

Logic Analysis of Resource-Levelled Schedules (MS Project)

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Effective management of resources – i.e. planning, procuring, mobilizing, and deploying – is a core competency for successful companies in project-focused industries like construction. Most scheduling tools based on the Critical Path Method (CPM) – like Microsoft Project – can generate project schedules without resources, but they also include methods for assigning, analyzing, and “leveling” project resources. In this context, “leveling” means selectively delaying some work (compared to the CPM-based schedule) pending the completion of other, more important works that demand the same resources.

This simple description could imply the imposition of a certain logical/sequential relationship between two competing tasks (i.e. the “less important” work can only start after the “more important” work is finished with the resources) – sometimes called “soft logic”. Unfortunately, the leveling engine in Project 2010 does not appear to use, much less preserve, any such soft logic. Consequently, logical analysis of the leveled schedule – including interpretation of Total Slack to determine critical path or driving logical path – appears invalid.

Figure 1 is a simplified CPM model of a construction project involving multiple trades working in multiple areas. The model includes realistic resource loading, but the logical links have been limited to “hard logic” only (i.e. physical constraints). In other words, there is no preferential logic to guide the resource deployments. The default 5dx8h weekly calendar is universally applied, and a deadline of 25Feb’04 has been imposed. The unleveled CPM schedule includes a forecast completion that is nearly 3 months ahead of the deadline, but resources are severely over-allocated – the schedule appears unrealistic and needs to be leveled.

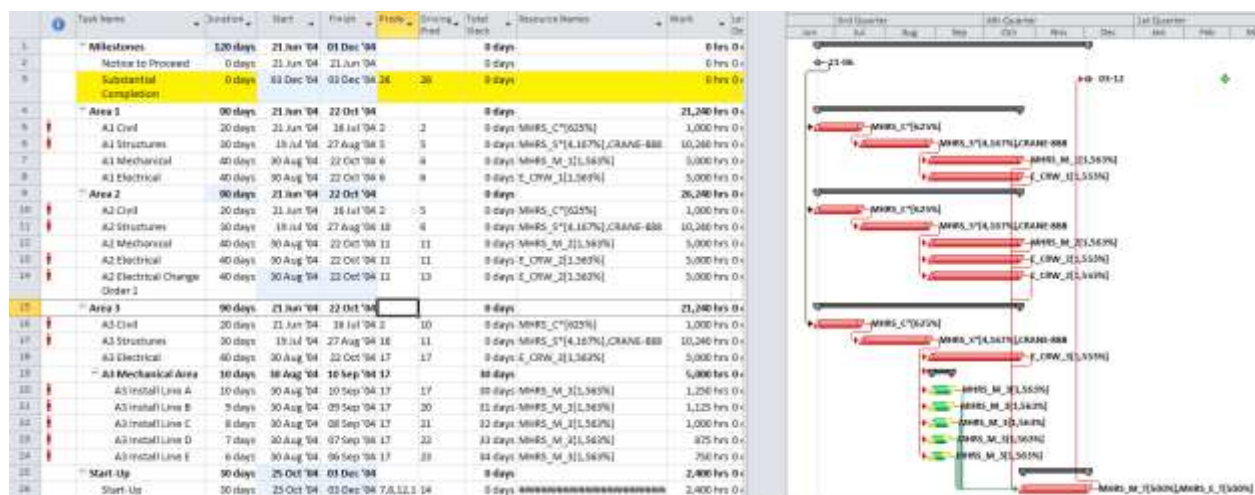


Figure 1: Simple Construction Project with Resource Loading

Specifically:

1. Three civil works tasks are running concurrently, but there is only sufficient manpower to run them sequentially. (Figure 2.)

Resource Name	Task	Max Units	Max Daily Manpower	Material Units	Initials	Group	Est Rate	Ord Rate	Cost/Unit	Resource #	Base Calendar	Code	Add New Column
MWRS_C*	Work	100%	50	MC			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E*	Work	100%	8	ME			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E_T	Work	100%	40	MCT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M*	Work	100%	8	MN			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_1	Work	1,563%	125.04	MN1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_2	Work	1,563%	125.04	MN2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_T	Work	1,563%	125.04	MNT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_S*	Work	8,500%	680	MS			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_1	Work	1,563%	125.04	E1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_2	Work	1,563%	125.04	E2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_3	Work	1,563%	125.04	E3			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
CRANE-888	Work	100%	8	888			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		

Resource Name	Work	Max Units	Working Delay	Start	Finish	Max Daily Manpower	Add New Color	Details	SA	T	W	T	F	S	13 Jul '24
MWRS_C*	1,000 hrs	100%	0 days	21 Jun '24	26 Jul '24	50		Work	150h	150h	150h	150h	150h		
A3 Cid	1,000 hrs		0 days	21 Jun '24	26 Jul '24	0		Work	30h	30h	30h	30h	30h		
A2 Cid	1,000 hrs		0 days	21 Jun '24	26 Jul '24	0		Work	30h	30h	30h	30h	30h		
A3 Cid	1,000 hrs		0 days	21 Jun '24	26 Jul '24	0		Work	30h	30h	30h	30h	30h		

Figure 2: Over-Allocation of Civil Works Manpower

2. Three structural tasks are also running concurrently, and these require both manpower (Figure 3) and a crane (Figure 4), which is the limiting resource. They must be done sequentially.

Resource Name	Task	Max Units	Max Daily Manpower	Material Units	Initials	Group	Est Rate	Ord Rate	Cost/Unit	Resource #	Base Calendar	Code	Add New Column
MWRS_C*	Work	100%	50	MC			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E*	Work	100%	8	ME			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E_T	Work	100%	40	MCT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M*	Work	100%	8	MN			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_1	Work	1,563%	125.04	MN1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_2	Work	1,563%	125.04	MN2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_T	Work	1,563%	125.04	MNT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_S*	Work	8,500%	680	MS			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_1	Work	1,563%	125.04	E1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_2	Work	1,563%	125.04	E2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_3	Work	1,563%	125.04	E3			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
CRANE-888	Work	100%	8	888			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		

Resource Name	Work	Max Units	Working Delay	Start	Finish	Max Daily Manpower	Add New Color	Details	SA	T	W	T	F	S	13 Jul '24
MWRS_S*	10,000 hrs	8,500%	0 days	19 Jul '24	27 Aug '24	680		Work	2,000h	2,000h	2,000h	2,000h	2,000h		
A2 Structures	10,000 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	333.33h	333.33h	333.33h	333.33h	333.33h		
A2 Structures	10,000 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	333.33h	333.33h	333.33h	333.33h	333.33h		
A3 Structures	10,000 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	333.33h	333.33h	333.33h	333.33h	333.33h		

Figure 3: Over-Allocation of Structural Erection Manpower

Resource Name	Task	Max Units	Max Daily Manpower	Material Units	Initials	Group	Est Rate	Ord Rate	Cost/Unit	Resource #	Base Calendar	Code	Add New Column
MWRS_C*	Work	100%	50	MC			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E*	Work	100%	8	ME			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_E_T	Work	100%	40	MCT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M*	Work	100%	8	MN			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_1	Work	1,563%	125.04	MN1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_2	Work	1,563%	125.04	MN2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_M_T	Work	1,563%	125.04	MNT			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
MWRS_S*	Work	8,500%	680	MS			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_1	Work	1,563%	125.04	E1			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_2	Work	1,563%	125.04	E2			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
E_CFW_3	Work	1,563%	125.04	E3			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		
CRANE-888	Work	100%	8	888			\$0.00/hr	\$0.00/hr	\$0.00	Prorated	Standard		

Resource Name	Work	Max Units	Working Delay	Start	Finish	Max Daily Manpower	Add New Color	Details	SA	T	W	T	F	S	13 Jul '24
CRANE-888	720 hrs	100%	0 days	19 Jul '24	27 Aug '24	8		Work	24h	24h	24h	24h	24h		
A2 Structures	240 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	0h	0h	0h	0h	0h		
A2 Structures	240 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	0h	0h	0h	0h	0h		
A3 Structures	240 hrs		0 days	19 Jul '24	27 Aug '24	0		Work	0h	0h	0h	0h	0h		

Figure 4: Over-Allocation of Crane for Structural Erection

3. There is room to install the five separate manufacturing lines concurrently, but there is only enough skilled manpower to install them sequentially. (Figure 5).

	Resource Name	Type	Max Units	Max Daily Manhours	Material Label	Initials	Group	Est. Rate	Est. Rate	Cost/Unit	Account A/B	Base Calendar	Code	Add New Column
1	MHRS_C*	Work	625%	50	ME			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
2	MHRS_E*	Work	100%	8	ME			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
3	MHRS_E_T	Work	500%	40	ME/T			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
4	MHRS_M*	Work	100%	8	MW			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
5	MHRS_M_1	Work	1,363%	125.04	MW1			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
6	MHRS_M_2	Work	1,363%	125.04	MW2			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
7	MHRS_M_3	Work	1,363%	125.04	MW3			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
8	MHRS_M_4	Work	100%	40	MW/T			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
9	MHRS_S*	Work	8,500%	680	MS			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
10	E_CRW_1	Work	1,363%	125.04	E1			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
11	E_CRW_2	Work	1,363%	125.04	E2			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
12	E_CRW_3	Work	1,363%	125.04	E3			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			
13	CRANE-008	Work	100%	8	008			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard			

	Resource Name	Work	Max Units	Leaving Delay	Start	Finish	Max Daily Manhours	Add New Color	Details	11 Sep '14						
7	MHRS_M_3	5,000 hrs	1,363%		30 Aug '14	18 Sep '14	125.04		Work	125%	125%	125%	125%	125%	125%	125%
	A2 install Line A	2,250 hrs		0 days	30 Aug '14	18 Sep '14			Work	125%	125%	125%	125%	125%	125%	125%
	A2 install Line B	2,225 hrs		0 days	30 Aug '14	09 Sep '14			Work	125%	125%	125%	125%	125%	125%	125%
	A3 install Line C	1,000 hrs		0 days	30 Aug '14	08 Sep '14			Work	125%	125%	125%	125%	125%	125%	125%
	A3 install Line D	675 hrs		0 days	30 Aug '14	07 Sep '14			Work	125%	125%	125%	125%	125%	125%	125%
	A3 install Line E	750 hrs		0 days	30 Aug '14	08 Sep '14			Work	125%	125%	125%	125%	125%	125%	125%

Figure 5: Over-Allocation of Area 3 Specialized Mechanical Installation Manpower

- An electrical change order has been approved in area 2, but this requires the same specialized crew that is already working there. The Change-order work must be delayed (Figure 6).

Resource Name	Resource Name	Type	Max Units	Max Daily Manhours	Material Label	Remarks	Group	Est. Rate	Est. Rate	Cost/Unit	NUTRA M	Base Calendar	Code	Add New Column		
	MHRS_C*	Work	625%	50	ME			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_E*	Work	100%	8	ME			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_E_T	Work	500%	40	ME/T			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_M*	Work	100%	8	MW			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_M_1	Work	1,363%	125.04	MW1			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_M_2	Work	1,363%	125.04	MW2			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_M_3	Work	1,363%	125.04	MW3			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_M_4	Work	100%	40	MW/T			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	MHRS_S*	Work	8,500%	680	MS			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	E_CRW_1	Work	1,363%	125.04	E1			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	E_CRW_2	Work	1,363%	125.04	E2			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	E_CRW_3	Work	1,363%	125.04	E3			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	CRANE-008	Work	100%	8	008			\$0.00/hr	\$0.00/hr	\$0.00/Prorated	Standard					
	Resource Name	Work	Max Units	Leaving Delay	Start	Finish	Max Daily Manhours	Add New Color	Details	11 Sep '14	12					
	E_CRW_2	10,800 hrs	1,363%		30 Aug '14	22 Oct '14	125.04		Work	125%	125%	125%	125%	125%	125%	125%
	A2 Electrical	5,000 hrs		0 days	30 Aug '14	22 Oct '14			Work	125%	125%	125%	125%	125%	125%	125%
	A2 Electrical Change Order 2	5,800 hrs		0 days	30 Aug '14	22 Oct '14			Work	125%	125%	125%	125%	125%	125%	125%

Figure 6: Over-Allocation of Area 2 Specialized Electrical Manpower

It is a simple matter to remove the over-allocations by manually executing Project's leveling engine using near-default conditions (Figure 7).

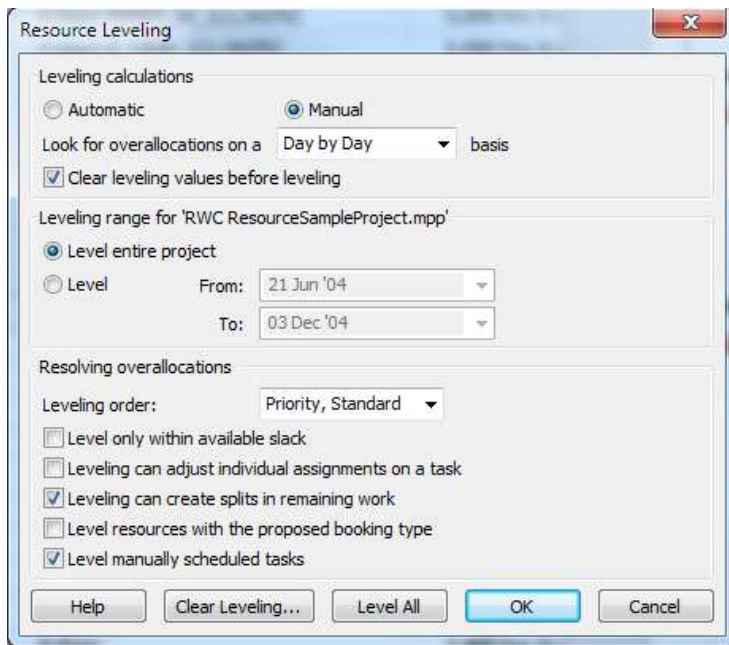


Figure 7: Resource Leveling Options

The leveling engine resolves the over-allocations by selectively delaying those tasks (and task resource assignments, if specified) which are judged to be lower-priority according to Project’s proprietary rules. Figure 8 illustrates the results of the leveling exercise:

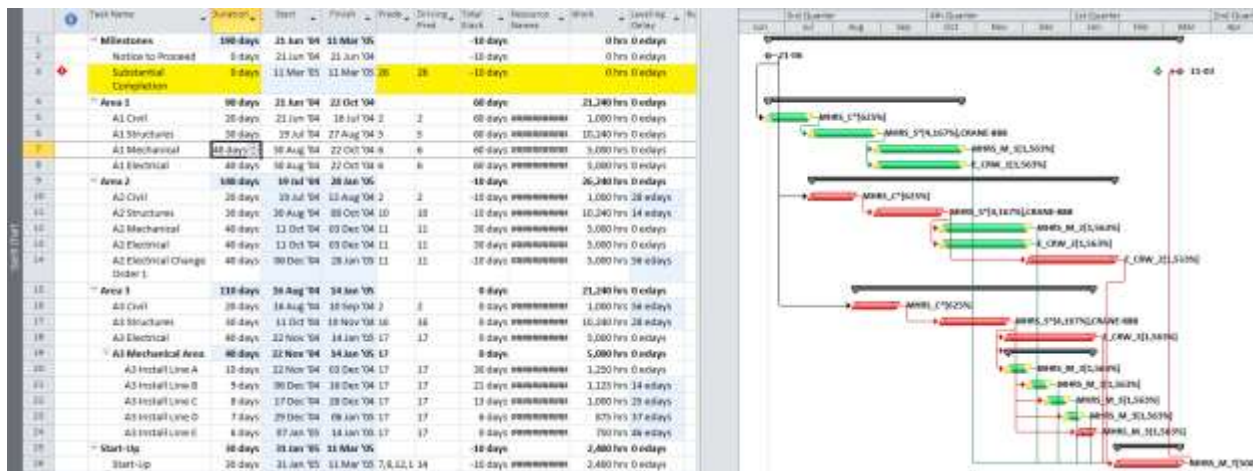


Figure 8: Resource-Leveled Schedule

1. The primary artifact of the leveling process is the “leveling delay” task property, which is in units of elapsed-duration (i.e. “edays”). The leveling delay is incorporated into the forward-pass schedule calculation, pushing the early start dates of the affected tasks. (Separate leveling delays can also be applied to resource assignments, which can extend task durations. This has not been done here and is generally not recommended when assigned resources are expected to work concurrently – e.g. Crane and structural erection crew.) Leveling delay is also incorporated into the backward pass, removing “phantom slack” from logically-connected tasks.

2. Through the task leveling delay, the civil, structural, mechanical, and electrical tasks have been re-scheduled sequentially.
3. Substantial Completion has been delayed until two weeks after the deadline, resulting in 10 days of negative slack on the milestone and its logical driving predecessors.
4. There is not an obvious (-10d) total-slack path from beginning to end of the project.

Figure 9 illustrates the use of BPC Logic Filter to determine the driving path logic of the Substantial Completion task after leveling. The driving path is comprised of four tasks and two milestones separated by gaps, and the intervals of the gaps are determined by the “leveling delay.” Unfortunately, this does not describe a “resource constrained critical path.” In fact, the obviously critical tasks without leveling delay – including the first (i.e. “A1”) Civil and Structural works and the A2 Electrical works – now have high values of total slack and are shown far from the critical path. Consequently, it is clear that logical path analysis – including any evaluation of Total Slack – is not consistent with the rule-based resource leveling algorithm used by Microsoft Project.

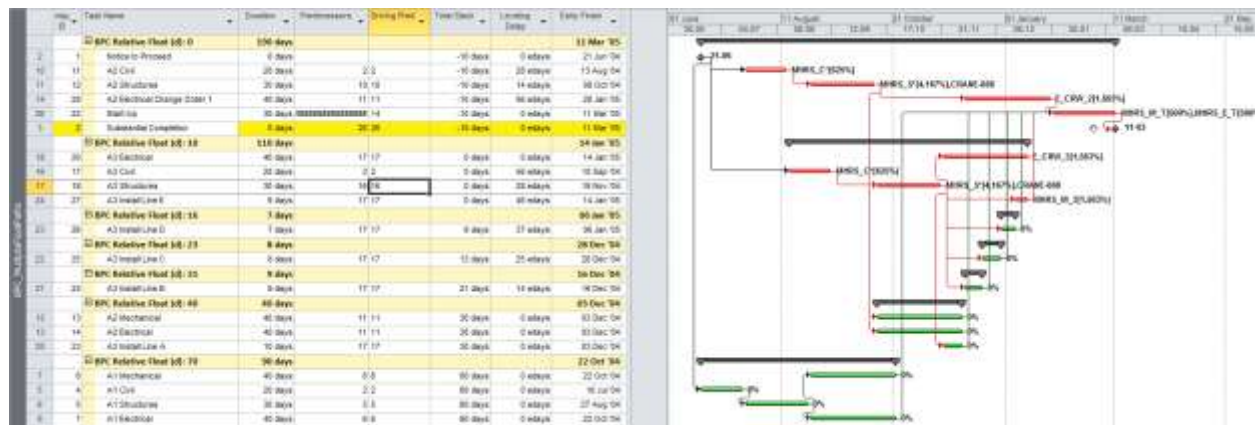


Figure 9: Logic Analysis of Leveled Schedule

Figure 10 illustrates the un-leveled schedule, revised to include preferential logic for avoiding resource conflicts. The preferential logic results in schedule dates that are identical to those of the leveled schedule seen earlier. As shown in Figure 11, however, the logic paths are clear and consistent with the real resource constraints of the project. The “BPC Relative Float (d): 0” group appears to represent the true resource constrained critical path for the project.

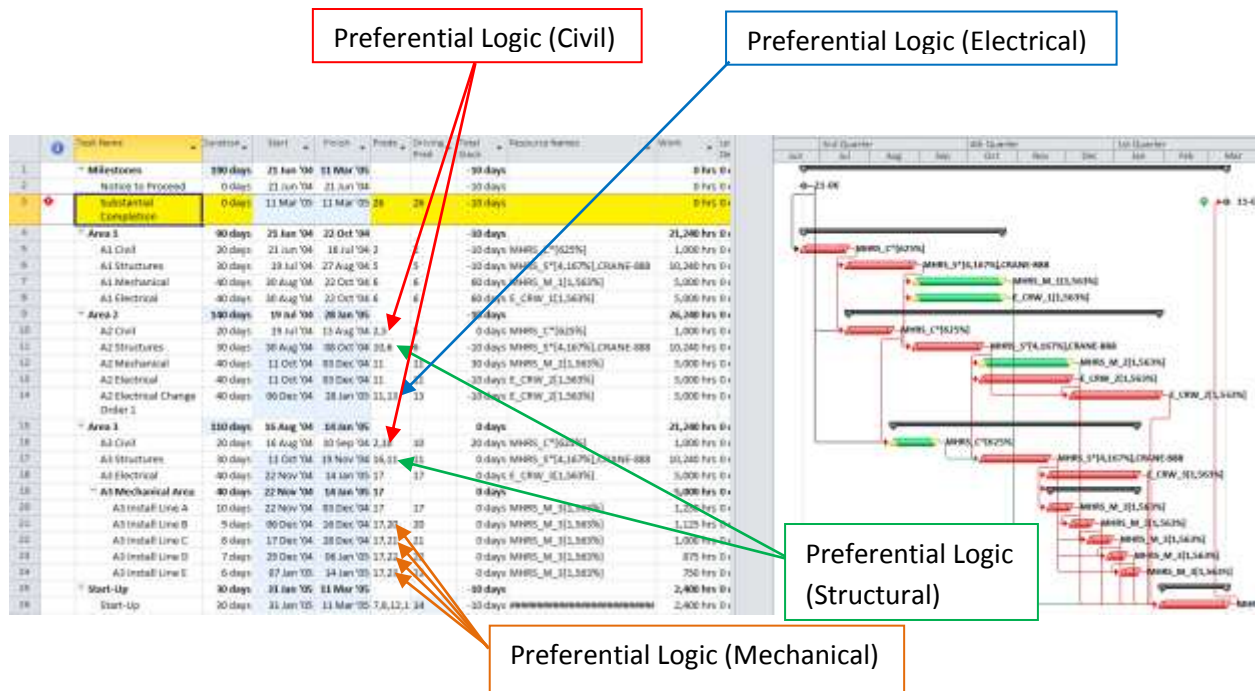


Figure 10: Preferential (Soft) Logic in Unleveled Schedule

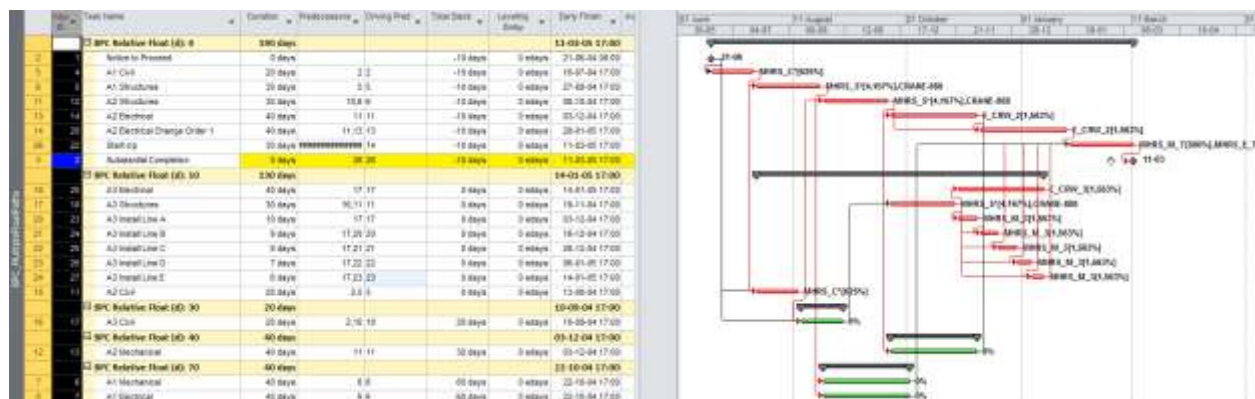


Figure 11: Logic Analysis of Unleveled Schedule with Preferential Logic

In conclusion, Microsoft Project's proprietary resource leveling engine offers a convenient tool for resolving resource conflicts in project schedules, and this functionality seems heavily used and highly valued in some industries. It does not appear appropriate, however, for use in complex projects where formal logical sequencing of tasks - including identification of Critical Path or Critical Chain - is required. In particular, Project's "Critical" flag will fail to mark the complete critical path in a resource-leveled schedule. Consequently, a project specification that requires both a logic-driven schedule basis and heuristic resource leveling appear contradictory.

[31Mar'16: The latest (pending) release of BPC Logic Filter now includes resource leveling constraints in the logical path analysis. I've written another article to summarize and amend this one: [The Resource-Constrained Critical Path - Logic Analysis of Resource-Leveled Schedules \(MS Project\), Part 2](#) .]