Resource Constrained Scheduling Capabilities of PM Software

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Introduction

To be used for reliable project planning and what-if evaluations required for informed decision making, a good project model must reflect reality.

A good reflection of reality means that:
- Activity properties include all information used by people for planning and management
- Resource data includes all information used by people for planning their projects
- Resources are assigned the same way people do it
- Costs are assigned the same way people do it

Introduction

When resources are not limited, the Critical Path Method (CPM) easily finds the best project schedule but CPM does not consider resource, supply, space, and cost constraints.

With limited resources, calculating the best schedule is a complicated task that has no mathematical solution that can be found within reasonable time.

Introduction

Project management packages use different algorithms for resource-constrained scheduling and produce different results for the same projects. They also have different capabilities to simulate real-life resource-constrained scenarios.

In this presentation we will discuss the main activity, resource, and assignment properties and project constraints that should be simulated by scheduling software, as well as resource-constrained scheduling capabilities of the popular scheduling tools.

Project Data

Project Data – Activity Properties

Most activities belong to one of the following types:
Duration: Activities for which duration is initial information and does not depend on the volume of work to be done.
Volume: Activities characterized by the volume of work to be done that is usually measured in physical units. Duration of this type of activity depends on the productivity of assigned resources.
Level of Effort or **Hammock** type where activity duration is determined by external events so that such activities last from event till another.
M**ilestone**: an activity with zero duration that usually reflects some event in the project schedule.

Project Data – Activity Properties

Activity cost and material requirements may be defined as:
fixed amount that does not depend on activity volume or duration,
amount **per unit of volume**,
amount **per unit of duration**

Activity calendar defines the time periods when an activity may be executed.

Activities belong to the same **Type** if they share the same properties like cost and material requirements per volume unit, resource requirements and productivity.

Project Data – Renewable Resources

Project resources may be divided into two main classes:

- **Renewable resources** that may be used again after they complete the job to which they were assigned,
- **Consumable resources** that are spent on activities to which they were assigned and therefore cannot be used again.

Renewable resource (labor, machines) properties include:

- available **quantities** at different time periods
- resource **calendar**
- **per hour cost**
- **per hour consumption of project materials** (a machine may use a certain amount of fuel or electricity per work hour)

Project Data – Consumable Resources

Consumable resource properties include:

- **unit** of measure,
- **unit cost** that may be different for different time periods.

Consumable resources do not have special calendars.

Resources (both renewable and consumable) can be **produced** on project activities (examples: mobilization of renewable resources and supply for materials), spent or **removed** from the project team on other activities (usually milestones).

Project Data – Resource Assignment Properties

Renewable resources may be assigned in different ways:

- **Team assignment** means that resources assigned as a team do the job together; if a resource belonging to an assigned team is not available, the whole team will not work
- **Independent assignment** means that resources may work independently of each other and at different times

Independent assignments are useful for simulating working in several **shifts**.

Project Data – Resource Assignment Properties

- Assignments may be **partial** when an assigned resource works on an activity for only a part of its work time. In this case the assigned resource may use the rest of its work time working on other activities.
- Assignments may be **variable** when activity resource requirements are defined as a range with a minimum and maximum quantity and workload.
- Resource assignment **productivity** determines the duration of volume type activities.
- Resource **workload** is 100% for full-time assignments and may be less for part-time assignments.

Project Data – Resource Assignment Properties

Resource assignment properties may also include **assignment cost** and **assignment material consumption** that may be set as **fixed** or as an **amount per volume or duration unit**.

Another way of assigning resources is assigning **resource skills** rather than concrete resources. Resources have the same skill if they can perform a certain type of activity although probably with different productivity and cost.

Project resource-constrained scheduling with automatic resource assignment based on assigned resource skills and availability is called **skill scheduling**.

Project Data – Activity Dependencies

Standard FS, SS, FF and SF links connect start and finish points of activities with **No Earlier Than** dependencies.

SS and FF dependencies usually mean that the two activities may be executed in parallel but with some lag. I.e. the next activity may start after a certain amount of work on a preceding activity is done, defining a certain minimal “distance” between crews on preceding and succeeding activities. This distance is usually measured in volume units and thus-defined lag is called **volume lag**.

Time lag defines the time interval between an activity’s start or finish and another activity’s start or finish points, and is used mostly for duration-type activities. Time lag may have its own calendar.

Project Data – Activity Dependencies

It may also be helpful to use the **point-to-point dependency** that we call the **double-lag dependency** when a certain point of a preceding activity is linked to some point of a succeeding activity. These points may be defined as Start Plus Volume Lags.

In real life, the way a project is executed depends on its status. When the major milestones are late, people apply corrective actions, use additional resources or more advanced technologies on the rest of the project.

It is useful to develop **conditional networks** where such corrective actions are applied automatically when needed.

Project Data

Unfortunately the most popular project management packages do not simulate:

- activity volumes
- consumption of materials by renewable resources
- resource assignment productivity
- resource skills
- unit cost and material requirements
- work in several shifts
- variable resource assignments
- volume lags
- point-to-point dependencies
- conditional networks

Resource-Constrained Scheduling

Resource-Constrained Scheduling

It is generally accepted in project management that a feasible project schedule that finishes earlier is the best.

The benefits of finishing a project earlier include (but are not necessarily limited to):

- Reduced costs due to lower indirect costs
- Reduced costs due to better resource utilization
- Better return on investment (“time is money”)
- Better customer satisfaction

In the modern competitive environment, being able to produce a shorter project schedule can win you a tender. The package that produces shorter schedules saves a lot to its users.

Resource-Constrained Scheduling

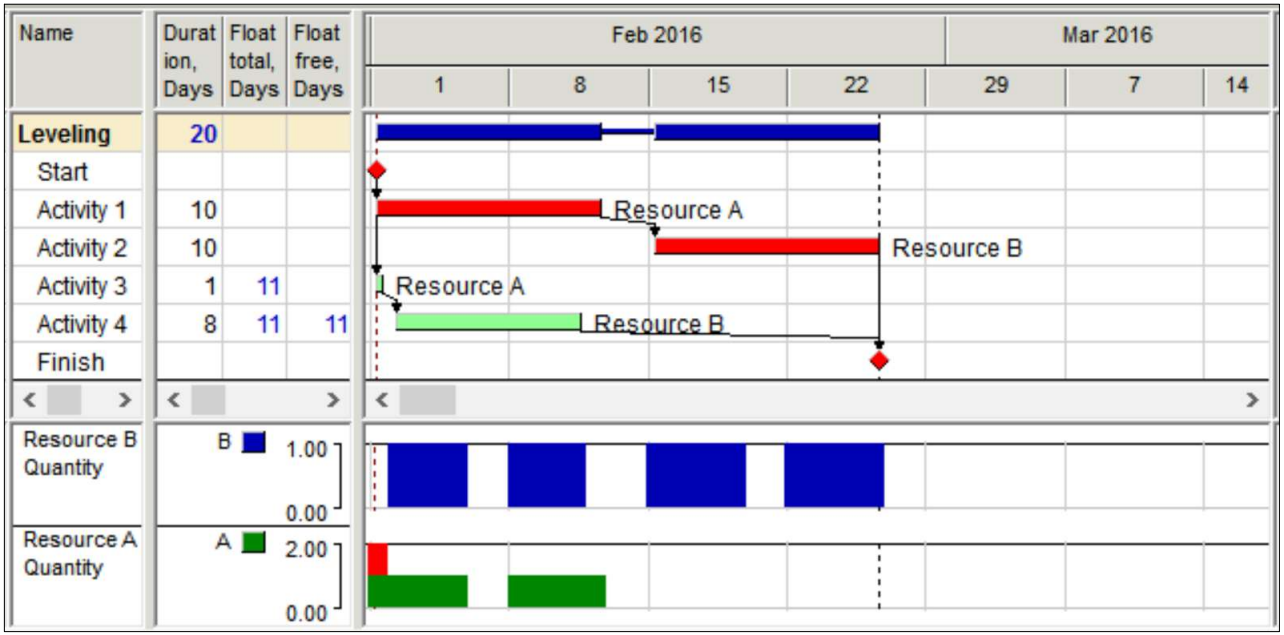
Resource leveling heuristics determines the rules by which the activities competing for the same overallocated resource will be selected and delayed.

Some packages use a single rule, others offer a choice of leveling heuristics to use for scheduling, still others employ sophisticated approaches using several rules or iterative processes for finding the best solution.

Different packages create different resource-constrained schedules for the same project. Therefore project planners must not blindly rely on the schedules proposed by their tools but look out for possible improvements in these schedules.

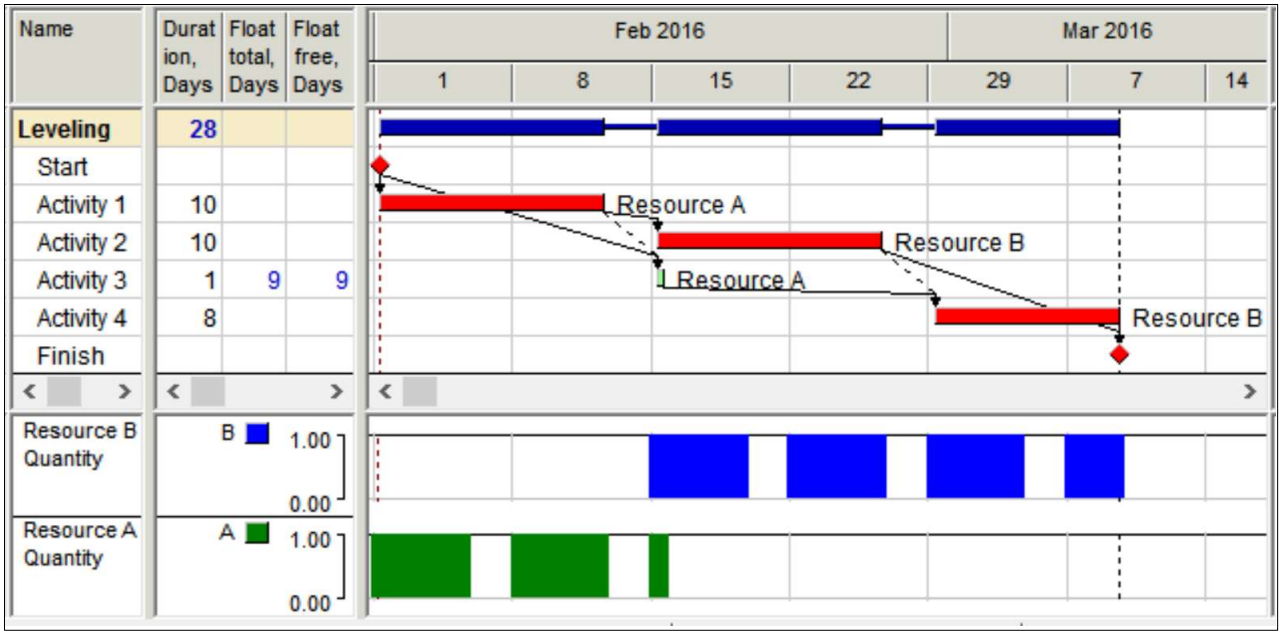
Resource-Constrained Scheduling

Look at the Sample Schedule below. This schedule was created using the Critical Path Method and resource A is overallocated. Activities 1 and 2 constitute the Critical Path, activities 3 and 4 have 11 days total float, but this CPM schedule is not feasible and requires adjustment.



Resource-Constrained Scheduling

The most widely used heuristics for resource leveling assigns highest priority to activities with the least total float in CPM schedule. Applying this rule to our Sample Project, we get the following schedule. Project duration is longer but resource overallocation is resolved.



Resource-Constrained Scheduling

Activity **floats** in resource-constrained schedules must be calculated taking into account the resource constraints on both the forward and backward passes.

A sequence of activities with the least total float (usually zero) in a resource-constrained schedule is called the **Resource Critical Path** or **Critical Chain**.

In our example it is the sequence of activities 1, 2, and 4 (and, of course, the Start and Finish milestones).

When resources are not limited, the Resource Critical Path is the same as traditional Critical Path, so the Critical Path is a particular case of the Resource Critical Path.

Resource-Constrained Scheduling

When a project has resource constraints, the schedule itself, activity floats and the Resource Critical Path are determined by the leveling rules.

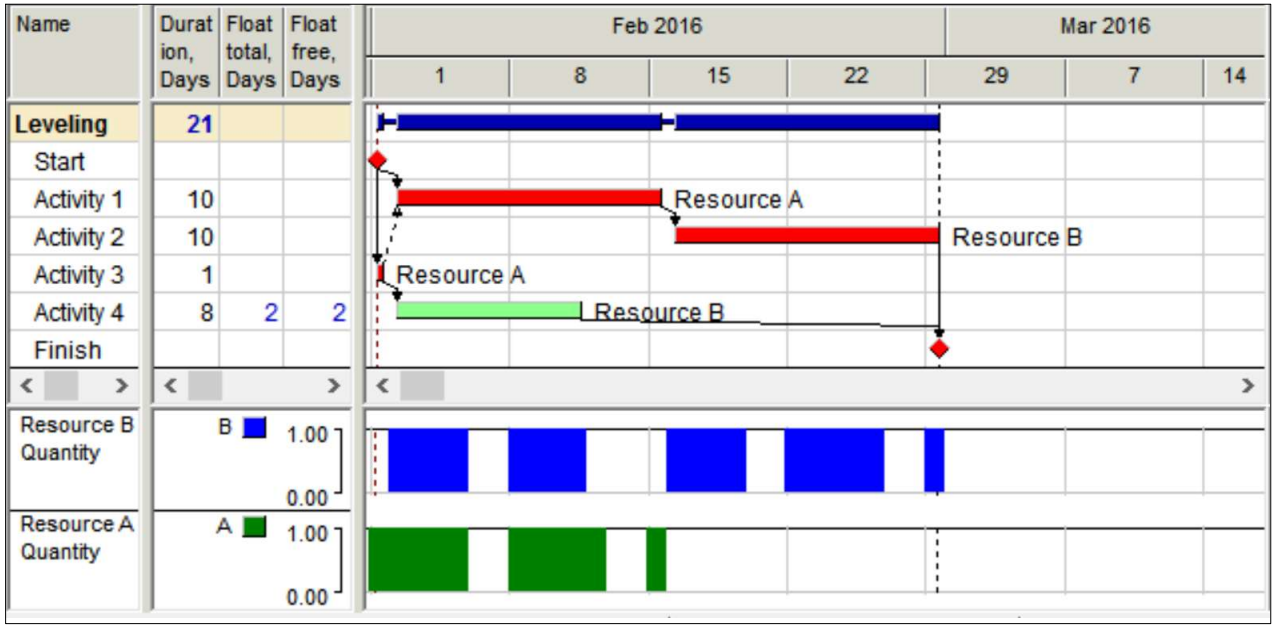
If your software permits using different priority rules, it makes sense to try several of them and then select the best schedule.

It is even better if your scheduling tool features a resource-constrained schedule optimization option. It means that the software analyzes and improves project schedule, using an iterative process, and thus can deliver better results than any simple priority rule.

Resource-Constrained Scheduling

Activities can be critical in one schedule and have a positive total float in another like in the optimal schedule presented below and the schedule we considered earlier.

This must be taken into account by Project planners who use different project scheduling tools and/or import project models from one tool to another.



Comparison of automatic resource-constrained scheduling capabilities of popular PM tools

Comparison of resource-scheduling capabilities

Requirements for resource work simulation depend on the project nature, planning maturity and many other factors. But whatever the case, people expect from their project management software to create good schedules for their projects.

Comparative analysis of the resource-constrained scheduling capabilities of popular project management tools may help to select the right scheduling software and to understand whether the schedules created by certain project management packages can be improved.

Comparison of resource-scheduling capabilities

The leveling algorithms of Microsoft Project, Oracle Primavera P6, and Spider Project were tested on a set of sample projects.

These sample projects were selected, based on the following requirements:

Anyone should be able to verify this comparison and test other tools with the same projects

It should be possible to use the selected projects to test any project management software that has an automatic resource leveling feature.

The choice of sample projects must be regarded as non-biased as possible by the PM community.

Comparison of resource-scheduling capabilities

Based on these criteria, the tests were performed, using the projects from Resource-Constrained Project Scheduling Problems (RCPSP) of the Project Scheduling Problem Library – PSPLIB, made available by the Technical University of Munich.

This Library contains different problem sets for various types of resource-constrained project scheduling problems. All projects in this library use only FS activity dependencies and team resource assignments – nothing complicated such as variable resource assignments, activity splitting, different calendars, etc. In all tests, activity splitting was not permitted.

Comparison of resource-scheduling capabilities

The PSPLIB library contains 2040 problems (projects) including:
480 problems with 30 tasks and 4 resources (j30 - series)
480 problems with 60 tasks and 4 resources (j60 series)
480 problems with 90 tasks and 4 resources (j90 series)
600 problems with 120 tasks and 4 resources (j120 series)

Only 25 most interesting of these problems were selected for the current test (10 from j120 series, 5 from j90 series, 5 from j60 series, and 5 from j30 series).

The problems that resulted in the biggest project extension due to resource leveling were considered as the "most interesting" *([duration resource leveled] / [duration not resource leveled])*.

Comparison of resource-scheduling capabilities

The selected 25 projects were leveled using 3 popular project management packages including the different versions of Microsoft Project:
Spider Project 11.03.155
Primavera P6 v 15.1
Microsoft Project 2007, Microsoft Project 2010, Microsoft Project 2013, Microsoft Project 2016.

We also planned to test Asta PowerProject but were surprised to learn that Asta does not simulate team resource assignments and failed to produce feasible schedules for the projects from PSLIB.

Comparison of resource-scheduling capabilities

The goal of the exercise was to get the best-achievable result from each of these tools.

For Microsoft Project, there is little choice but to use the Standard leveling algorithm.

Oracle Primavera P6 was also tested with the standard leveling algorithm but, in addition to this, P6 permits to replace the default leveling heuristic with the customized leveling priorities.

Trautmann and Baumann have tested 196 priority combinations on P6 and produced a “best result out of 3 rules” recommendation for Primavera software.

Comparison of resource-scheduling capabilities

They recommended to perform 3 schedule runs with 3 different priority rules (A, B, C) and select the best result:

- Rule A: late start (1st), late finish (2nd)
- Rule B: late finish (1st), duration (2nd)
- Rule C: free float (1st), late start (2nd)

While we believe that asking a scheduler to manually change priority rules in a search of the shortest schedule is halfway between the manual and automated leveling, it can be practically usable with a small number of the rules.

Therefore P6 was also tested with the “best result out of 3 rules” approach as well.

Comparison of resource-scheduling capabilities

Spider Project also permits assigning multiple priority rules but there is no need in it since this software features an **Optimization Plus** algorithm it uses for finding the best resource-constrained schedule automatically.

Microsoft Project 2013 and 2016 showed exactly the same results for every single schedule. As most of the schedulers are likely to be using the latest versions of Microsoft Project, comparative results are shown for these versions only. Previous versions of Microsoft Project, however, showed different leveling results and the historical trend will be discussed in this presentation later.

Comparison of resource-scheduling capabilities

To compare the resource-leveling results produced by the different tools, we used the following integrated metrics that appears to be of the most interesting for practical users:

- Average ratio [resource-leveled duration] / [unleveled duration]
- Average excess of resource-leveled project duration over the best result produced by the compared tools
- Percentage of projects for which the tool created a schedule that was the shortest, 2nd, 3rd or 4th shortest.

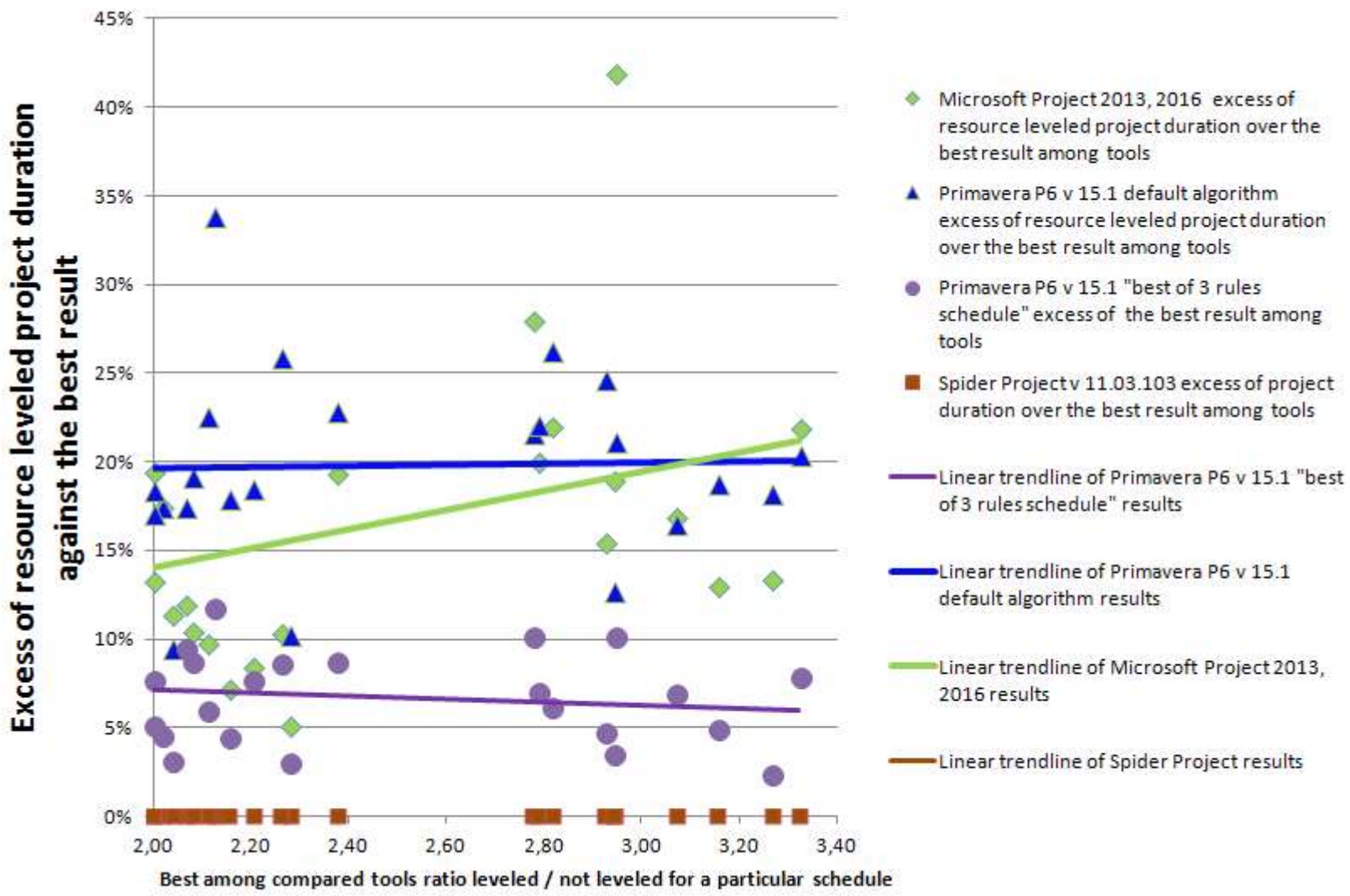
The aggregate statistics are shown in next slide.

Comparison of resource-scheduling capabilities

Comparison of resource leveling results produced by different scheduling tools

0	Microsoft Project	Spider Project	Primavera P6 Default	Primavera P6 Best of 3 rules
Ratio (Leveled / Not Leveled)	2,88	**2,46**	2,95	2,62
Average excess over the best result	16,48%	**0,00%**	19,78%	7%
% of schedules with the shortest duration	0	**100**	0	0
% of schedules with 2nd shortest duration	4	0	0	**100**
% of schedules with 3rd shortest duration	**64**	0	36	0
% of schedules with 4th shortest duration	32	0	**64**	0

Comparison of resource-scheduling capabilities



Comparison of resource-scheduling capabilities

Conclusions:

For each of 25 schedules, Spider Project came up with the shortest schedule

For 24 problems, P6 using the "best result out of 3 rules“ produced shorter schedules than Microsoft Project and the default P6 algorithm. For one problem, the duration was the same as produced by Microsoft Project

On the average, the default Microsoft Project algorithm was better than the default P6 algorithm but not in 100% of the cases

Oracle Primavera P6 users may consider using the partially manual "best result out of 3 rules“ approach as it gives significant improvement over using the default leveling algorithm

Comparison of resource-scheduling capabilities

The results of testing the different versions of Microsoft Project showed a gradual degradation of resource leveling algorithms from version 2007 to versions 2013/2016:

Aggregated statistics	MSP 2007	MSP 2010	MSP 2013 & 2016
Average ratio leveled / not leveled	2,78	2,81	2,88
Average excess of resource-leveled project duration over the best result	0,77%	1,65%	3,95%
% of shortest schedules	**60**	36	16
% of 2nd shortest schedules	20	**52**	32
% of 3rd shortest schedules	20	12	**52**

Manual Leveling

Manual Leveling

When project planners are not happy with the schedules produced by their tools, they can try to adjust project schedules manually. It may be done by manually applying activity priorities, adding artificial activity dependencies (soft links), or adding artificial Start No Earlier Than constraints.

When a project uses many different limited resources, manual leveling is a difficult and time-consuming process when you are trying to find the best solution. It includes comparing numerous what-if scenarios and rarely produces the best results just because people cannot consider too many options.

Manual Leveling

The most serious problems with manual leveling, however, arise when the project is executed. Projects are not usually executed exactly as planned: some activities are delayed, others are executed out of sequence; resource availability can change for many reasons. When such events occur, the remaining part of the project must be rescheduled, which means that previous artificial constraints and priorities must be removed and the process of manual project leveling must be repeated. It takes too much time and effort to be practical.

In any case when manual resource leveling is used we suggest to play with activity priorities and try to avoid using soft links and artificial time constraints.

Schedule Stability

Schedule Stability

After a project schedule is approved, the project planner may want to maintain the scheduled order of activity execution. Automatic resource leveling may change this order when project data are changed (for example, after entering actual data). When changes are undesirable and maintaining the approved order of activity execution is necessary, it is nice to have this option featuring in the automatic resource leveling settings.

Resource-Constrained Schedule Analysis

Resource-Constrained Schedule Analysis

Resource-constrained schedule must provide project planners the same information that is available in CPM schedules including calculated activity resource-constrained floats, Resource Critical Path, etc.

Unfortunately most tools do not provide this information to their users.

Activity Floats and Resource Critical Path

Resource-constrained floats can be calculated the same way as in CPM schedule comparing activity dates scheduled in forward and backward passes both of which are calculated taking into account resource limitations.

Activities with minimal resource-constrained total floats (usually zero) are **critical**.

The sequence of resource-critical activities from the project start to the project finish constitutes the **Resource Critical Path**.

Like in CPM schedules, Resource Critical Path may be shorter, starting from the date defined by No Earlier Than constraint or by specific activity or resource calendar.

Activity Floats and Resource Critical Path

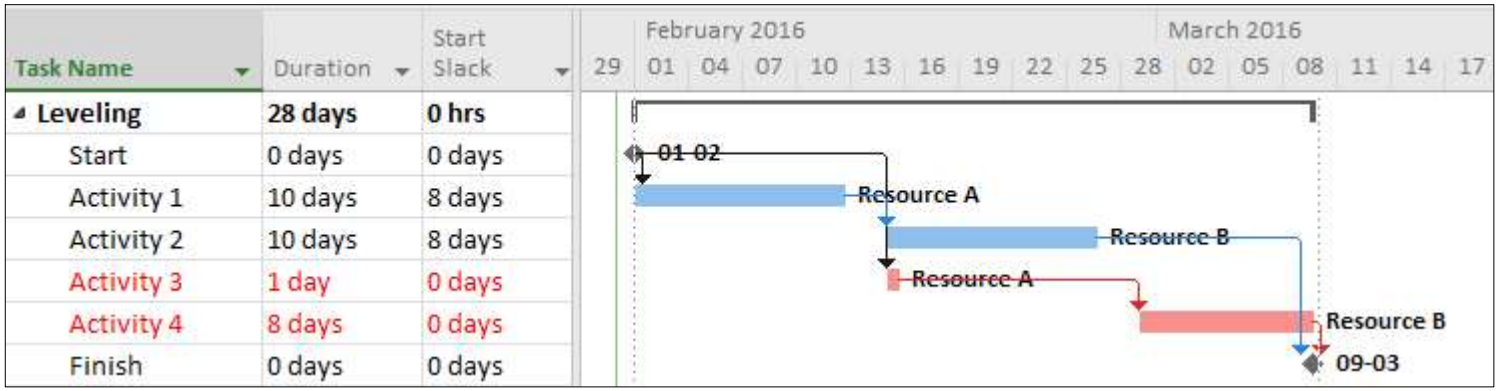
The resource-constrained floats and the Resource Critical Path must be calculated with all existing constraints taken into account. In a particular case where only renewable resource constraints are considered, the Resource Critical Path is the same as **Critical Chain**.

Other constraints (material supply, funding, space) may also be taken into account if you use Spider Project leveling engine.

Unfortunately, both Microsoft Project and Oracle Primavera P6 do not calculate the resource-constrained total floats and RCP correctly.

Activity Floats and Resource Critical Path

Let's have a look at the simple example below that shows MSP schedule for a small project that was used as a sample project:



Task Name	Duration	Start Slack
Leveling	28 days	0 hrs
Start	0 days	0 days
Activity 1	10 days	8 days
Activity 2	10 days	8 days
Activity 3	1 day	0 days
Activity 4	8 days	0 days
Finish	0 days	0 days

You may notice that the schedule created by MSP is not optimal and resource-constrained total floats are wrong. In the MSP schedule, activity 3 is critical although it has a 9-day free float and activities 1 and 2 have 8-day total floats although actually they are resource-critical.

Resource Dependencies

Resource dependencies are very useful for resource-constrained schedule analysis. They show why an activity is delayed for longer than required by activity logic dependencies.

Activity A precedes Activity B with the resource dependency if activity B was delayed because a resource required on activity B was busy on activity A.

Resource dependencies are created as the result of the current schedule analysis and are reconsidered every time when the project is rescheduled.

They are not the same as soft links people create when leveling projects manually to fix resource conflicts.

Resource Assignment Float

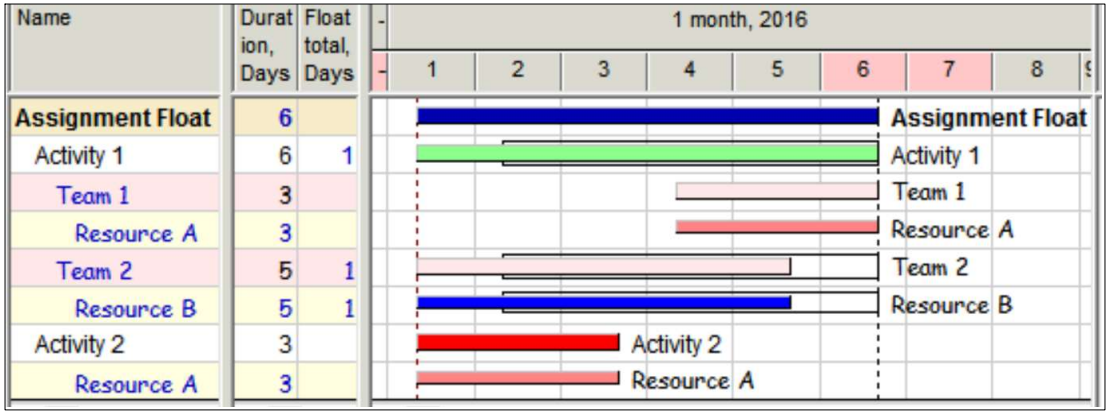
With the independent resource assignments, activity floats and resource assignment floats may be different. Moreover, resource assignment may be critical while an activity this resource is assigned to has a positive total float.

Like activity total float, **resource assignment float** is the time period for which an assignment may be delayed without delaying the project finish.

The project shown in the next slide has two activities and two resources A and B.

Resource Assignment Float

Resource assignments on Activity 1 are independent, the planned duration of resource A assignment is three days and resource B is assigned for five days. Activity 2 has a three-day duration and requires resource A.



As a result of resource leveling, Activity 1 duration is six days and its start may be delayed for 1 day without delaying the project finish; however, resource A assignment on activity 1 cannot be delayed which makes this assignment critical.

Conclusions

Conclusions

We have discussed the requirements for simulating resource work that must be met for creating an adequate project model that can be used for simulating the real-world resource assignments and constraints. Failing to meet these requirements restricts the areas and projects where scheduling tools may be successfully applied.

Resource-constrained scheduling capabilities of popular project management tools were compared using a set of 25 sample projects taken from PSLIB library. The test results show that Spider Project always creates the shortest resource-constrained schedules and that the default resource-constrained schedules produced by Microsoft Project and Oracle Primavera P6 may be improved.

Conclusions

Oracle Primavera P6 users may try several predefined simple leveling heuristics and select the one that produces the shortest schedule for their project. They must keep in mind, however, that the same leveling heuristics may be good for one project and bad for another.

Microsoft Project users do not have such opportunity.

Another option available to users of all PM packages is a manual improvement of automatically created resource-constrained schedule. This must be done by applying user-defined activity priorities that modify the automatic resource leveling heuristics. These priorities, however, must be reconsidered with any change of initial data.

Conclusions

Resource-constrained schedule analysis may be done using the same tools as those used for non-leveled schedules including activity total and free floats, Critical Path, etc. However, MS Project and Oracle Primavera P6 do not calculate resource-constrained activity floats correctly and these analysis tools are not available for their users.

There are other tools specifically intended for resource-constrained schedule analysis like resource dependencies and assignment floats. We hope that in future these tools will be available in other packages, not only in Spider Project.

Conclusions

Proper resource-constrained scheduling and project duration optimization can save resources and money, and improve the reliability and credibility of project planning using scheduling tools.

Resource-constrained scheduling and project duration optimization deserve much more attention than they currently get.

Thank you!

Questions?

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