Project Planning and Control Methods

Lecture #7-P2

Schedule Constraints (Resources)

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Outline

- Project resources
- Resource allocation
- Resource leveling
  - Resource leveling – Technique
  - Resource Leveling - MSP
- Resource over-allocation
- Resource calendar constraint
- MSP (more features)

Project resources

- We need resources to carry out different activities. There are three main resource types used in projects:
  - People (engineer, labor, operator)
  - Equipment (loader, crane, truck)
  - Material (steel, concrete, asphalt)
- Material-type resources are ***expendable*** resources, i.e., they are depleted during activity execution (e.g., use of concrete during “pouring foundation concrete” activity).
- People-type and equipment–type resources are ***non-expendable*** resources, i.e., they are busy when participating in an activity execution and become available for other activities after that. E.g., use of shovel and shovel operator for “digging the ditch” activity.
- Several resources might be used to carry out an activity (e.g., to install a steel column we need steel column, iron workers, crane and crane operator).

Resource allocation

- Resource allocation (or resource loading) is the assignment of the resources required to each activity, in the required amount and timing.
- When we first estimate an activity duration, to be able to estimate the duration, we automatically assign normal number of resources required to each activity. This is basically the initial resource allocation.
- **Example:** Remember our “prepare foundation form work” example in *lecture 5* when we first estimated the activities, all durations came with number of resources required, we have allocated resources by mentioning resources for each activity:
    1) Extract foundation sizes from drawings (1 engineer, 1 day)
    2) Order form sheets (1 purchaser, 0.5 day)
    3) Hire two form-workers for the job(1 HR-person, 1 day)
    4) Size form sheets (2 form-worker, 2 day)
    5) Install form sheets in place (2 form-worker, 4 days)

Resource leveling

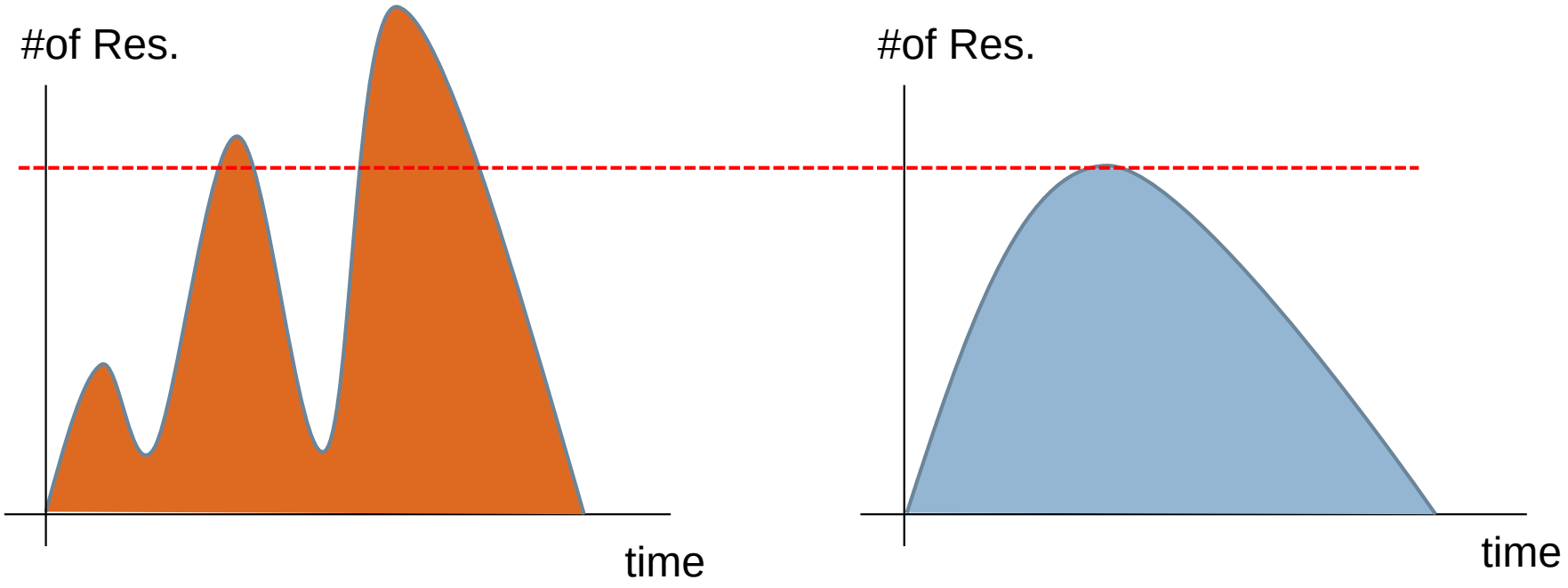
- Fluctuations in number of *some* (not all) of project resources over the course of the project are undesirable. For these resources we are trying to level their number over the time.

  Note: Resource leveling is the case for most (not all!) people and equipment resource types (or non-expendable resources) but not for material resource type (or expendable resources)! (*why? see the justification in below!*)

- Every time we are forced to increase/ decrease number of our resources (i.e., hire/ fire our workers or set up / pack up our equipment) for the project we are imposing some costs to the project. Some examples of these additional costs are:
  - Time spent by HR person for hiring/ firing workers
  - Low performance of the new workers
  - Time spent by procurement person to sign rental/ purchase contract
  - Time spent for picking up/ dropping off and install/ uninstall the equipment

Resource leveling

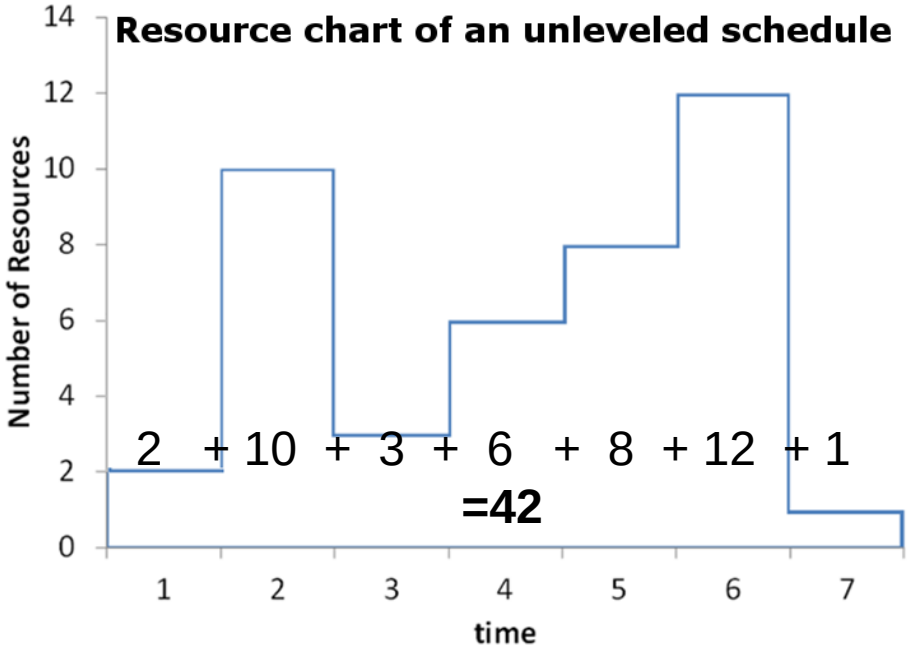
With equal total Man-Hour used in both project plans, which one of the following resource curves causes less cost to the project?

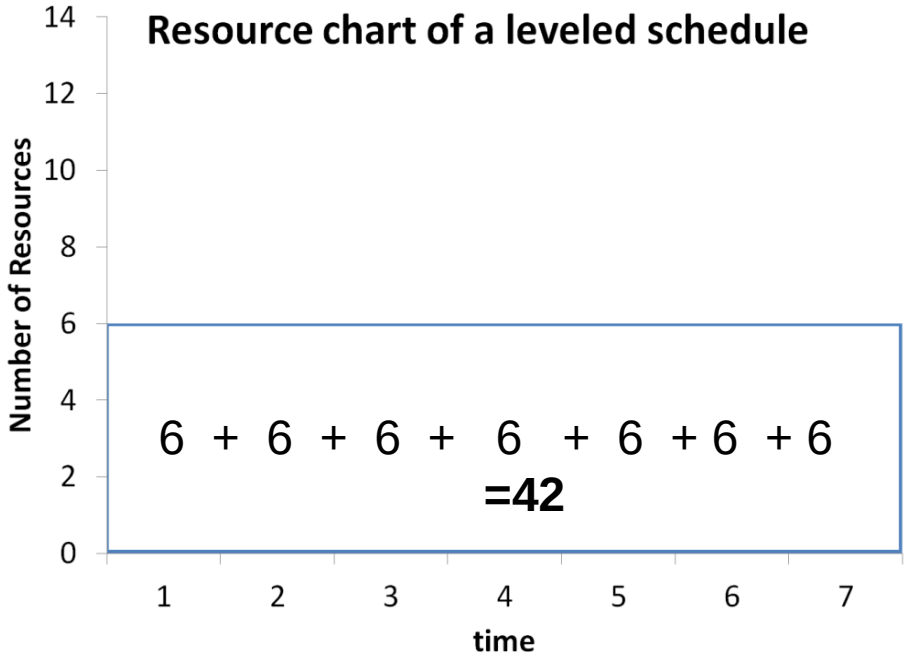


Project managers also whish to cut the resource peaks! Why?

Resource leveling

- **Example 1**: Following resource charts represent resource distribution over course of a project before and after resource leveling. Total number of resources per time unit in both schedules is 42. However, we are expecting less cost in the leveled schedule since project will have no cost regarding resource fluctuations!





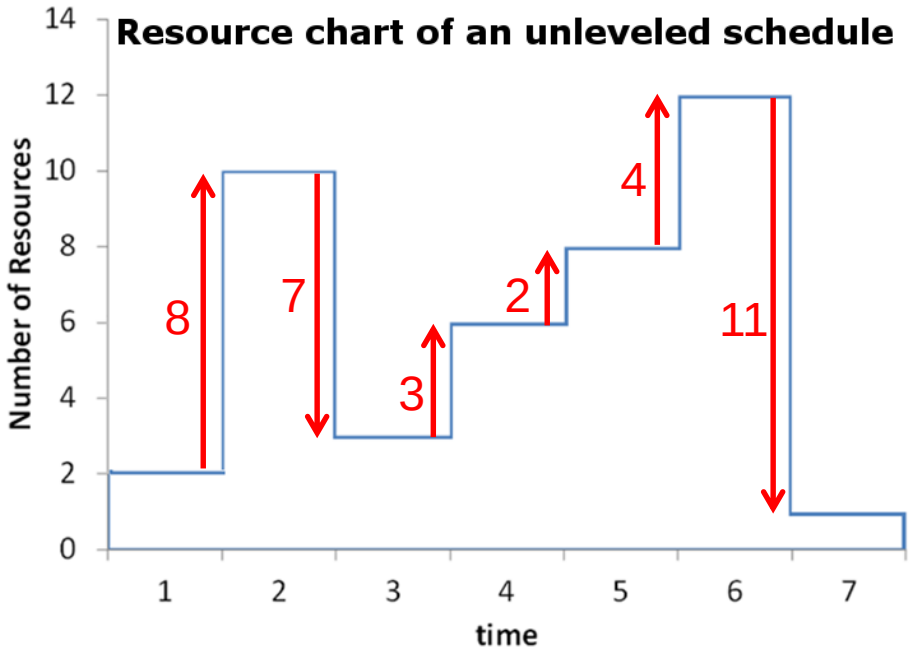
Question: In reality is a completely leveled schedule possible?

Resource leveling

- **Example 1 (cont'd)**:
  - For calculating resource fluctuations in resource chart we need to sum up the amount of all ups and downs of the resource level!

Resource fluctuation=

8 + 7 + 3 + 2 + 4 + 11 = **35**



Question: How can we reduce resource fluctuations (or level the resources) in a project?

Resource leveling

- Resource leveling has different types according to different types of project constraints. Resource leveling we are discussing here is for projects with *unlimited* resources and *limited* duration (the duration calculated in CPM).

  Note: A project might have different types of resources (with different expertise or applications). Leveling different types of resources are done separately (e.g., welders, painters, cranes, etc. need to be leveled separately); most important resources are leveled the latest! **Why?**

- To be able to level the resources we need to *adjust activities start* (*or finish*) time in a way that resource fluctuations are reduced.

Question: For doing resource leveling on our schedule what type of activities we need to shift? (critical or non-critical) (easy question!!!!)

Resource leveling

- **Example 2:** We are trying to level the project schedule presented in resource aggregate (or resource load) table in below by moving activities start time:

					Working Day								
WBS	**Predecessor**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	2	2	2	2	2				
2	1SS	1	4	3	2	2							
3	2	3	6	3			3	3	3	3			
4	2	3	8	5			2	2					
5	1,2	1	1	0						2	2	2	
6	5	1	1	0									1
Sum					**4**	**4**	**7**	**7**	**5**	**5**	**2**	**2**	**1**

Resource fluctuations= 0+3+0+2+0+3+0+1=9

Resource leveling

- **Example 2 (cont'd):**

Moving activity 4 forward:
Resource fluctuations=
0+1+0+0+0+1+0+3=5

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	2	2	2	2	2				
2	1SS	1	4	3	2	2							
3	2	3	6	3			3	3	3	3			
4	2	3	8	5							2	2	
5	1,2	1	1	0						2	2	2	
6	5	1	1	0									1
Sum					4	4	5	5	5	5	4	4	1

Moving activity 3 forward:
Resource fluctuations=
0+0+0+1+0+0+0+4=5

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	2	2	2	2	2				
2	1SS	1	4	3	2	2							
3	2	3	6	3					3	3	3	3	
4	2	3	8	5			2	2					
5	1,2	1	1	0						2	2	2	
6	5	1	1	0									1
Sum					4	4	4	4	5	5	5	5	1

Resource leveling

- **Example 3 (cont'd):**

Moving activity 3 to ultimate forward:

Resource fluctuations=

0+0+0+2+3+0+0+1=6

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	2	2	2	2	2				
2	1SS	1	4	3	2	2							
3	2	3	6	3						3	3	3	3
4	2	3	8	5			2	2					
5	1,2	1	1	0						2	2	2	
6	5	1	1	0									1
Sum					4	4	4	4	2	5	5	5	4

Moving activity 3 to ultimate Forward and activity 2 and 4 1 step forward:

Resource fluctuations=

2+0+0+0+1+0+0+1=**4**

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	2	2	2	2	2				
2	1SS	1	4	3		2	2						
3	2	3	6	3						3	3	3	3
4	2	3	8	5				2	2				
5	1,2	1	1	0						2	2	2	
6	5	1	1	0									1
Sum					2	4	4	4	4	5	5	5	4

Resource leveling

- To find the best possible resource distribution in a project's schedule, there is no way other than comparing resource fluctuations in all possible activity combinations in the project and picking the combination that has the minimum resource fluctuation!
- For a real world project schedules (e.g., with more than 100s or even1000s of activities), we are going to have a considerable number (e.g., 100s or 1000s) of non-critical activities which are candidates for changing their start time. Many of them have slack time of more than 1 which adds to the number of possible activity combinations.
- **Example 3:** A project schedule has total130 activities (30 of them on the critical path and 100 are non-critical). Average slack time for non-critical activities is 3 days. Total combination of activities will be in the order of:

  3^100= 5.2 * 10^47

Resource leveling

- **Example 3 (cont'd):** If we suppose just 1 simple calculation is required for calculating every schedule combination (!!!!!) and the computer can handle 10 billion (10^10) calculations in a second. Total calculation time for finding the best possible activity combination is:

  5.2 * 10^47 / 10^10 = 5.2 * 10^37 seconds = 1.6 * 10^30 years (!!!!!!!)

- Resource leveling problems are considered computationally complex problem (so call non-deterministic polynomial time hard or NP-Hard). For real scale projects there is no way that we can guarantee optimum answer for the problem.

- To address resource the leveling concern there are heuristic and meta-heuristic methods developed with the main purpose of converging toward the optimum answer!

In class exercise 1

Try to find the most leveled schedule for the project schedule presented in resource aggregate (or resource load) table in below:

					Working Day								
WBS	**Predecessor**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	1	1							
3	2	3	6	3			2	2	2	2			
4	2	3	8	5			3	3					
	Sum				**2**	**2**	**6**	**6**	**3**	**3**	**1**	**1**	**1**

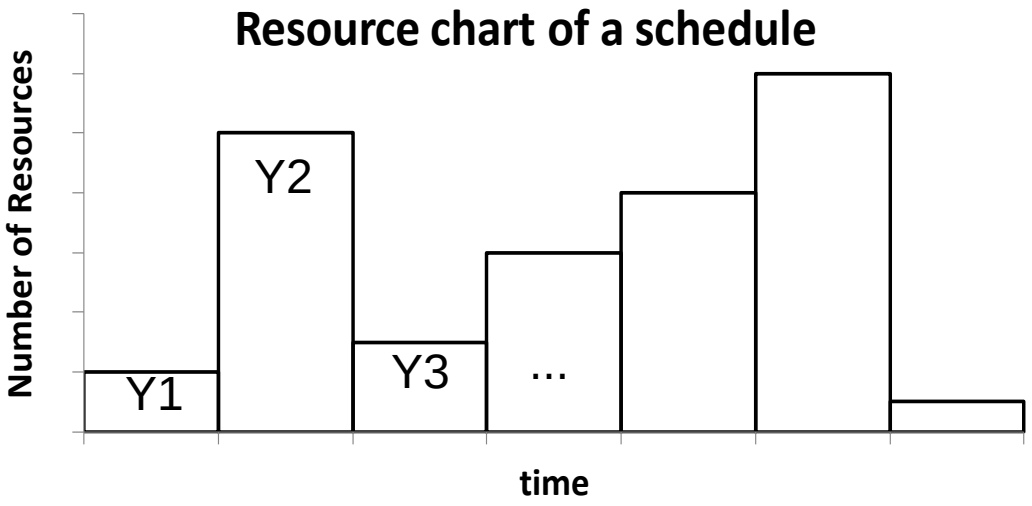
Resource leveling - Technique

- **Definition:** Resource moment (torque):
  - A resource moment at the specified time of i with the resource number of Yi about the time axis is:

$$\frac{1}{2}(Y_i)^2$$

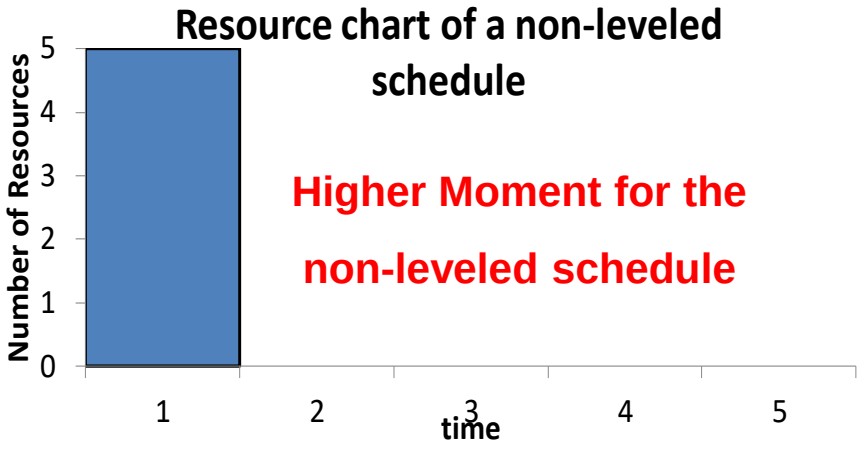
  - Total schedule moment (M) for a resource is calculated:

$$M = \frac{1}{2}\sum_{i}(Y_i)^2$$

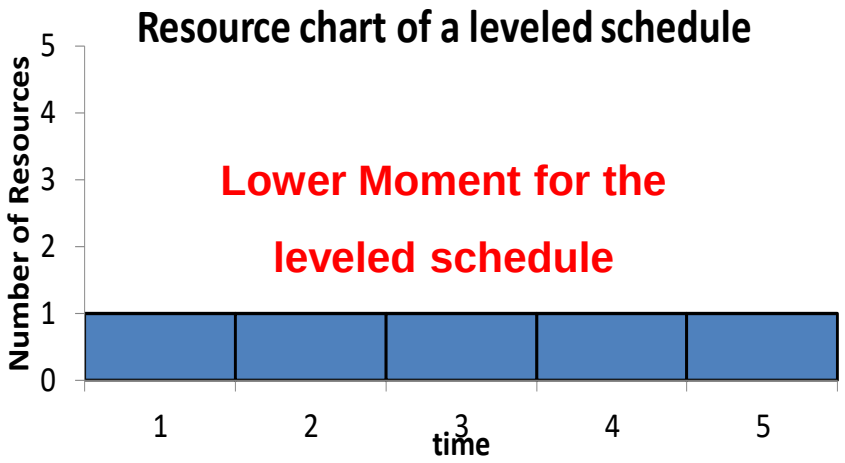


Resource leveling - Technique

- ***Minimum Moment Technique (MMT) for resource leveling*** ***(Harris 1978)*** is a widely used heuristic method for resource leveling we will discuss here!
  - Dr. Harris has based minimum moment technique up on the fact that with the constant total number of resource-time unit (e.g., worker-day, man-hour) (ΣYi=A) the more leveled the schedule the less resource moment value will be resulted.
  - **Example 5**: Calculate the resource moment for the resource charts presented below:



M=1/2 *(5^2+0+0+0+0)=**12.5**



M=1/2 * (1^2+1^2+1^2+1^2+1^2)=**2.5**

Harris, R. I. (1978). Precedence and arrow networking techniques for construction, Wiley, New York.

Resource leveling - Technique

- MMT consists of two cycles: forward cycle and backward cycle. These two cycles are run consecutively up until we could not see any progresses in none of cycles. The main steps of the MMT are as follows:

  1) Start with the forward cycle, where you go to the *last* non-critical activity in the schedule (with the latest start).

					Working Day								
WBS	**Predec**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3					3	3			
				Total resources	**3**	**3**	**6**	**6**	**7**	**4**	**1**	**1**	**1**

Resource leveling - Technique

2) Shift the activity forward within its slack time (make sure no dependency rule is broken). Calculate total moment of different possible shifts.

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3					3	3			
Total resources					3	3	6	6	7	4	1	1	1
Moment				*79*	4.5	4.5	18	18	24.5	8	0.5	0.5	0.5

Forward shift

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3						3	3		
Total resources					3	3	6	6	4	4	4	1	1
Moment				*70*	4.5	4.5	18	18	8	8	8	0.5	0.5

Resource leveling - Technique

2) Shift the activity forward within its slack time (make sure no dependency rule is broken). Calculate total moment of different possible shifts.

Forward shift

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3							3	3	
Total resources					3	3	6	6	4	1	4	4	1
Moment				*70*	4.5	4.5	18	18	8	0.5	8	8	0.5

Forward shift

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3								3	3
Total resources					3	3	6	6	4	1	1	4	4
Moment				*70*	4.5	4.5	18	18	8	0.5	0.5	8	8

Resource leveling - Technique

3) Shift the activity to the location with minimum total moment

Note: If several activity shifts result in similar total moment choose the shift with the latest start date!

					Working Day								
WBS	**Predecessor**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3								**3**	**3**
Total resources					**3**	**3**	**6**	**6**	**4**	**1**	**1**	**4**	**4**
Moment				***70***	**4.5**	**4.5**	**18**	**18**	**8**	**0.5**	**0.5**	**8**	**8**

The shift with the minimum total moment and the latest start is selected and set as new updated schedule!

Resource leveling - Technique

4) Continue steps 2 and 3 for all activities from last to the first non-critical activities

5) Start backward cycle from the first non-critical activity

6) Shift the activity backward within its slack time (make sure no dependency rule is broken). Calculate total moment of different possible shifts.

7) In the *backward cycle* the activity to the location with the minimum total moment.

Note: In case that you have several locations with equal minimum total moments, move the activity to the location with the *latest* start!

8) Continue steps 6 and 7 for all activities from first to the last non-critical activities

9) Continue steps 1 through 8 until there is no improvement achieved after two (i.e., one forward and one backward) cycles.

Resource leveling - Technique

Simplified MMT Calculations: To speed up the calculation of the moment changes. Dr. Harris has introduced a shortcut method as follows. Suppose:

- The activity requires R number of resources
- The duration of the activity is t
- You have shifted the activity by S time units
- X1, X2, ... are number of resources in the days in which total number of resources reduced (by R) (prior to the shift)
-W1, W2, ... are number of resources in the days in which total number of resources increased (by R) (prior to the shift)
-m is number of days with resource increase which is equal to minimum of S and t

The change made in the moment (M1-M0) can be calculated as in below:

$$M_1 - M_0 = \Delta M = \frac{1}{2}\sum_i^m (X_i - R)^2 + \frac{1}{2}\sum_i^m (W_i + R)^2 - \frac{1}{2}\sum_i^m (X_i)^2 - \frac{1}{2}\sum_i^m (W_i)^2$$

Resource leveling - Technique

Example 6:

R=Number of resources for activity 5 = 3 resources

t= Duration of activity 5 = 2 days

s= acitivity shift= 3 days

X1=7; X2=4 (resources)
W1=1; W2=1 (resources)

m=number days with resource increase =Min(t,s)=2

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3					3	3			
Total resources					3	3	6	6	7	4	1	1	1
Moment				*79*	4.5	4.5	18	18	X1	X2	1.5	W1	W2

					Working Day								
WBS	Predecessor	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3								3	3
Total resources					3	3	6	6	4	1	1	4	4
Moment				*70*	4.5	4.5	18	18	8	0.5	0.5	8	8

M1-M0= 1/2*[(7-3)^2+(4-3)^2+(1+3)^2+(1+3)^2-7^2-4^2-1^2-1^2]= -9 (So move it!!!)

Resource leveling - Technique

Simplified MMT Calculations (cont'd):

By simplifying this equation we have:

$$\Delta M = R(-\Sigma Xi + \Sigma Wi + mR)$$

In this calculations we are not interested in the actual value of the moment or even ΔM. What is important in MMT is the direction of changes (positive or negative). The fact is a decrease in ΔM represents a positive shift or an improvement and an increase in ΔM represents a negative shift or a decline. To make the sign (+ and -) of the formula more consistent with our purpose we define the Improvement Factor (or IF) as the negative value of ΔM. Since R is a positive constant value within the activity we are going to remove R factor from the formula. The simplified formula will become:

$$IF = (\Sigma Xi - \Sigma Wi - mR)$$

Note: In the simplified method you need to follow the same steps discussed for *MMT*, but just replace total moment with IF!

Resource leveling - Technique

- **Example 7:** Follow MMT to level the project schedule presented in resource aggregate (or resource load) table in below:

					Working Day								
WBS	**Predec**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3					3	3			
				Total resources	**3**	**3**	**6**	**6**	**7**	**4**	**1**	**1**	**1**

- Start from Activity 5 and forward cycle
- Activity 5 can shifted 1, 2 or 3 days. The IF result for each is:

  IF1= 7-1-1*3=3; IF2=(7+4)-(1+1)-2*3=3; IF3=(7+4)-(1+1)-2*3=3

  Since all IFs are in the same value we are going to shift activity by 3 days

Resource leveling - Technique

- **Example 7 (cont'd):**

					Working Day								
WBS	Predec	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3			2	2					
5	4	5	8	3								3	3
				Total resources	3	3	6	6	4	1	1	4	4

- Continue with activity 4 which can be shifted 1, 2 or 3 days. The IF result for each is:

  IF1=6-4-2=0; IF2=(6+6)-(4+1)-2*2=3; IF3=(6+6)-(1+1)-2*2=6

  IF3 shows the maximum improvement

					Working Day								
WBS	Predec	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3						2	2		
5	4	5	8	3								3	3
				Total resources	3	3	4	4	4	3	3	4	4

Resource leveling - Technique

- **Example 7 (cont'd):**
  - Continue with activity 3 which can be shifted 1, 2, 3 or 4 days. The IF result for each is:

    IF1=4-3-3=-2; IF2=(4+4)-(3+3)-2*3=-4; IF3=(4+4+4)-(3+3+4)-3*3=-7;

    IF4= =(4+4+4)-(3+4+4)-3*3=-8

    No improvement will be made by shifting activity 3
  - Continue with activity 2. But it can be shifted forward since its FS dependency with activity 3 will be violated.
  - Continue with backward cycle.
  - Activity 2 do not have any backward move!
  - Activity 3 do not have any backward move!
  - Activity 4 has 3 backward shifts, 1, 2 and 3 days. The IF result for each is:

    IF1=3-4-2=-3; IF2=(3+3)-(4+4)-2*2=-6; IF3= =(3+3)-(4+4)-2*2=-6;

    No improvement will be made by shifting activity 4
  - Activity 5 do not have any backward move!

Resource leveling - Technique

- **Example 7 (cont'd):**
  - Continue with forward cycle from activity 5
  - Activity 5 do not have any forward move!
  - Activity 4 do not have any forward move!
  - Activity 3 has 3 forward shifts, 1, 2, 3 and 4 days. The IF result for each is:

    IF1=4-3-3=-2; IF2=(4+4)-(3+3)-2*3=-4; IF3=(4+4+4)-(3+3+4)-3*3=-7;

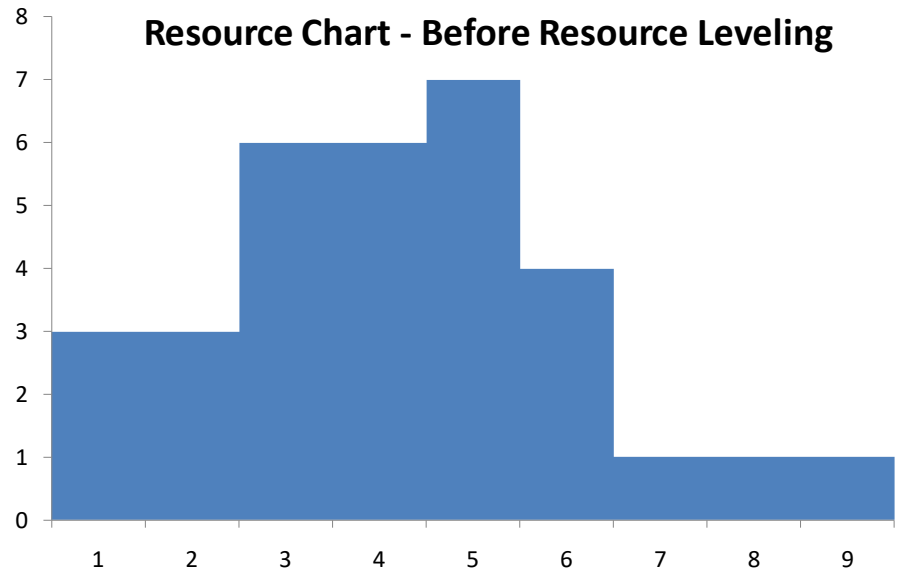
    IF4= =(4+4+4)-(3+4+4)-3*3=-8

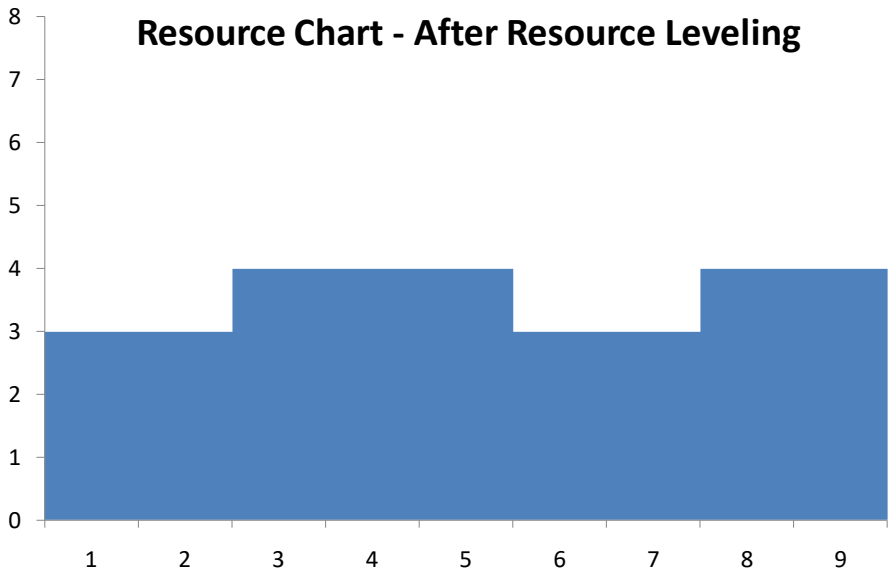
    No improvement will be made by shifting activity 3
  - Activity 2 do not have any forward move!
  - We are going to stop at this stage since we had 2 consecutive cycles with no improvement. The final leveled schedule is:

					Working Day								
WBS	Predec	ES	LS	Slack	1	2	3	4	5	6	7	8	9
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	2	2							
3	2	3	7	4			3	3	3				
4	2	3	6	3						2	2		
5	4	5	8	3								3	3
Total resources					3	3	4	4	4	3	3	4	4

Resource leveling - Technique

- **Example 7 (cont'd):**





In class exercise 2

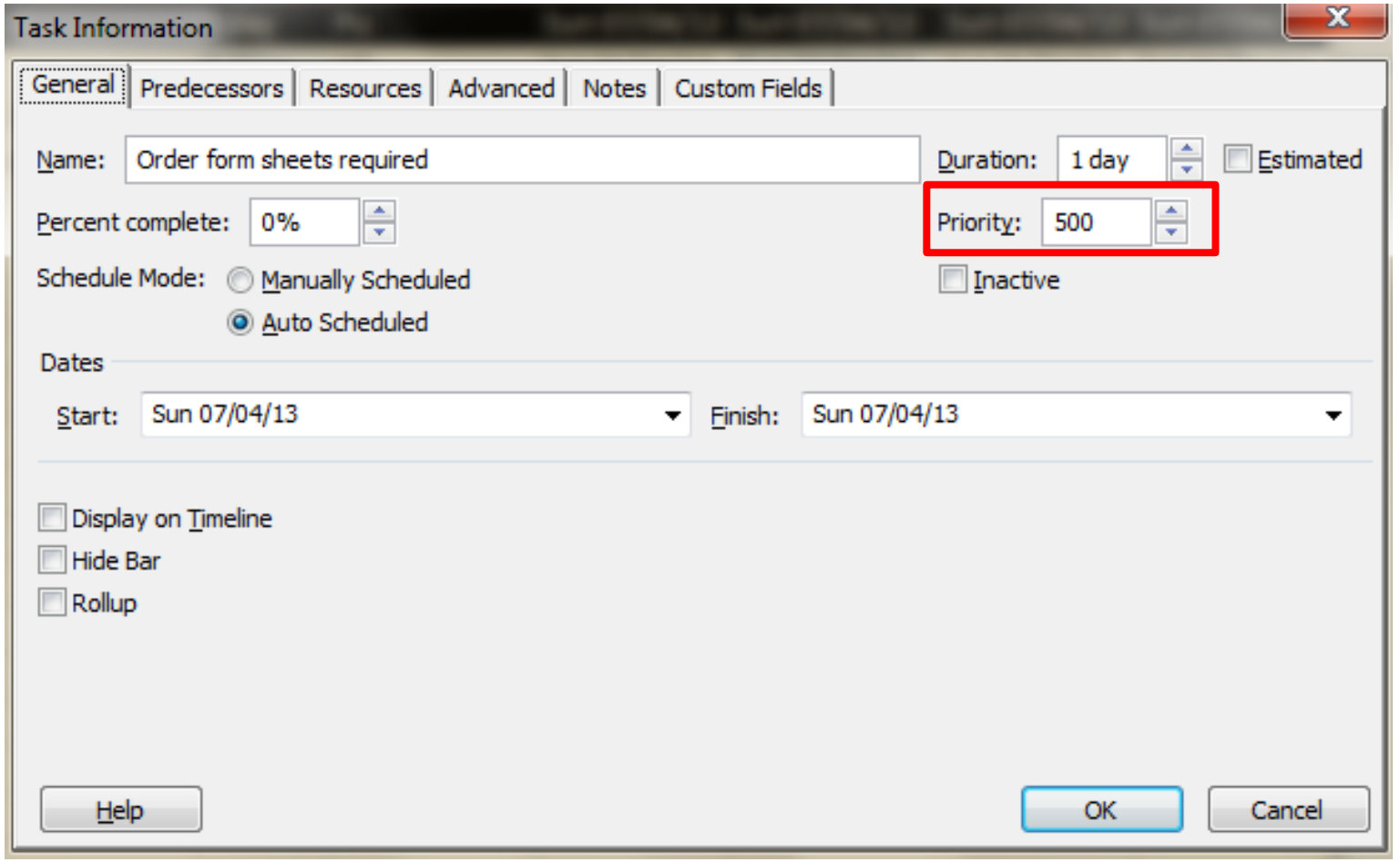
Follow simplified MMT method to level the project schedule presented in below:

					Working Day								
WBS	**Predecessor**	**ES**	**LS**	**Slack**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
1		1	1	0	1	1	1	1	1	1	1	1	1
2	1SS	1	4	3	1	1							
3	2	3	6	3			2	2	2	2			
4	2	3	8	5			3	3					
	Sum				**2**	**2**	**6**	**6**	**3**	**3**	**1**	**1**	**1**

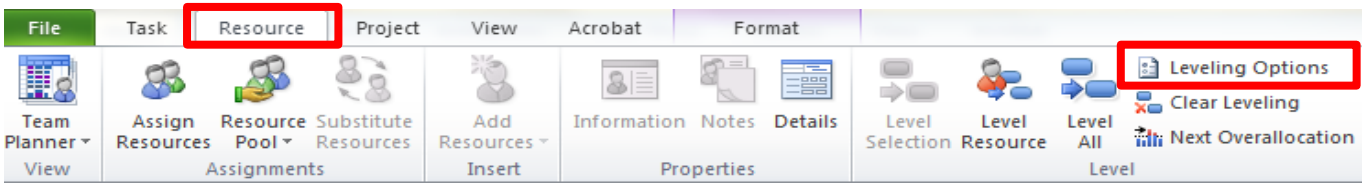
Resource leveling - MSP

- **Priority:** In MSP activities with lower priorities are first on the line to be delayed!

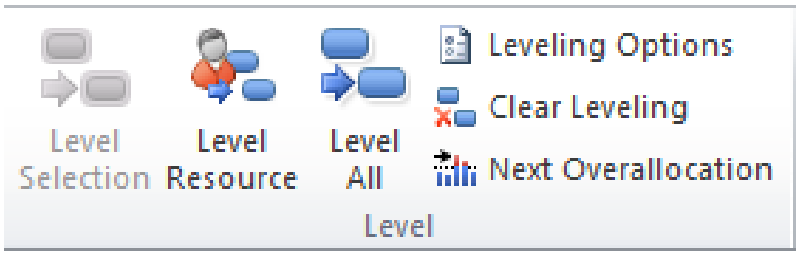
- Before resource leveling make sure about the priority of activities in Task information> General:

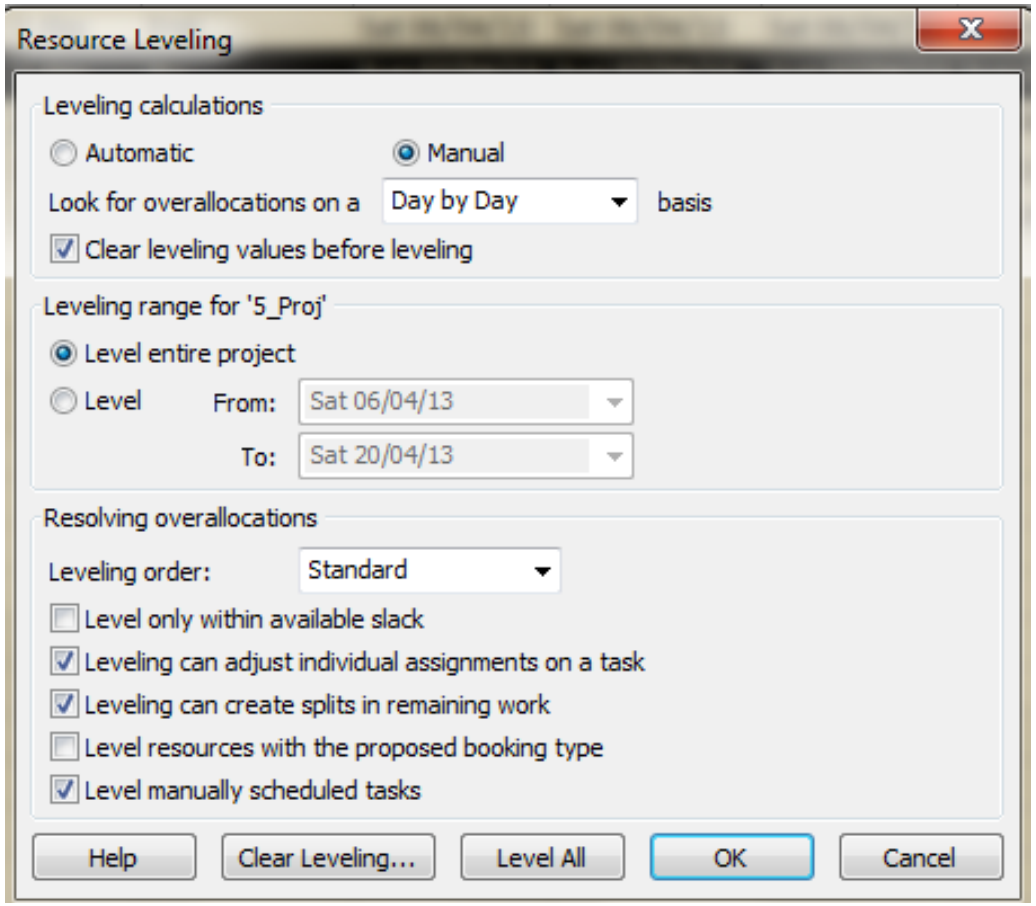


Resource leveling- MSP

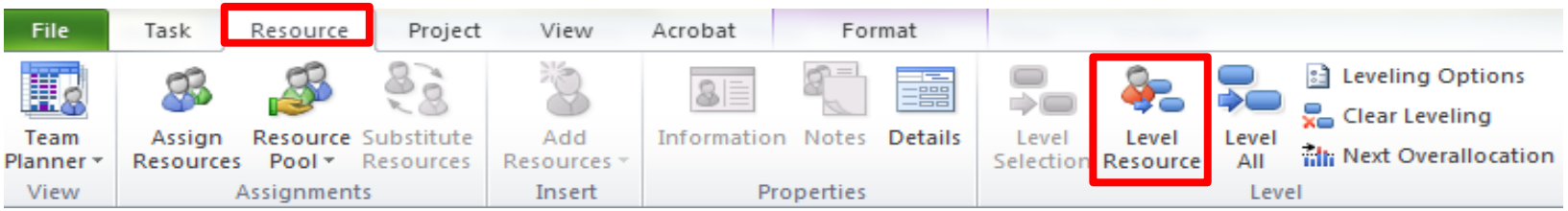


- Make sure about the options then start the resource leveling

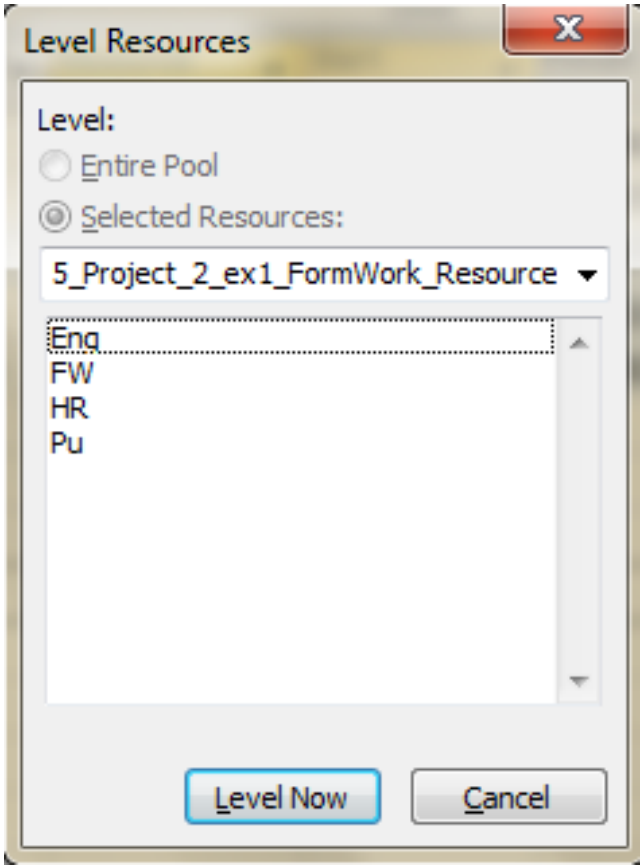




Resource leveling – MSP

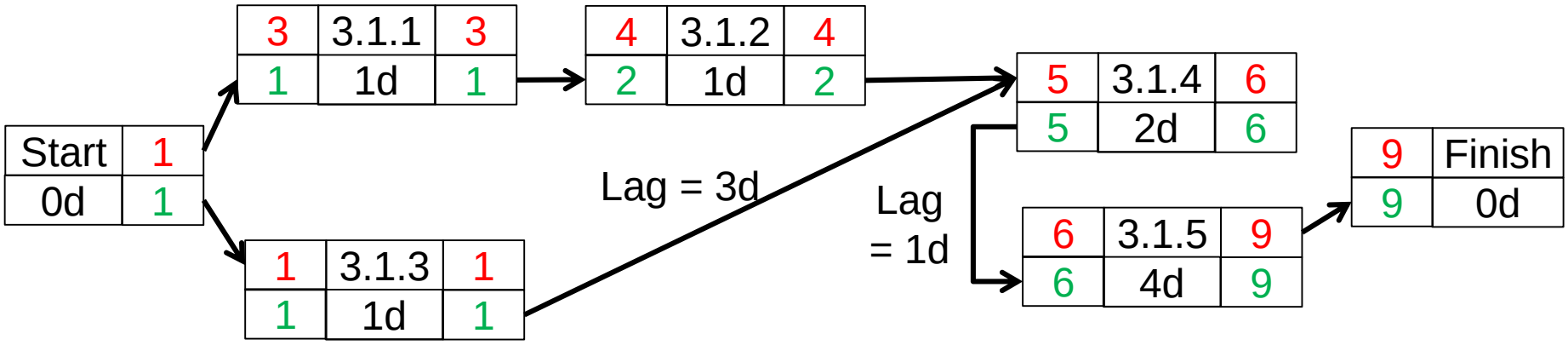


- Select the resources you want to level and then push “Level Now” button!



Resource over-allocation

- **Example 8:** Remember initial schedule we developed for our “prepare foundation form work” in *lecture 5* using CPM method.
  1) Extract foundation sizes from drawings (1 engineer, 1 day)
  2) Order form sheets (1 purchaser, 0.5 day)
  3) Hire two form-workers for the job(1 HR-person, 1 day)
  4) Size form sheets (2 form-worker, 2 day)
  5) Install form sheets in place (2 form-worker, 4 days)



Resource over-allocation

- **Example 8 (cont'd):**

Schedule in MSP:

Task Name	Duration	Start	Finish	Predecessors	Resource Names
Prepare foundation form work	**9 days**	**Sat 15/11/14**	**Tue 25/11/14**		
Extract foundation sizes from drawings	1 day	Sat 15/11/14	Sat 15/11/14		Eng
Order form sheets required	1 day	Sun 16/11/14	Sun 16/11/14	1	Pu
Hire two form-workers for the job	1 day	Sat 15/11/14	Sat 15/11/14		HR
Size the form-sheets	2 days	Wed 19/11/14	Sat 22/11/14	3FS+3 days,2	FW[200%]
Install form-sheets in place	4 days	Sat 22/11/14	Tue 25/11/14	4SS+1 day	FW[200%]

Question: What if we have a limited number of form-workers of 3 available for the job (e.g., there are maximum of 3 form-workers available in the area)?

Resource over-allocation

- **Example 8 (cont'd):** To answer this question we are going to use resource-aggregation or resource-loading table to show daily summation of resources required to complete activities on each day.

		Working Day								
WBS	**Description**	**1**	**2**	**3***	**4***	**5**	**6**	**7**	**8**	**9**
3.1.1	Extract foundation sizes from drawings	1Eng								
3.1.2	Order form sheets required		1Pu							
3.1.3	Hire two form-workers for the job	1HR								
3.1.4	Size the form-sheets					2FW	2Fw			
3.1.5	Install form-sheets in place						2Fw	2Fw	2Fw	2Fw
	Total resources	**1Eng, 1HR**	**1Pu**			**2FW**	**4FW**	**2FW**	**2FW**	**2FW**

*Days 3 and 4 are working days in which no activity can be carried out

Resource over-allocation

- **Example 8 (cont'd):** To answer this question we are going to use resource-aggregation or resource-loading table to show daily summation of resources required to complete activities on each day.

		Working Day								
WBS	**Description**	**1**	**2**	**3***	**4***	**5**	**6**	**7**	**8**	**9**
3.1.1	Extract foundation sizes from drawings	1Eng								
3.1.2	Order form sheets required		1Pu							
3.1.3	Hire two form-workers for the job	1HR								
3.1.4	Size the form-sheets					2FW	2Fw			
3.1.5	Install form-sheets in place						2Fw	2Fw	2Fw	2Fw
	Total resources	**1Eng, 1HR**	**1Pu**			**2FW**	**4FW**	**2FW**	**2FW**	**2FW**

*Days 3 and 4 are working days in which no activity can be carried out

- In day 6 total number form-workers reaches 4FW which is a resource over-allocation (one more than maximum form-worker availability of 3).

Resource over-allocation

- **Example 8 (cont'd):** By shifting "install form-sheets in place" activity one day a head, we can eliminate this resource constraint violation! This shift results in 1 day increase in the project duration (from 9 days to 10 days)!

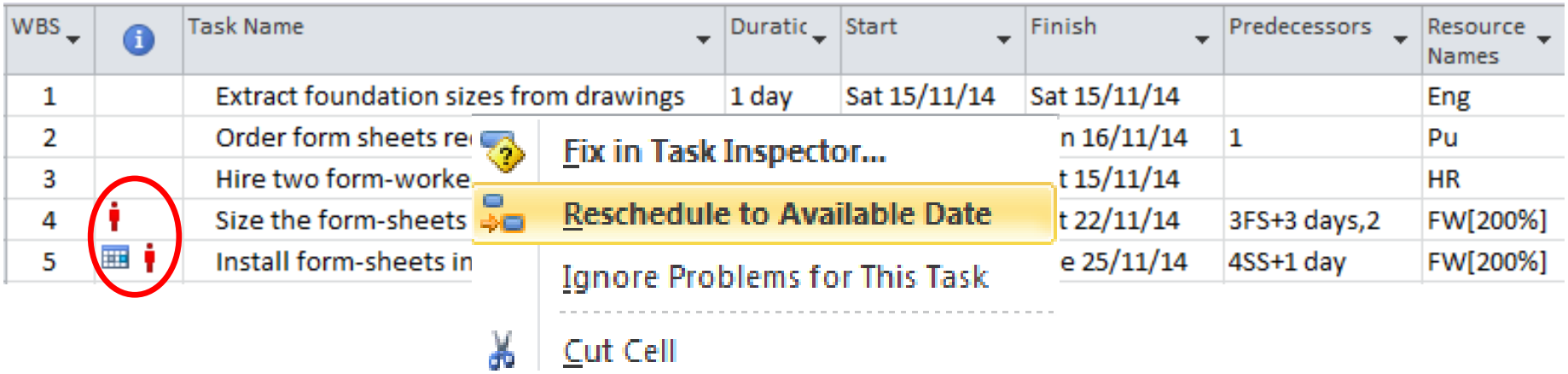
		Working Day									
WBS	**Description**	**1**	**2**	**3***	**4***	**5**	**6**	**7**	**8**	**9**	**10**
3.1.1	Extract foundation sizes from drawings	1Eng									
3.1.2	Order form sheets required		1Pu								
3.1.3	Hire two form-workers for the job	1HR									
3.1.4	Size the form-sheets					2FW	2Fw				
3.1.5	Install form-sheets in place							2Fw	2Fw	2Fw	2Fw
	Total resources	**1Eng, 1HR**	**1Pu**			**2FW**	**2FW**	**2FW**	**2FW**	**2FW**	**2FW**

*Days 3 and 4 are working days in which no activity can be carried out

To eliminate resource over-allocation we need to shift the violator activity and all of its direct and indirect successor-activities forward until the maximum resource violation (resource over-allocation) is eliminated! However there is no guarantee that the total duration of the project will stay untouched!

Resource over-allocation-MSP

- Depending on the location of the activities involved (on the critical path or off the critical path) and the activity slack, maximum resource constraint might increase or not increase the project duration!
- Recognizing and eliminating maximum resource constraint violation is a capability within project scheduling computer programs!



Highlighting over-allocated activities and the rescheduling option in M.S. Project software

Resource over-allocation-MSP

WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
0	**Prepare foundation form work**	**10 days**	**Sat 15/11/14**	**Wed 26/11/14**		
1	Extract foundation sizes from drawings	1 day	Sat 15/11/14	Sat 15/11/14		Eng
2	Order form sheets required	1 day	Sun 16/11/14	Sun 16/11/14	1	Pu
3	Hire two form-workers for the job	1 day	Sat 15/11/14	Sat 15/11/14		HR
4	Size the form-sheets	2 days	Wed 19/11/14	Sat 22/11/14	3FS+3 days,2	FW[200%]
5	Install form-sheets in place	4 days	Sun 23/11/14	Wed 26/11/14	4SS+1 day	FW[200%]

Question: Talking about resource over-allocation which types of resources are usually involved (people, equipment, or material)?

Resource over-allocation

- Resource over-allocation is the issue with non-expendable (or reusable) resources, i.e., people and equipment types!
- We need to have enough material resources to be able to do the project. No matter how (i.e., in what sequence) we are allocating the materials to the activities, no over-allocation will happen with the material resources!
- In this perspective, reusability of the people and equipment resource types adds to the complexity of their planning.
- In some cases resource over-allocation problems can get very complicated

Resource calendar constraint

- In a project different resources might be available with different working time (calendars) :
  - Hauling trucks can enter the city from 11pm to 5am due to traffic regulation. Therefore Hauling the tunneling mucks out of the city by hauling trucks is limited to 11pm to 5am.
  - Mill delivers 10-inch HSS sections after 6 months from order.
  - External certified NDT inspector is available one day a month.
  - Foreign consulting company works Monday through Friday
- If initial schedule violates resource working time constraints we need to update the schedule accordingly by applying these constraints to all related activities and recalculating the schedule!

Resource calendar constraint

- **Example 9:** in our “prepare foundation form work” example suppose that HR person is in vacation until Aban 27th,1393 (Nov 18th, 2014).

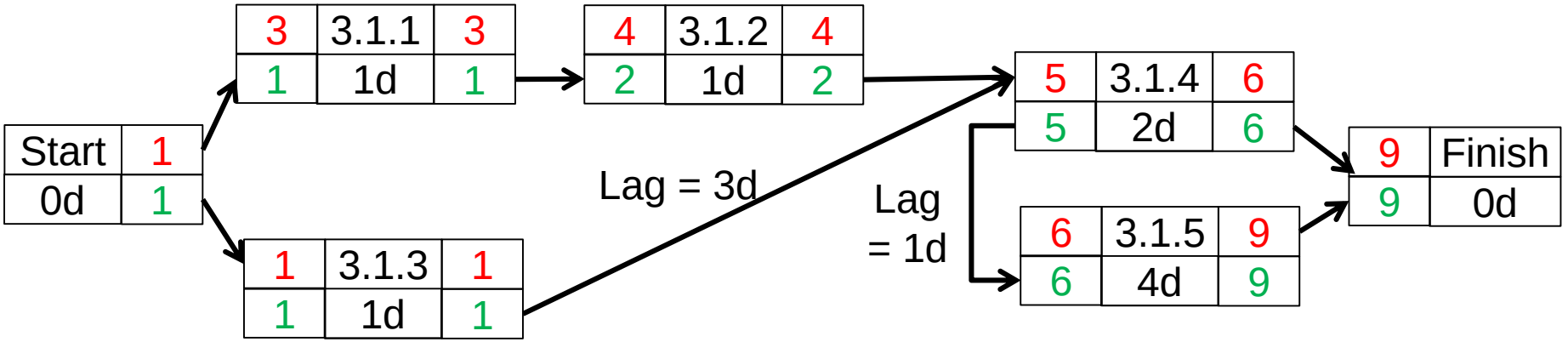
  Initial schedule is:

WBS	Task Name	Duratic	Start	Finish	Predecessors	Resource Names
1	Extract foundation sizes from drawings	1 day	Sat 15/11/14	Sat 15/11/14		Eng
2	Order form sheets required	1 day	Sun 16/11/14	Sun 16/11/14	1	Pu
3	Hire two form-workers for the job	1 day	Sat 15/11/14	Sat 15/11/14		HR
4	Size the form-sheets	2 days	Wed 19/11/14	Sat 22/11/14	3FS+3 days,2	FW[200%]
5	Install form-sheets in place	4 days	Sat 22/11/14	Tue 25/11/14	4SS+1 day	FW[200%]

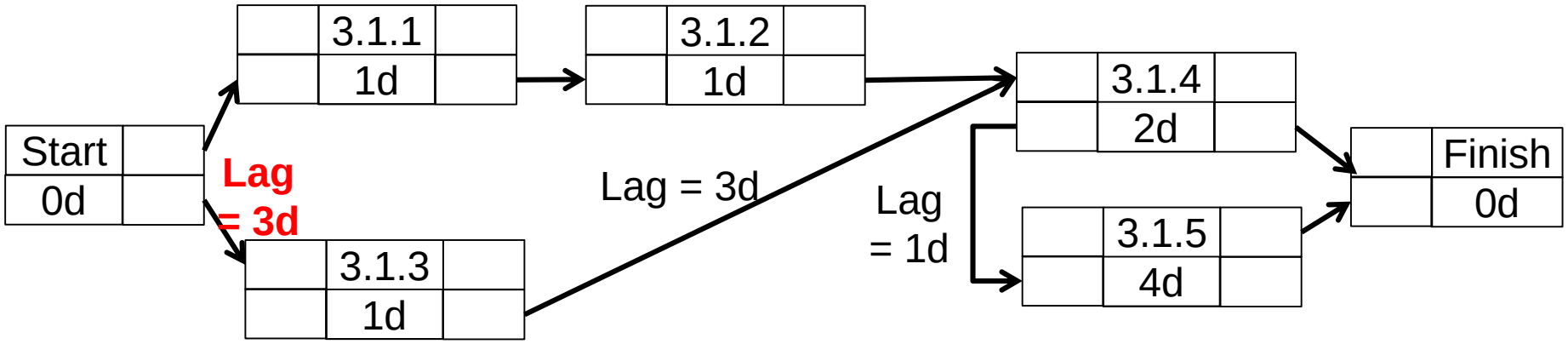
- “Hire two form-workers for the job” (3.1.3) is the only activity requiring the HR-person to be carried out. In the initial schedule it starts from Aban 24th,1393 (Nov 15th, 2014) which violates the HR-person calendar constraint. We need to re-calculate the schedule to address this constraint.

Resource calendar constraint

- **Example 9 (cont'd):** previous CPM calculations resulted in:

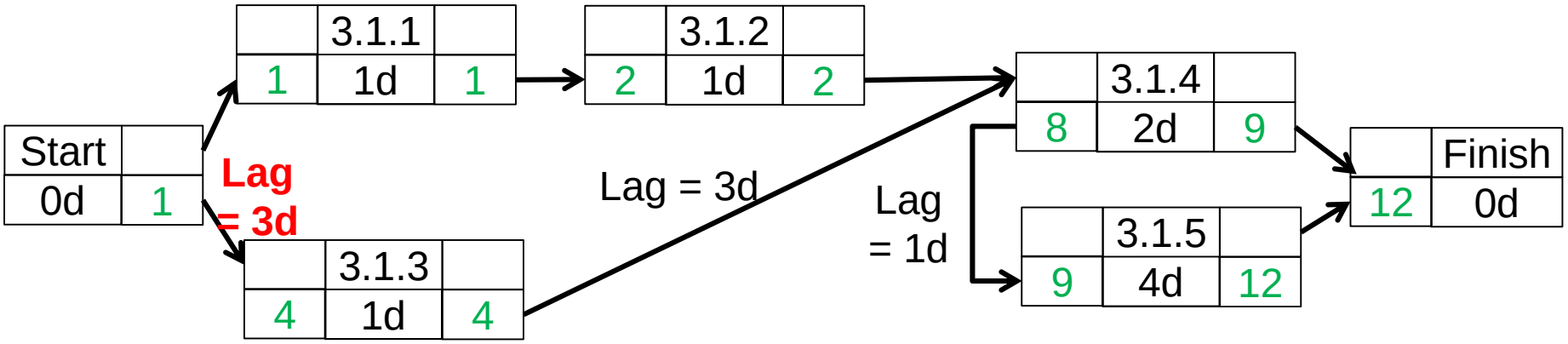


- HR- person calendar constraint can be reflected on the AON network by adding a 3-day lag for the start of activity 3.1.3



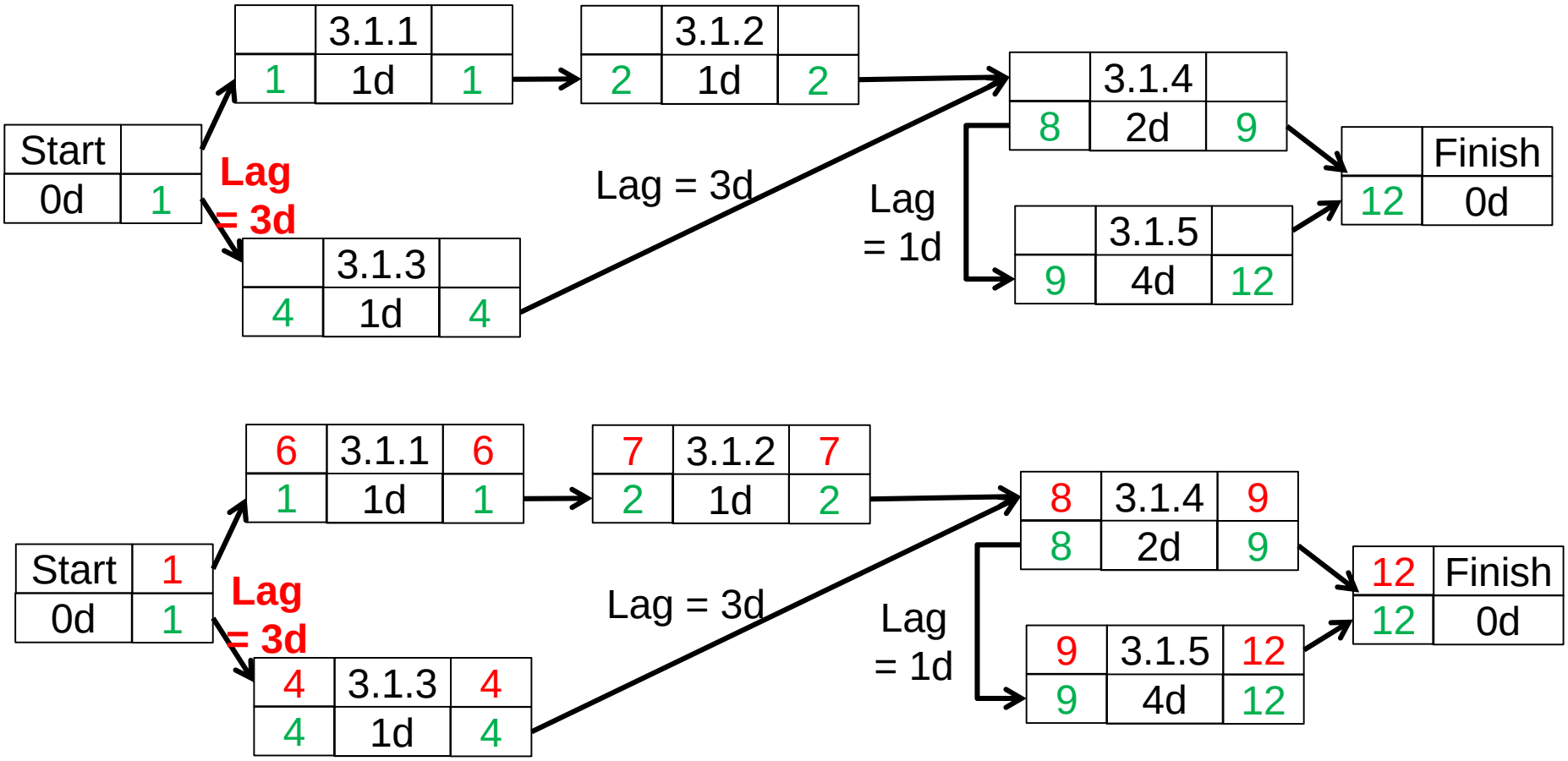
Resource calendar constraint

- **Example 9 (cont'd):** previous CPM calculations resulted in:



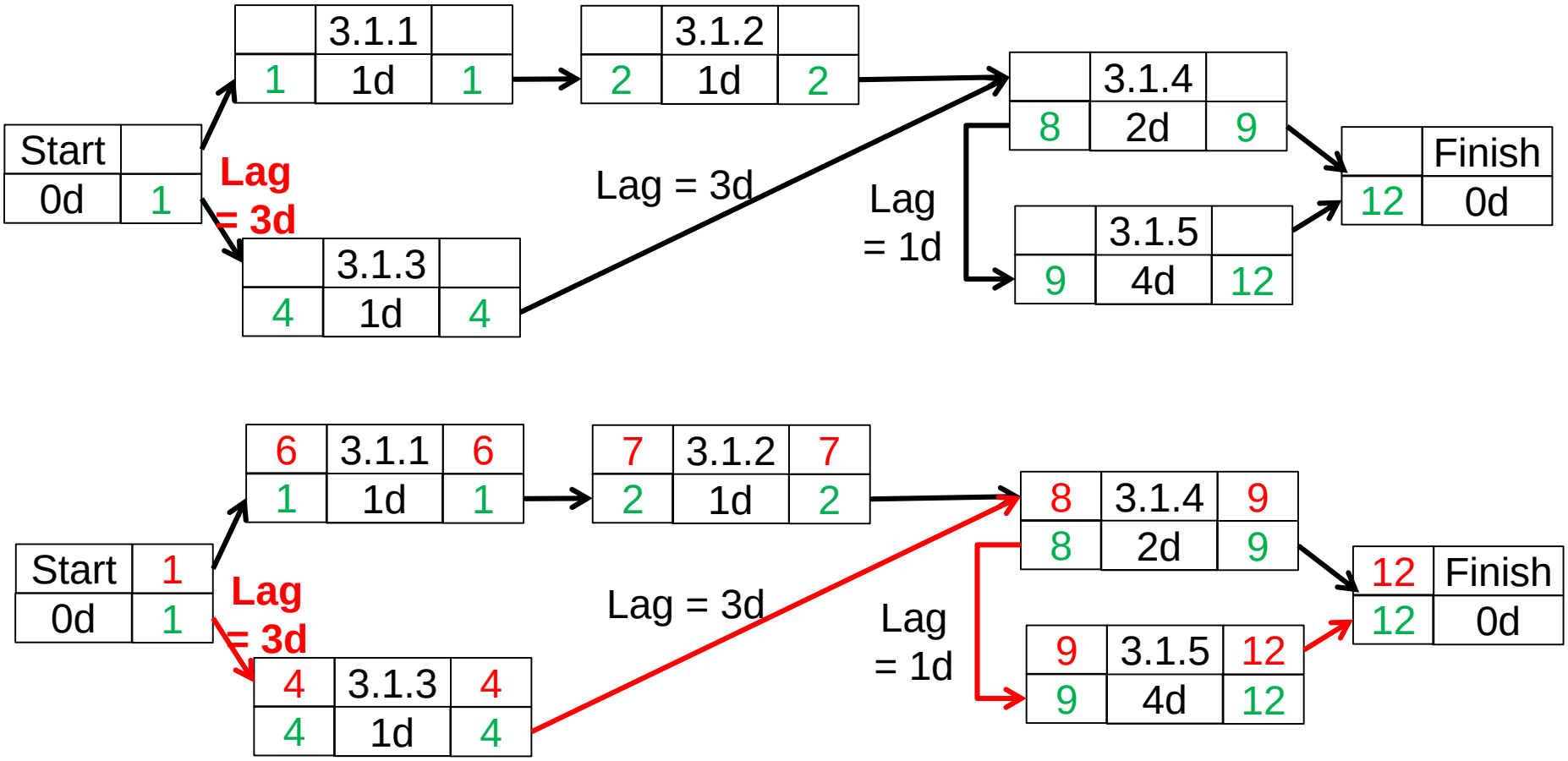
Resource calendar constraint

- **Example 9 (cont'd):** previous CPM calculations resulted in:



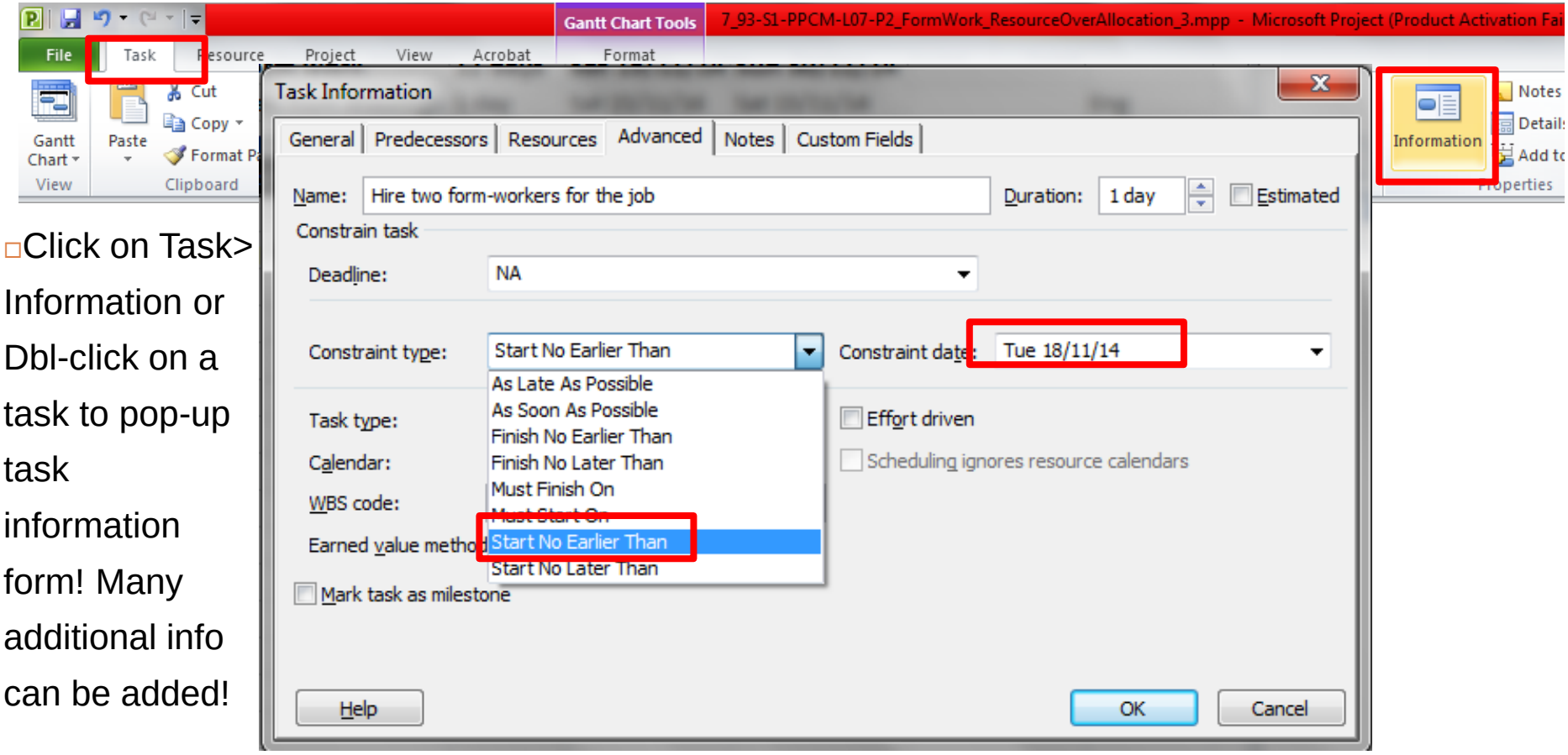
Resource calendar constraint

- **Example 9 (cont'd):** previous CPM calculations resulted in:



Resource calendar constraint-MSP

- Setting calendar constraints for activities and resources and incorporating them in the project scheduling is one of the prevalent features offered by project scheduling programs.

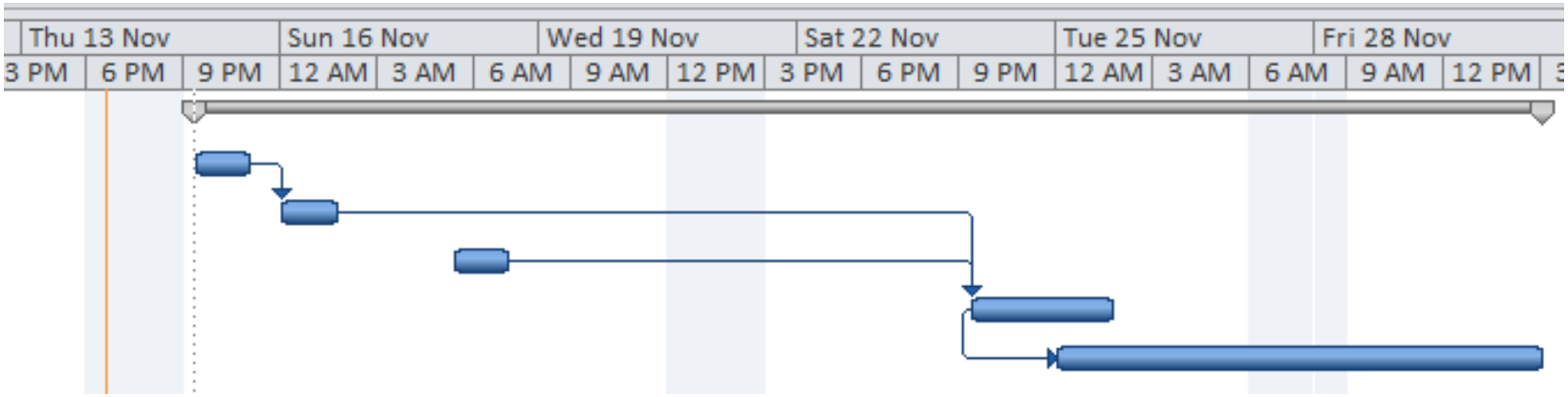


Click on Task> Information or Dbl-click on a task to pop-up task information form! Many additional info can be added!

Resource calendar constraint-MSP

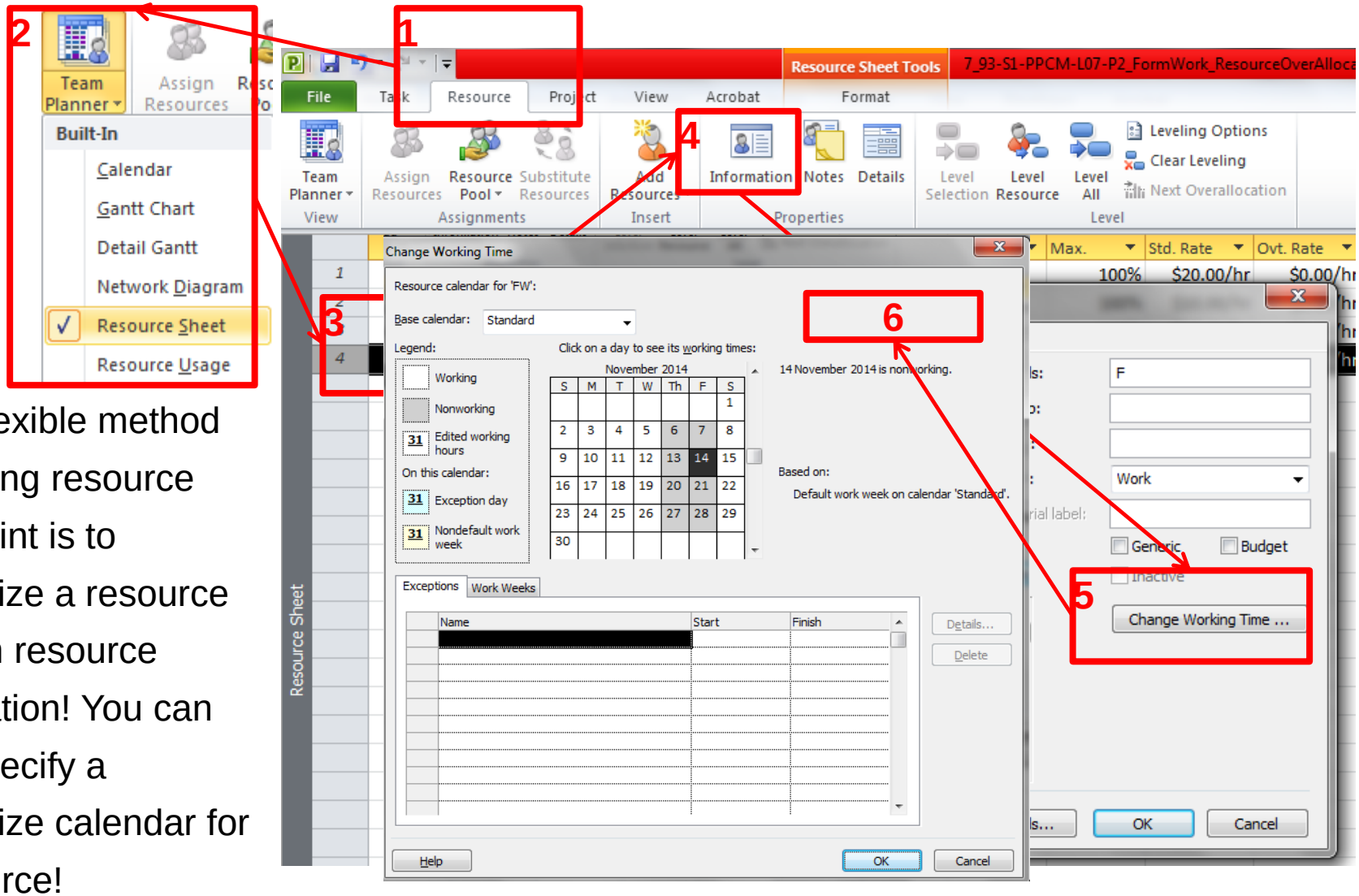
- **Example 9 (cont'd):** project's duration increases from 9 working days and 2 non-working days (initially from Nov 15 to Nov 25) to 12 working days and 4 non-working (from Nov 15 to Nov 30) days!

WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names
0	**Prepare foundation form work**	**12 days**	**Sat 15/11/14**	**Sun 30/11/14**		
1	Extract foundation sizes from drawings	1 day	Sat 15/11/14	Sat 15/11/14		Eng
2	Order form sheets required	1 day	Sun 16/11/14	Sun 16/11/14	1	Pu
3	Hire two form-workers for the job	1 day	Tue 18/11/14	Tue 18/11/14		HR
4	Size the form-sheets	2 days	Mon 24/11/14	Tue 25/11/14	3FS+3 days,2	FW[200%]
5	Install form-sheets in place	4 days	Tue 25/11/14	Sun 30/11/14	4SS+1 day	FW[200%]



MSP – Specific resource calendar

- More flexible method for setting resource constraint is to customize a resource through resource information! You can then specify a customize calendar for a resource!



MSP-Time crashing

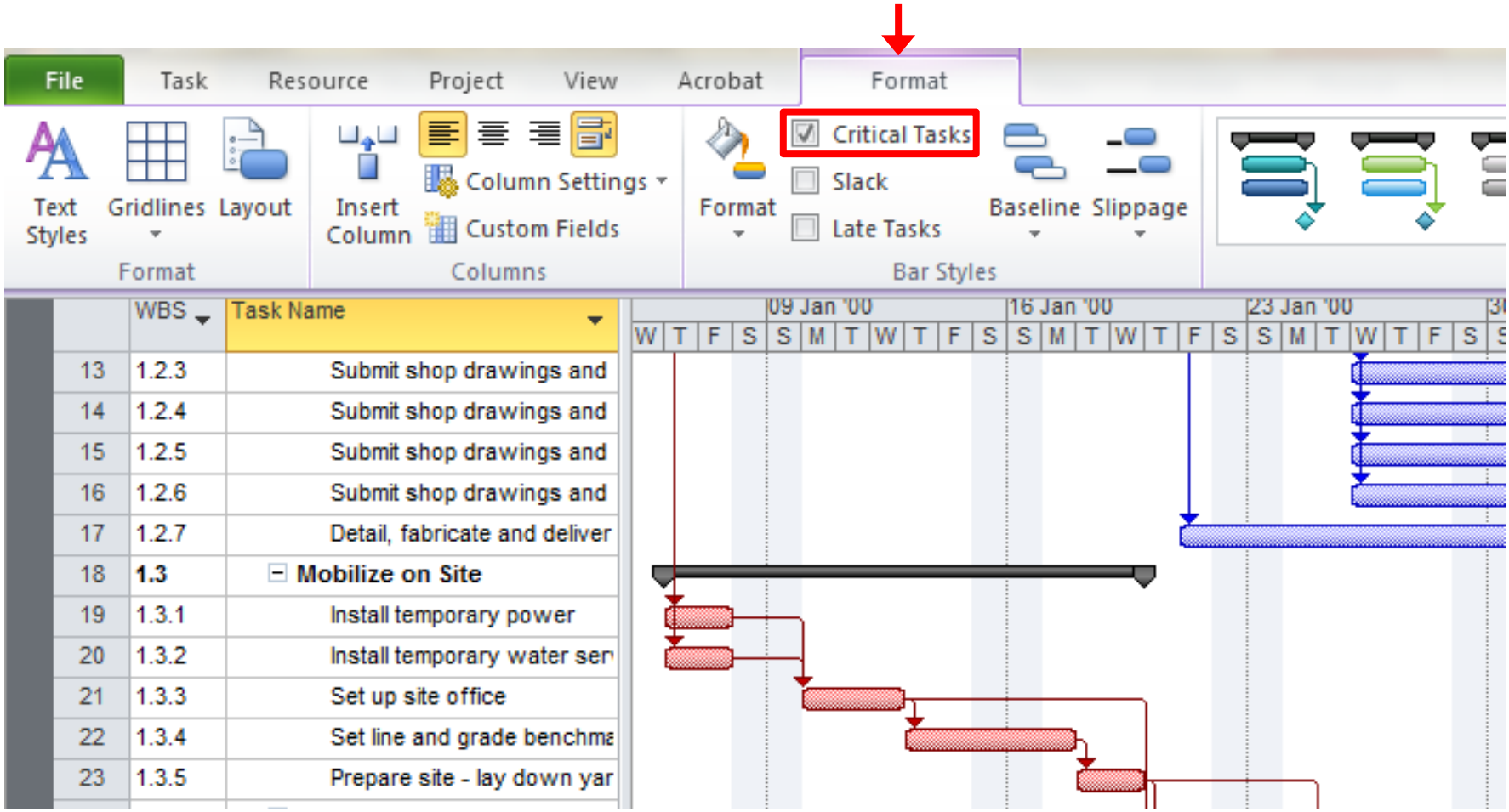
- Task duration is automatically changed by increasing/ decreasing resources after the first resource setting!

	Task Name	Predecessor	Duratic	Resource Names
1	Extract foundation sizes from drawings		1 day	Eng
2	Order form sheets required	1	1 day	Pu
3	Hire two form-workers for the job		2 days	HR
4	Size the form-sheets	3FS+3 days,2	1 day	FW[200%]
5	Install form-sheets in place	4SS+1 day	2 days	FW[200%]

	Task Name	Predecessor	Duratic	Resource Names
1	Extract foundation sizes from drawings		1 day	Eng
2	Order form sheets required	1	0.5 days	Pu[200%]
3	Hire two form-workers for the job		2 days	HR
4	Size the form-sheets	3FS+3 days,2	1 day	FW[200%]
5	Install form-sheets in place	4SS+1 day	2 days	FW[200%]

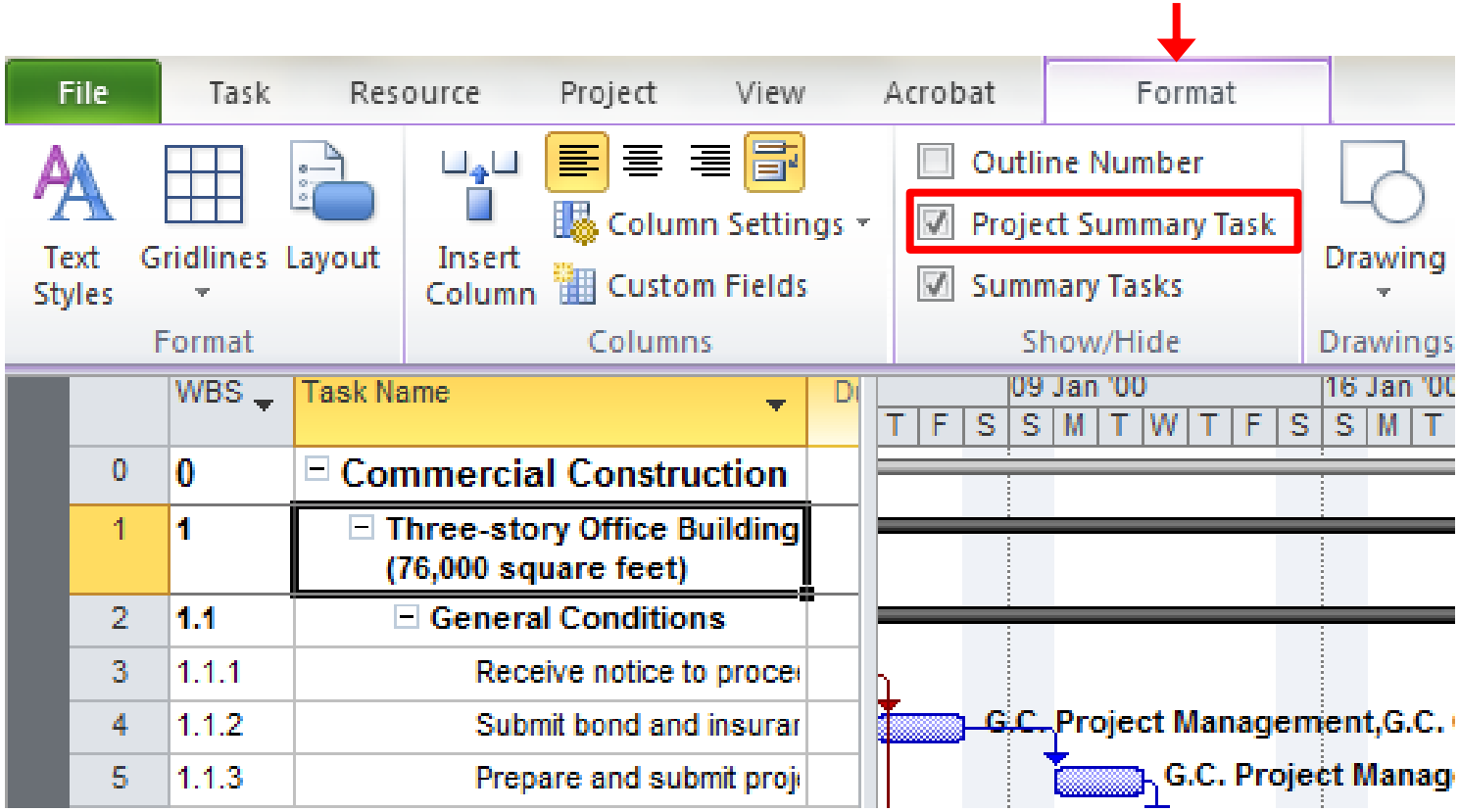
MSP-format- critical tasks

Critical tasks are shown red if you select *critical tasks on the format menu!*



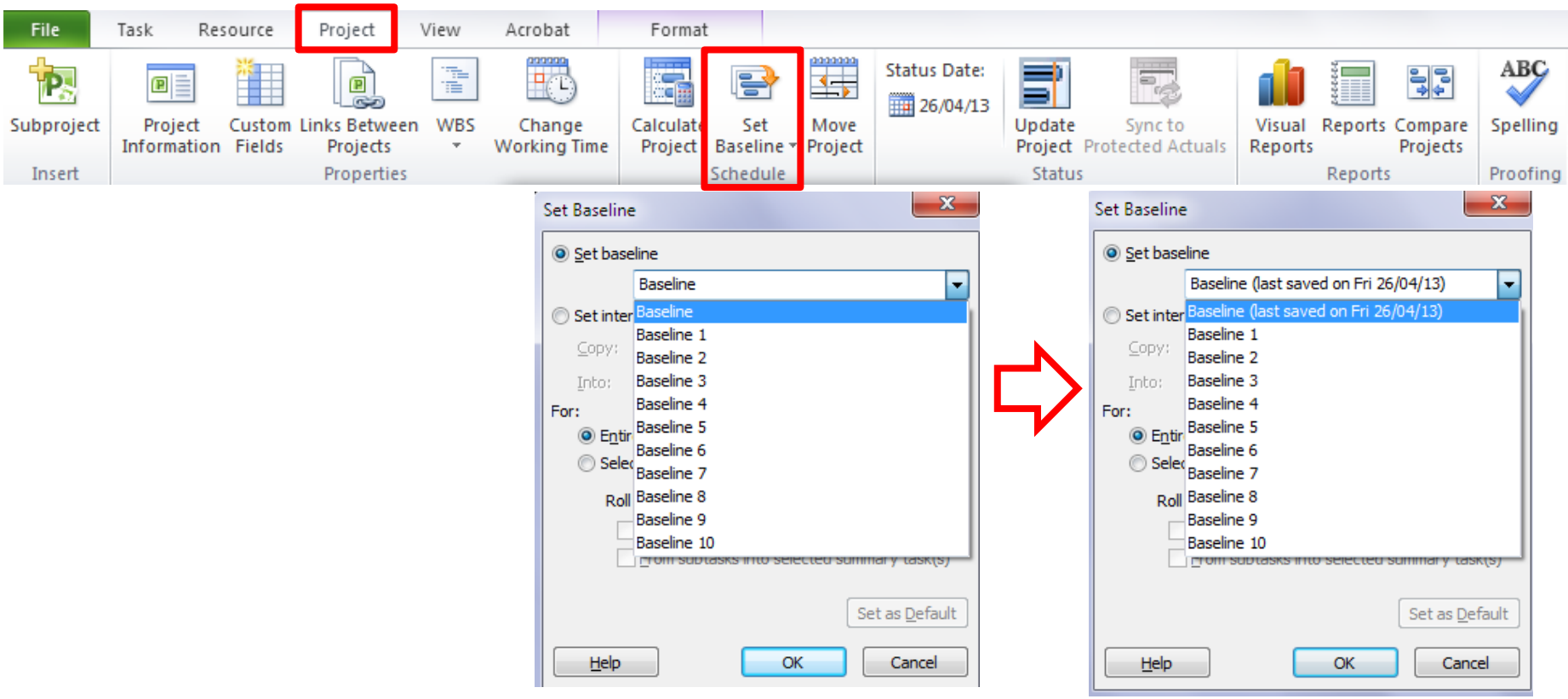
MSP-format- project summary task

Project summary task is added as a the project title with WBS 0 to aggregate the results!



MSP-Schedule baseline

	WB	Task Name	Duratic	Baseline Start	Baseline Finish	Start	Finish
1	3.1.1	Extract foundation sizes from drawings	1 day	NA	NA	Sat 06/04/13	Sat 06/04/13
2	3.1.2	Order form sheets required	1 day	NA	NA	Sun 07/04/13	Sun 07/04/13
3	3.1.3	Hire two form-workers for the job	1 day	NA	NA	Sat 06/04/13	Sat 06/04/13
4	3.1.4	Size the form-sheets	2 days	NA	NA	Wed 10/04/1:	Sat 13/04/13
5	3.1.5	Install form-sheets in place	4 days	NA	NA	Mon 15/04/1:	Sat 20/04/13

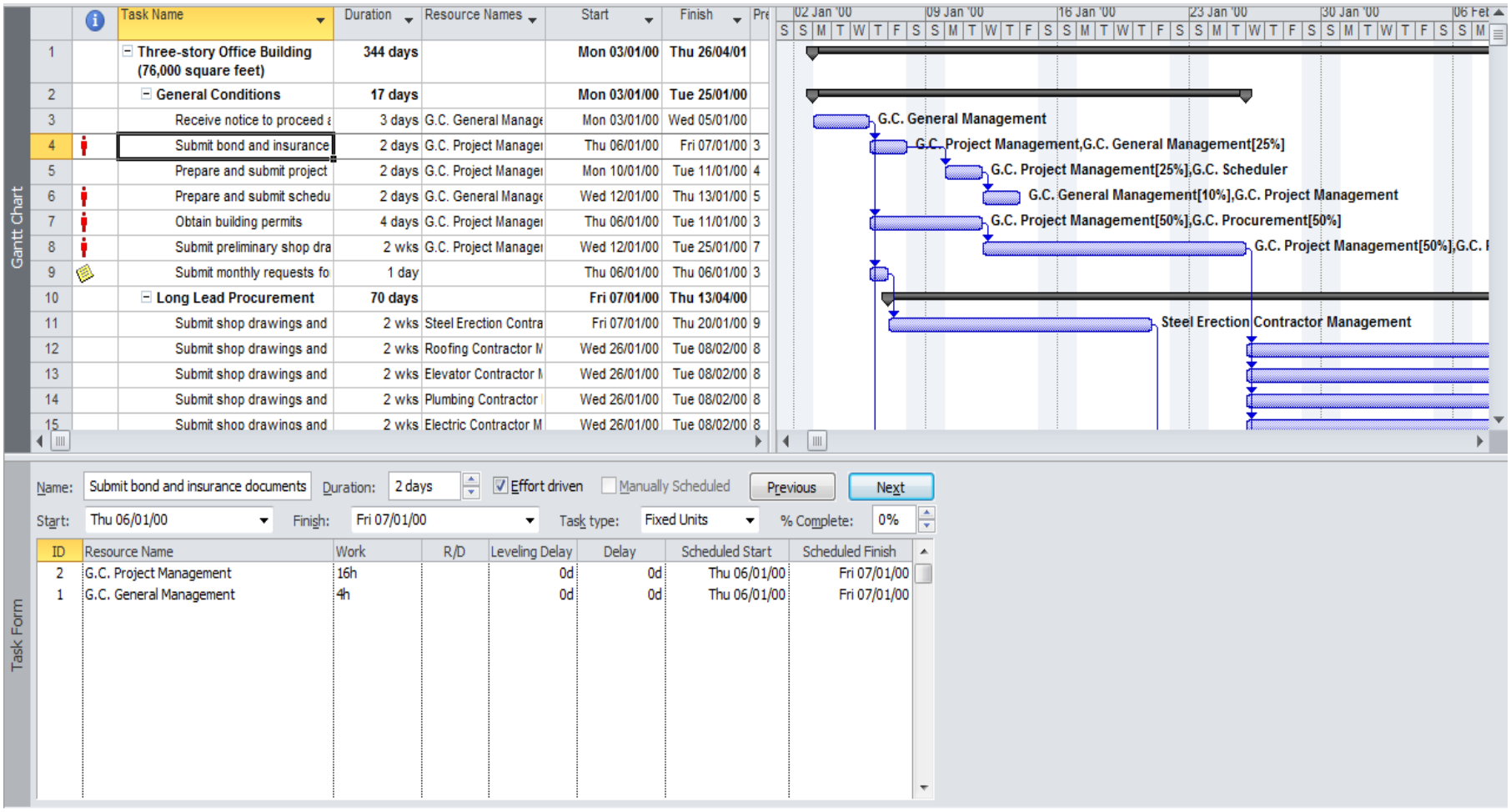


MSP-Schedule baseline

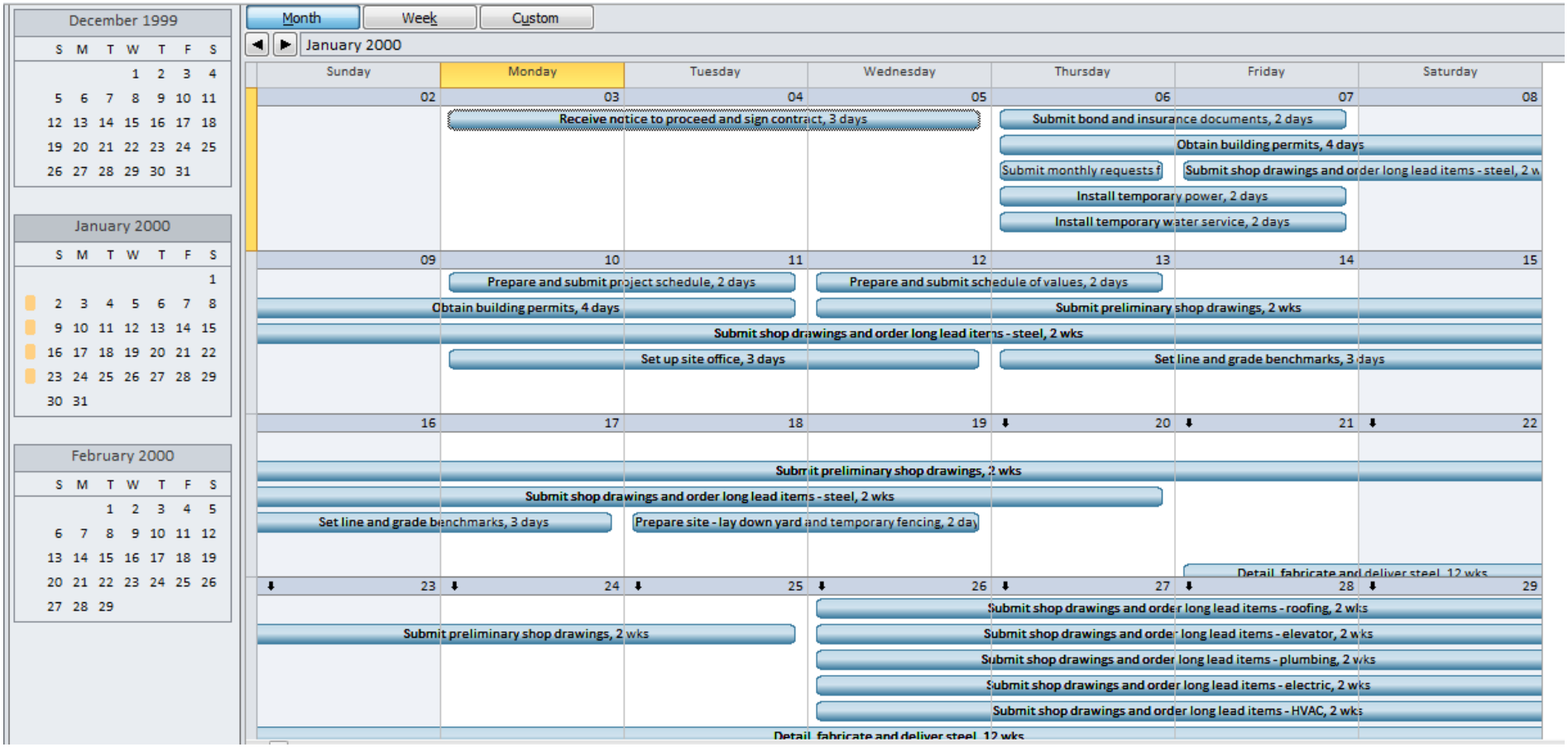
	WB	Task Name	Duratic	Baseline Start	Baseline Finish	Start	Finish
1	3.1.1	Extract foundation sizes from drawings	1 day	NA	NA	Sat 06/04/13	Sat 06/04/13
2	3.1.2	Order form sheets required	1 day	NA	NA	Sun 07/04/13	Sun 07/04/13
3	3.1.3	Hire two form-workers for the job	1 day	NA	NA	Sat 06/04/13	Sat 06/04/13
4	3.1.4	Size the form-sheets	2 days	NA	NA	Wed 10/04/1:	Sat 13/04/13
5	3.1.5	Install form-sheets in place	4 days	NA	NA	Mon 15/04/1:	Sat 20/04/13

	WB	Task Name	Duratic	Baseline Start	Baseline Finish	Start	Finish
1	3.1.1	Extract foundation sizes from drawings	1 day	Sat 06/04/13	Sat 06/04/13	Sat 06/04/13	Sat 06/04/13
2	3.1.2	Order form sheets required	1 day	Sun 07/04/13	Sun 07/04/13	Sun 07/04/13	Sun 07/04/13
3	3.1.3	Hire two form-workers for the job	1 day	Sat 06/04/13	Sat 06/04/13	Sat 06/04/13	Sat 06/04/13
4	3.1.4	Size the form-sheets	2 days	Wed 10/04/1:	Sat 13/04/13	Wed 10/04/1:	Sat 13/04/13
5	3.1.5	Install form-sheets in place	4 days	Mon 15/04/1:	Sat 20/04/13	Mon 15/04/1:	Sat 20/04/13

MSP - Split the view

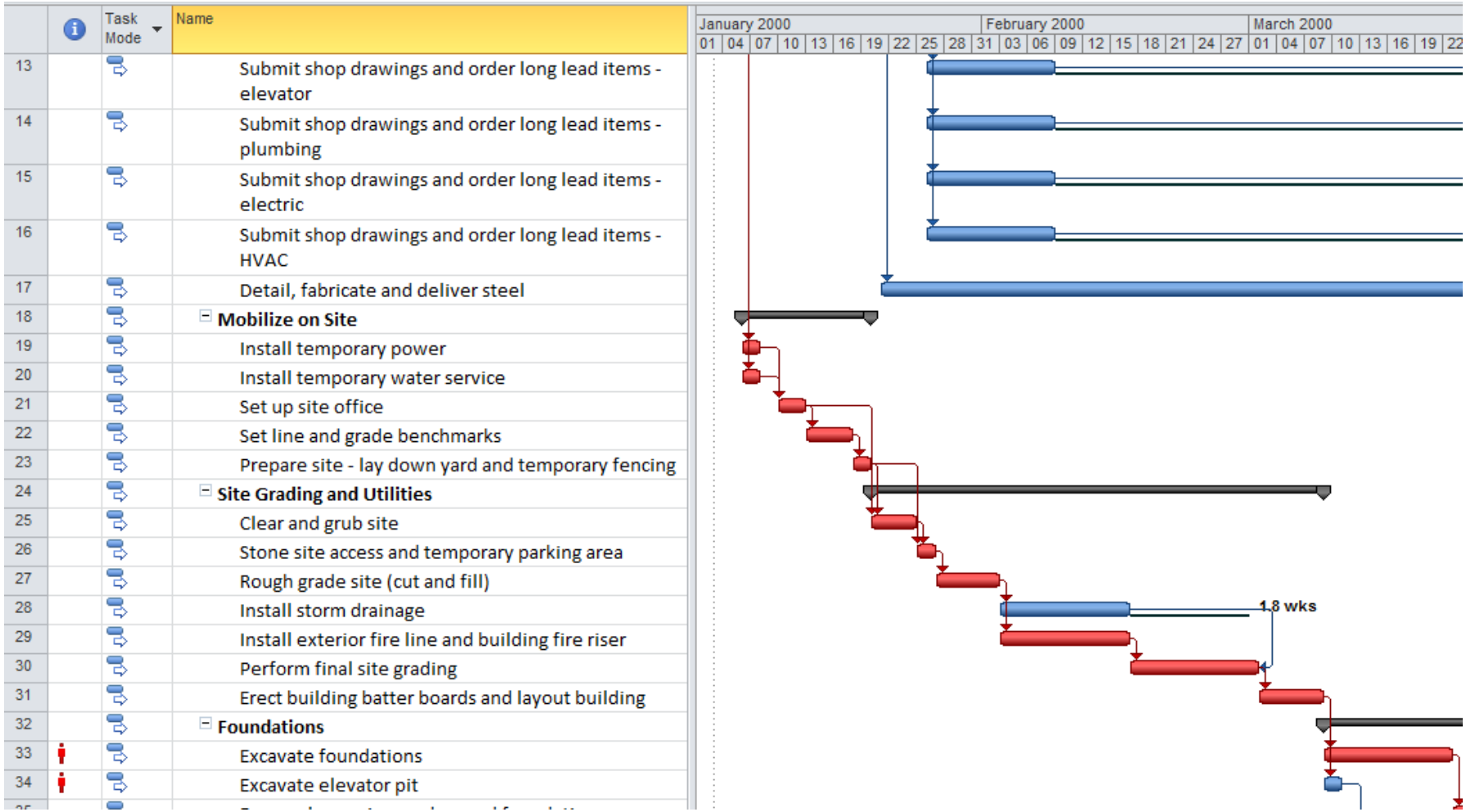


MSP- Calendar view



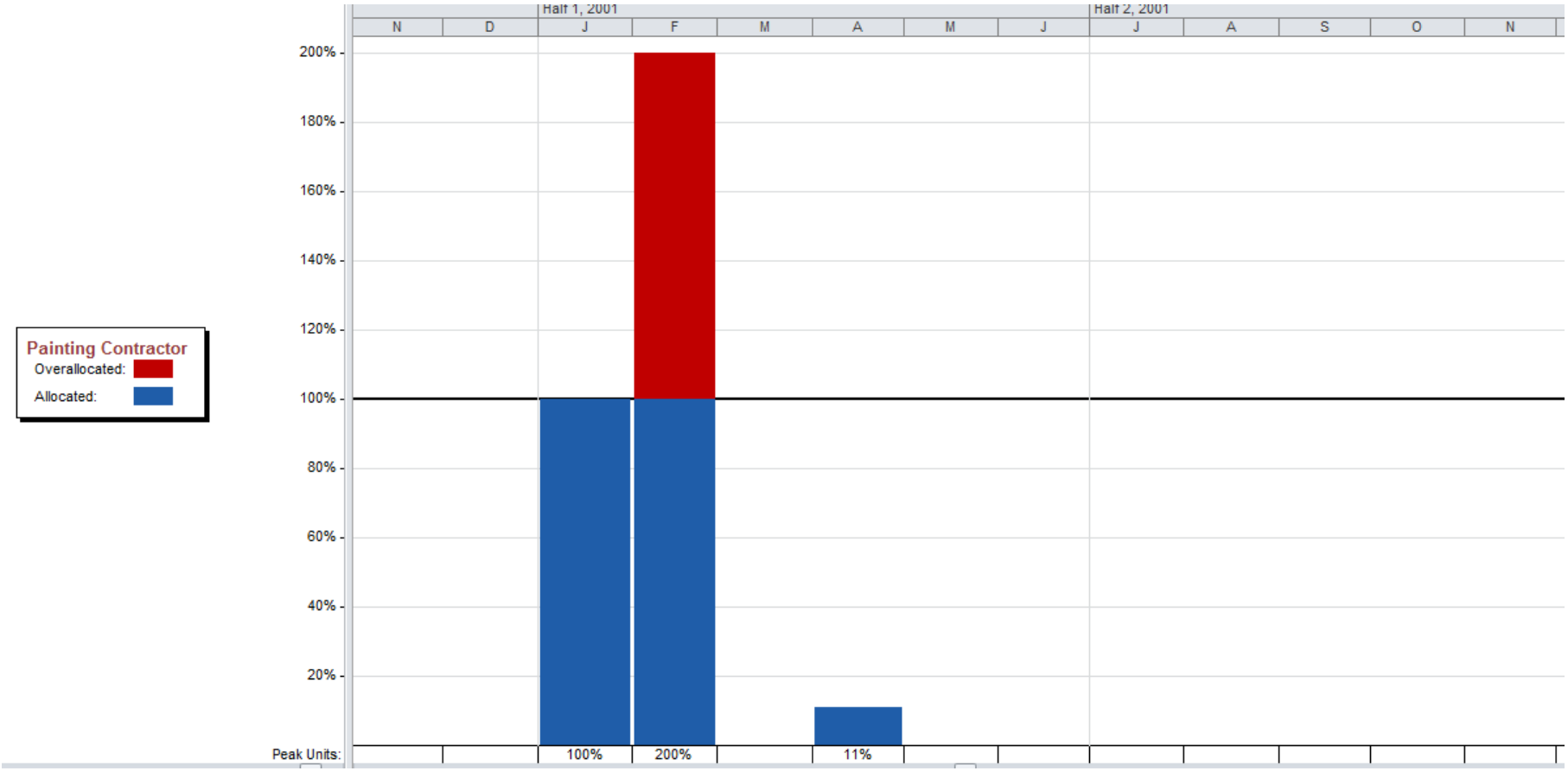
MSP- Detail Gantt

- Critical tasks are shown red in the Detail Gantt view!

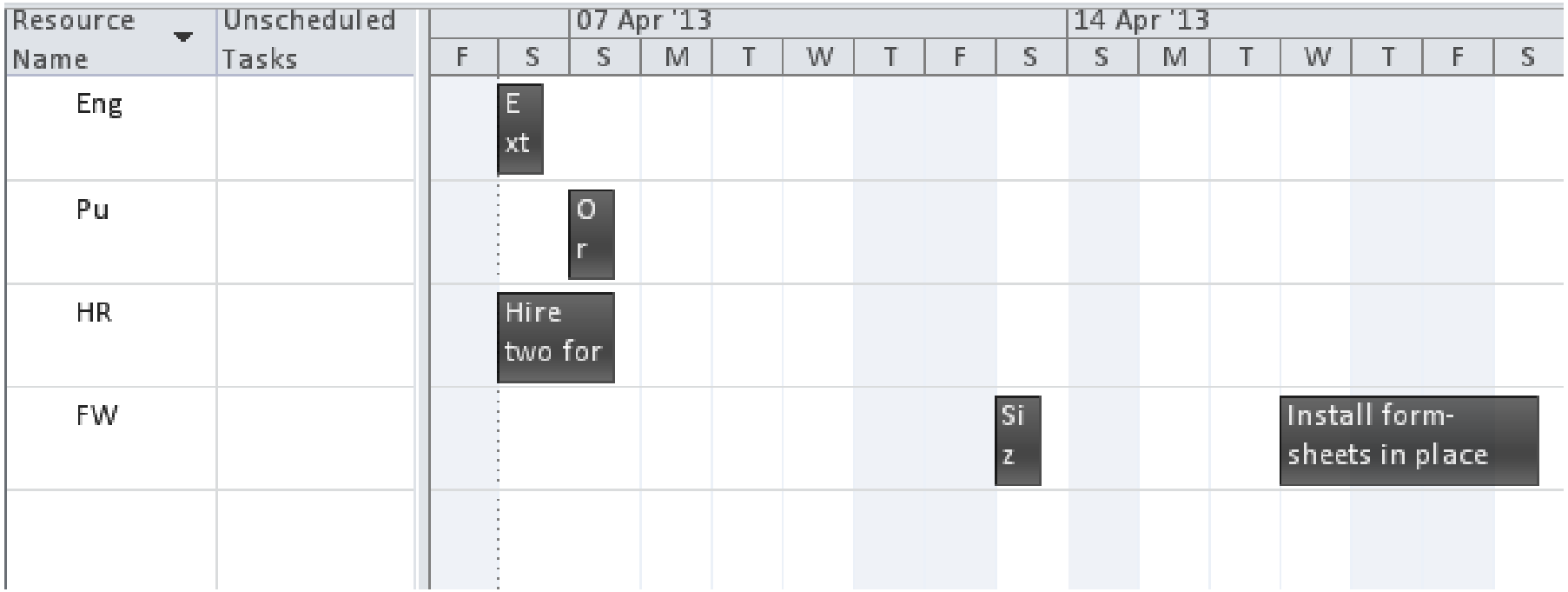


MSP – Network view

MSP- Resource graph view



MSP - Team planner view



Assignment 6 – resource constraint

Table presents site preparation and foundation project won by Pardis-e Kish construction company:

	WBS	Task	Predecessor	Resource	Estimated Duration
1	**1**	**Site Grading and Utilities**			
2	1-1	Clear and grub site		Dozer (2)	2w
3	1-2	Stone site access and temporary parking area	2	Dozer (1), Stone (10 truck bucker)	1w
4	1-3	Rough grade site (cut and fill)	2	Dozer (1)	4w
5	1-4	Install storm drainage	4	Excavator (1), Crane (1)	1w
6	1-5	Install exterior fire line and building fire riser	4	Excavator (1), Crane (1)	3w
7	1-6	Perform final site grading	4	Dozer (1)	1w
8	1-7	Erect building batter boards and layout building	5SS+1w, 7	Crane (1), Installtion crew(1)	2w
9	**2**	**Foundations**			
10	2-1	Excavate foundations	8	Excavator (3)	2w
11	2-2	Excavate elevator pit	8	Excavator (1)	1w
12	2-3	Form column piers and spread foundations	11	Form-Concrete crew (2)	2w
13	2-4	Rough-in electric and plumbing in elevator	12	Electrical crew (2)	2w
14	2-5	Form elevator pit walls	13	Form-Concrete crew (1)	2w
15	2-6	Set reinforcing and anchor bolts	13FF+2w,14	Form-Concrete crew (1)	1w
16	2-7	Pour column piers and foundations	15	Form-Concrete crew (1)	3w
17	2-8	Pour concrete elevator walls	16	Form-Concrete crew (2)	1w
18	2-9	Cure elevator wall concrete	17+1d	Labour (0.1)	2w
19	2-10	Cure piers and foundations	18	Labour (0.1)	2w
20	2-11	Strip wall forms	18	Form-Concrete crew (1)	1w
21	2-12	Strip column piers and foundation forms	19	Form-Concrete crew (2)	2w
22	2-13	Install pneumatic tube in elevator pit	21	Elevator crew (1)	1w
23	2-14	Prepare and pour concrete floor in elevator pit	22,20	Form-Concrete crew (1)	1w

Assignment 6 – resource constraint

Every working week is 5 working days (Saturday to Wednesday). The work starts from Azar 3rd.

- 1 –***(Mark: 20%)*** Set up an MS Project file for the project and develop the initial schedule! (submit a separate MSP file for it.)
- 2 –***(Mark: 50%)*** Follow Minimum Moment Technique steps for leveling “Form-Concrete crew” resources (NOT using MSP!)
- 3- ***(Mark: 10%)*** Use MSP’s resource leveling feature to level all resources!
- 4- ***(Mark: 20%)*** Suppose we have maximum “Form-Concrete crew” of 2 (we can employ enough number of resources for the rest). Remove all over allocations, finalize the schedule and save it as the baseline!

Due date one week

Thank you!