear. If you do not follow the plan, you will be working at less than optimum in your resource usage. Once the plan gets 'out-of-sequence,' then the rest of the resource plan is also in jeopardy.

If you start an activity out of order earlier than envisioned, then that resource will be busy on the following days when the schedule anticipated resource availability for other tasks. We assume that once you start an activity that the most productive profile is to keep working on that same task until it is complete.

On the other hand, if you don't start a control point activity when planned, then the resource will be under-utilized and later this activity will need to be executed when that resource may not be available. Even just 'swapping' one activity for another is potentially schedule-threatening as resource requirements and activity durations may not match.

RESOURCE LEVELING REEVALUATION

Just as you would seldom just follow an unaltered baseline schedule to project completion, so should you not just keep executing the same resource leveling plan without reevaluation. You must status and assess how well you performed in order to determine if levels and parameters need to be adjusted.

We assume that your foremen will not blindly follow the plan that you gave them if conditions are wrong. If the needed resources were busy elsewhere, then they will not begin the control point work when you told them to do so. If resources are available early, they will not wait until the 'correct' time to begin the next activity.

Considering the number of resource leveling options and parameters, it is highly probable that they will need adjusting to better describe the way resources are being assigned on the field. You also need to reassess resource availability and the efficiency of the workers that you have already scheduled. Even if you were 'spot-on' previously, conditions do change and this change should be taken into account when assigning resources. The idea here is to match the resource availability, requirements, and usage in the computer to those same conditions on the field.

Assessing how well we executed a resource leveling plan is actually a lot more difficult than just comparing the schedule update with the target schedule. It is important to isolate the resource leveling performance from the standard CPM schedule performance. Unexpected events and progress occurs often and these aberrations must be discounted as well. Finally, a method to measure resource leveling performance cannot be time-intensive, as that is often the 'resource' in shortest supply on the field.

To save time and to focus on the issue at hand, I propose that we look at those same control points that we identified earlier when we were planning our resource usage. We need to track how well we did at starting the control point activities on-time. Focusing on the start and not the durations or finish dates helps us to reduce the effects of work performance and to concentrate on a simplistic metric.

To measure the start of each control point, we need to note the absolute difference between planned start and actual start. I use an absolute measurement due to the fact that it is just as 'bad' to start an activity early as it is to start it late. We then list all control points scheduled to occur during the last update period and note the trends.

I have written another software program does this function and produces a report, called "Resource Checker." [12] It is a part of the Schedule Analyzer Forensic series. Figure 5 shows a typical report output.

```

Schedule = C:\P3WIN\PROJECTS\Mant\RW10
Schedule Data Date = 30NOV04

Resource Leveling Report = C:\P3WIN\P3OUT\M-RW09.OUT
Resources leveled on Data Date = EX      ELEC      CAR      PF
Smoothing will be used in this leveling run.
Latest date for which resource availability can be calculated: 17JAN13
Resource Plan was made for Schedule RW09 on Data Date: 31OCT04

This analysis will cover the period of 31OCT04 through 30NOV04 = 30 calendar days.
Activities were started an average of 3 days later than resource leveling allowed.

```

Activity ID	Description	Early	Actual	Resource	Delta (Act-Res)
030COPC120	1st Soffit (EL 1	01NOV04	8NOV04	13JAN05	-66
YYYUG3W200	ELB 8/4" 3W (Nor	01NOV04	29NOV04	18JAN05	-50
040COPC170	FPS Walkways (EL	23NOV04	15NOV04	23DEC04	-38
040COPC180	FPS Primary Sed	01NOV04	20OCT04	03NOV04	-14
030COPC130	FPS Walls East o	01NOV04	27OCT04	03NOV04	-7
YYYELDB106	ELB Ductbank: MV	01NOV04	1NOV04	05NOV04	-4
065COPC100	FPS Footings & F	01NOV04	1NOV04	05NOV04	-4
YYYELDB102	ELB Ductbank: MV	04NOV04	22NOV04	24NOV04	-2
040COPC140	FPS Prim Sed Bas	03NOV04	12NOV04	09NOV04	3
070MEEQ160	Install FRP Scum	12NOV04		16NOV04	14+
160COPC120	FPS Blower / Tra	01NOV04		12NOV04	18+
YYYELEP120	Install New WAS	01NOV04		08NOV04	22+
YYYUGCN180	ELB 6" CEN (from	01NOV04		04NOV04	26+
YYYUGML140	ELB 48" ML Closu	03NOV04		04NOV04	26+
YYYUGSD170	ELB 6" SD East &	01NOV04		04NOV04	26+

Figure 5 – Resource Checker Report

What knowledge can we gain from comparing the actual start dates from the actual start dates of the control point activities? We will use Figure 5 as an example to evaluate. This is an actual report from a real construction project using resource leveling. We will concentrate on the last three columns in the table at the end of the report.

First, we will look at the activities that actually started during the past period (the first 9 activities in the list.) Comparing the actual date with the planned resource-leveled date gives us numbers from -66 through +3, as shown in the column labeled, "Delta."

Reviewing the actual part of the list, we note that none of the control points were actually started on time. One started 3 days late, one 2 days early, and the rest started progressively earlier than planned. Considering the fact that the period was only 30 days long, values like 38, 50, and 66 seem to be unbelievably high.

Looking the top activity in the list, Activity 040ELCD110, "Install Branch C...", we see that the CPM calculation says that it could start as early as 01NOV04 but was delayed for resource leveling purposes until 13JAN05. Even though our plan told us to delay the start for several months, the activity was actually started on 08NOV06, 8 days later than the CPM early start. This means that the activity

started 66 days earlier than it was supposed to start, had the resource leveling process been correct.

Let's now look at the bottom 6 activities in the list that have not started as yet. The resource leveling process scheduled them to start last period but they were not. The days listed under the Delta column all have a "+" listed to the right to indicate that the measurement was taken at the data date and will most certainly grow larger as we wait for them to actually start.

The report in Figure 5 shows an average absolute delta of 21 days. During a 30-day period, the average resource-leveled control point was executed 21 days off. (Don't forget that this figure is low as the bottom 6 activities have not actually started as yet.) Considering this fact, I believe that one could very clearly state that resource leveling was not effectively being implemented on the project in question.

What are the ramifications of this test? If you were the Owner of this project and a delay not attributable to the Contractor occurred, could you rely on resource leveling to calculate the 'real' effect on the project? If Activity 030COPC120 was actually executed 66 days earlier than the resource leveling allows, then clearly you cannot rely on this prediction for change order considerations.

Fine Tuning your Resource Plan

What if our evaluation of the execution of the resource leveling plan had been much closer to on-time? What if the plan was flawed but still valid? What should we do to bring corrections on-line and improve the plan further?

It is permissible to disregard and single activity with deviation if an unexpected delay or other unplanned event strongly affected it. Then, we should look at the resources actually used as opposed to those that the program says is required. Are your manhour estimates for the tasks still valid? Did the trigger activities in your Resource Deployment Order finish on-time?

For control point activities that started earlier than planned, we must consider that perhaps the availability limits for that resource are set too low and that the foremen have access to greater numbers or workers. Perhaps the splitting or crunching figures are too stringent. Are they executing the activity continuously, or is the work being performed in 'chunks'?

If the control point activities are starting late (or not starting at all,) confirm that your foremen were trying to work the plan that you had handed them. Are the resource availability limits too high? Were the resources used roughly equal to the planned amounts?

Finally, Document your findings. Just as you need to document your progress, you also need to document your efforts to track and refine your resource plan. This will be crucial if you ever actually need to demonstrate your reasoning in a courtroom situation. You can only expect others to take your resource leveling findings seriously if you can prove that you did the same. No plan is perfect and must be monitored and adjusted if it is to be believed.

CONCLUSION

Resource leveling is a valid scheduling technique that can be used on construction projects, provided that it is implemented correctly. Contractors have a strong desire to use this technique, as it can more accurately reflect the resultant impact of an unplanned delay not just on the project, but also on the contractor's workforce. Typically, the project extension resulting from a Time Impact Analysis using resource leveling is greater than that when just CPM is used alone.

Correct implementation of resource loading requires a full understanding of the process and input parameters, a contentious effort to assess and model expected conditions, proper implementation, assessment of results, and corrective adjustments. Accuracy and validity of resource loading can be measured and verified.

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