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A SCHEDULING TECHNIQUE FOR MULTIPLE RESOURCE ALLOCATION TO MULTIPLE PROJECTS IN CONSTRUCTION

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ABSTRACT: Today's highly competitive construction scenario forces all the major players in the field to take up multiple projects which have put an undue pressure on the resources available within the organization. Under such a situation, there are many instances where in the resource requirement exceeds its availability due to multiple activities (with same resource requirement) which are scheduled to start simultaneously and thus results in the constrained resource becoming a bottleneck of the project.
As a consequence of sharing resources, this paper studies the impact on the completion date of two similar projects under two different conditions, the first one resulting in a postponed end date and the second without any postponement. The resource utilization, the possibility of substitution of a resource and its subsequent impact on the deadline of the project is analyzed under these two circumstances. The study is done on a Critical Chain Project Management (CCPM) platform instead of leaving the schedule with a traditional Critical Path Method (CPM) finish, which gives an added advantage of validating the robustness of the emerging CCPM trend in the field of resource management.

Keywords: RACP; CCPM; Resource Constraint; Multi-Project management

1. INTRODUCTION

Resources are the backbone of any project environment, especially construction. They dictate the performance of the project in the two vital areas of time and cost and as a result, by controlling them, the project manager is enabled to have a greater control over the project and its progress. This fact makes resource management inevitable. Though resource management may not be explicitly and formally carried out at a project site, it exists in every job site. The effectiveness of this management is the factor to be evaluated especially in the case of a multi-project management scenario. In case of a single or stand alone project, the project manager is not very concerned about the release date of vital resources from his project site. However, this cannot be the situation in the case of a programme manager who is in-charge of multiple projects. Any change in the release date of such resources which are shared between projects may have a direct impact on the completion dates of all other dependent projects which utilize this resource. In case such a delay in release of critical resource takes place, the problem would be catastrophic if next activity that shares the resource is on the critical path. Hence in order to avoid adverse effect on schedules, the constrained resource should be identified along with back up plans in case of delay. If possible resource substitution may be done so that the inter-dependency between projects is reduced. However, the assumption here is that the resource which is being substituted will not have any negative effects on the quality and safety of the activity's result.

2. NEED

In order to schedule multiple projects the two most important details pertaining to the resources is required. The first and the foremost requirement is to know the schedule (or histogram) of the constraint resource in the project with highest priority, which is going to be scheduled first. Secondly the programme manager should know the total float of the next activity in the second project which is going to utilize this constraint resource in order to determine the total amount of delay which is acceptable to receive the resource such that the initial committed completion date of that project is not affected. Further, by some means even if such a schedule which can meet the above requirements is arrived at, there is no guarantee that the schedule will remain unchanged when it is applied on site. This is mainly because of many uncertainties which may evolve during the execution of the project. Uncertainties change the schedule's critical path and hence making monitoring and controlling a very challenging task. So in addition to the two requirements mentioned above, a schedule that is robust and resisting changes to maximum possible extent (uncertainties can be of any magnitude and hence we can only deal with some statistical variations still leaving the schedule vulnerable to very large variations like Force Majeure conditions which may not be under the project manager's control) is necessary. This paper aims to identify and develop such a schedule from the already available techniques which have the above mentioned attributes and be practically applicable at the project site with a greater ease to monitor and control.

3. BACKGROUND AND LITERATURE REVIEW

Based on the above discussion, the paper broadly identifies three needs which have to be catered to. They are, to develop

1. a schedule whose activities are scheduled considering both technological and resource constraints (as against a usual Critical Path Method which assumes that unlimited resources are available).
2. a schedule as above giving details of floats available for each and every activity.
3. a schedule which is immune to uncertainties which in turn eases monitoring and control.

Resource constrained scheduling technique dates back to the work of Wiest [1], in which, the paper identified a "critical sequence" of activities (instead of usual critical path) which took into consideration the resource dependency between activities in addition to their technological dependency and hence arrive at realistic floats of non-critical activities which would help in planning the scheduling of scarce resources. Further value addition and newer methods were developed in the subsequent studies by Davis [2], Woodworth and Shanahan [3], Badiru [4], Bowers [5], Bowers [6], Lu and Li [7]. The earlier papers concentrated on AOA networks while the latest ones are applicable on the popular AON networks. Each method has its own disadvantage and they have been criticised by many researchers [8]. Among the above, Resource – Activity Critical Path Method (RACPM) technique by Ming Lu and Heng Li [7], provides a robust heuristic which can be applied for multi-project management. In a nut-shell, RACPM satisfies the first two points identified above and also gives the vital information on the total float details of each activity considering both the technological and resource dependency.

Coming to the third point, there is a need for a method to absorb the changes due to uncertainties in the form of a buffer time for the schedule. This is the exact concept of Critical Chain Project Management (CCPM) technique which is an emerging trend in the field of project management. This CCPM concept is based on the "Theory of Constraints" developed by Goldratt [9, 10]. One such concept is the addition of the "weather delay" [11] to schedules. Since CCPM's introduction to the domain of project management, many researchers have commented on its practical implementation. Steyn [12], Herroelen and Leus [13], Zhao et al [14], Blackstone Jr. et al [15] are some of the papers that reflect the viewpoints of these critiques. Though these papers discuss length and breadth on the applicability of CCPM in projects, not much literature is available on multiple projects and multiple resource management which is the need of the day. The book on CCPM by Lawrence P Leach [16] is an exception since it does discuss the theoretical multi-project management. However direct application of CCPM to construction field is not easy since it involves restructuring the rules of the game which is not a simple task.

4. A NOTE ON RACPM AND CCPM TECHNIQUES

4.1 The Resource Activity Critical Path Method (RACPM) Technique

Developed by Ming Lu and Heng Li [7], they claim "the technique provides schedulers with a convenient vehicle for seamlessly integrating the technology/process perspective with the resource use perspective in construction planning" [7]. This heuristic technique tracks the movement of resources based on usage of each resource unit by different activities which require them [8].

The prominent feature in this method as against other methods is that the technique maps the usage of each unit of resource in a given category and hence useful in arriving at the usage schedule of each resource. From this, the mobilization pattern of the resources is obtained giving the details of working and the idle time of resources, a very important data in a multi-project scenario (a logical way of arriving at a resource histogram).

4.2 The Critical Chain Project Management (CCPM) technique

The main theory behind the concept of CCPM technique is the removal of individual task buffers and their accumulation at the end of the project schedule as a "Project Buffer". One question may arise as to how we identify the buffer time in the activity duration. According to CCPM, the fact that activity durations are estimated with an almost 90-95% probability of completion itself incorporates a significant amount of buffer in an activity. So, CCPM advices us to cut the task duration to 50% (this number can vary based on the site conditions and can be fixed by the planning/project manager to suit the site conditions) of what it is estimated initially. The 50% of the remaining half of the duration is taken as the project buffer protecting the "critical chain" (so called because it is the longest chain of activities linked considering both technological and resource constraints). The critical chain is protected from changing as a result of changes in the non-critical paths by introducing feeder buffers at the junction of critical and non-critical chains. Resource buffers are provided when 1) the succeeding activity in the chain requires a resource different from its preceding activity and 2) the required resource is being shared with some other activity scheduled before the current time. Whenever multiple projects are considered, a buffer similar to resource buffer is provided between projects among the activities that share constrained resources. This is also called a drum resource because it sets the rhythm in scheduling the multiple projects (follows the concepts of Theory of Constraints – TOC)

5. THE PROBLEM AND THE SOLUTION

The RACPM technique [7] explained above may be robust in scheduling the resources for a single or even for a multiple project, but it does not suggest methods to overcome the dynamic nature of schedule due to uncertainties that are inevitable in a project environment. As a result, this scheduling technique would be more practical if it is programmed to handle uncertainties.

The CCPM technique may be excellent in dealing with the uncertainties, but to start with, it requires an efficient method to initially prepare a schedule which is both technology and resource dependent. Most of the papers and books only deal with simple resource levelling techniques in order to remove resource conflicts. On doing this one can obtain a revised end date considering the resource constraints, but resource unit-wise break up of allotted resource distribution over the tasks and the revised total floats cannot be obtained. Further, it is also not possible to map the movement of one resource unit (for example an unskilled labour) from one task to the other. This is very important especially when one is evaluating the options of resource substitution.

On comparing the two challenges above, it is very clear that a schedule generated with a combination of the above two (RACPM and CCPM) techniques addresses the needs. Given the benefits of RACPM technique especially in cases where we are substituting one resource unit with the other, it stands advantageous to us.

6. THE WORK

In this paper the available resource constrained scheduling technique [7] is integrated with the CCPM technique in order to 1) develop an effective resource scheduling technique and identify the constrained resources to be substituted if needed and 2) make the technique thus identified insulated to common uncertainties (however as mentioned previously, it is not possible predict few uncertainties like the Force Majeure condition and hence they are not taken into consideration here), in a multiple project scenario. In order to illustrate the above technique, the same example of a small bridge construction project as given in the paper by Ming Lu and Heng Li [7] is considered.

The first step in providing the solution lies in preparing the multiple project schedules using the RACPM technique. In the paper on RACPM [7], the authors explain the algorithm for a single project taking an example. In the same paper [7], an unsolved example (only final solutions for the problem are given by the authors) of a footbridge construction project is given and it is considered in this paper for analysis, extending it to a multi-project scenario. The initial single project network and the resource allocation table are given in Figure 1 and Table 1 respectively. For a detailed description of the table parameters the reader is advised to read the paper on RACPM by Lu and Li [7]. In this paper, by multi-project management we mean two identical projects. But the logic derived from this study can as well be extended to two different projects of the same kind. As seen earlier, the project with the highest priority (many works have dealt with fixing priorities to projects [18], and any logic can be used as per the user's convenience) is first scheduled with the available resources (resource type and their numbers are given in the RACPM table – please refer to table 1 and 2). This gives us the usage data of each type of resource. From this, a Resource Availability Matrix (RAM) is prepared indicating the idle time of resources.

The next step involves scheduling the second project with the available resource, the data for which can be obtained from RAM. Here, there are two possibilities for analysis, 1) schedule the second project only the free resources available and the once that are released after their assignment in the first project, in which case no additional resource is mobilized and 2) schedule the second project along with the first project completing both as soon as possible with extra resources to be mobilized if need arises. The resulting multi-project multi-resource allocation table and final schedule for scenario 2 is given in Figure 2 and Table 2 respectively. The percentage utilization of resources in both the scenarios is given in Figures 3 and 4. In both the scenarios it can be clearly seen that the % utilization of resources has significantly increased for most of the resources. Further, during computation one can easily realise the need and subsequent benefits in substituting the resources in constraint. In the example considered in this paper, on scheduling, the importance in substitution of resource EX was observed. On substitution, two activities (A and E) using EX could be simultaneously scheduled (all the other resources were available) thereby directly reducing the total project duration of both projects. Substitution can be done in many ways like a machine can be replaced by the idle manpower (if possible) in that slot, or using some alternate technique, material etc. suiting the site requirements. It has to be noted here that if the resource manager had mobilized one more resource in its place, the resulting percentage utilization of that resource which is newly mobilized (the other as well) would be lesser than the one obtained by sharing the resource, indicating the advantage of sharing a constrained resource.

The final step consists of integrating RACPM with CCPM. Once the multiple project schedule is developed, the steps to be followed for integrating it with CCPM would be as follows [9,10], 1) Cut all the task durations by 50% and hence project duration will be halved 2) Identify the Resource Activity critical path [7] or the Critical Chain (as known in CCPM language) which is the longest chain of activities considering both the resource and technological constraints 3) Make all the activities to start as late as possible (this applies only to activities that have float) 4) Insert feeding buffers at all the locations where the non critical chain meets the critical chain (we have identified two ways of doing it and the snapshot of the result is shown in the figure 5 and 6- one has a greater duration than the other) 5) Resource buffers and capacity constrained resources are added at all the locations where resource from one project to other are transferred. A resource buffer here is a form of early information given indicating the completion status of the task in progress to the resource coming from the other project which is going to be assigned to the next activity. It may not necessarily add more days to the project since it is only a sort of indicator or a warning to mobilize the shared constraint resource and 6) Finally add the project buffer, calculated here as 50% of the critical chain length after inserting all the feeding and resource buffers. It has to be noted that sometimes after addition, the project duration may shoot up beyond the dates obtained by a simple RACPM scheduling technique. This is mainly due to the addition of feeding buffers (highlighted in the schedule) which are included as dummy tasks in the schedule with its duration same as the buffer duration. However if the buffers are not utilized, the duration of the project may not be extended.

Figure 1. Initial CPM Network

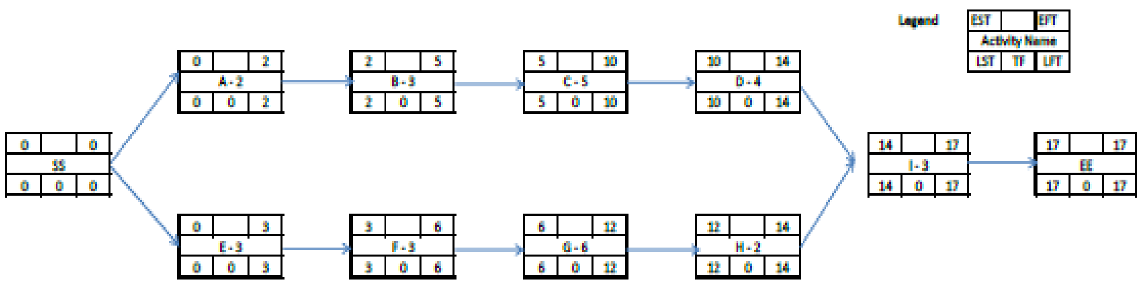

Table 1. Initial Single Project Resource Allocation Table

Current Activity			E			F			A			G			B			C			H			D			I			
Pre. Act. EFT			0			3			0			6			5			15			12			20			24			
																											14			
(1)	(2)	(3)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(4)
1	LB	0	0	1	0	3	1	0	6			6			6	1	6	15	1	0				20			20			20
2	LB	0	0	1	0	3	1	0	6			6			6	1	6	15	1	0				20			24	1	0	27
3	LB	0	0			3	1	0	6			6	1	0	12			12			12	1	0	17	1	3	24	1	0	27
4	LB	0	0			3	1	0	6			6	1	0	12			12			12	1	0	17	1	3	24	1	0	27
5	LB	0	0			0			0	1	3	5	1	1	12	1	0	15	1	0				20			20			20
6	LB	0	0			0			0	1	3	5	1	1	12	1	0	15	1	0				20			20			20
1	EX	0	0	1	0	3			3	1	0	5			5			5			5	1	7	18	1	2	24			24
1	MC	0	0			0	1	3	6			6			6	1	6	15						15			15	1	9	27
2	MC	0	0			0			0			0			0			0						0			23	1	1	27
1	ST	17	17			17			17			17			17			17						17			17	1	7	27
1	FM	0	0			0	1	3	6			6			6	1	6	15						15			15			15
EST			0			3			3			6			12			15			12			20			24			

Figure 2. Final RACPM/CCPM Multi-Project Network - Scenario 2

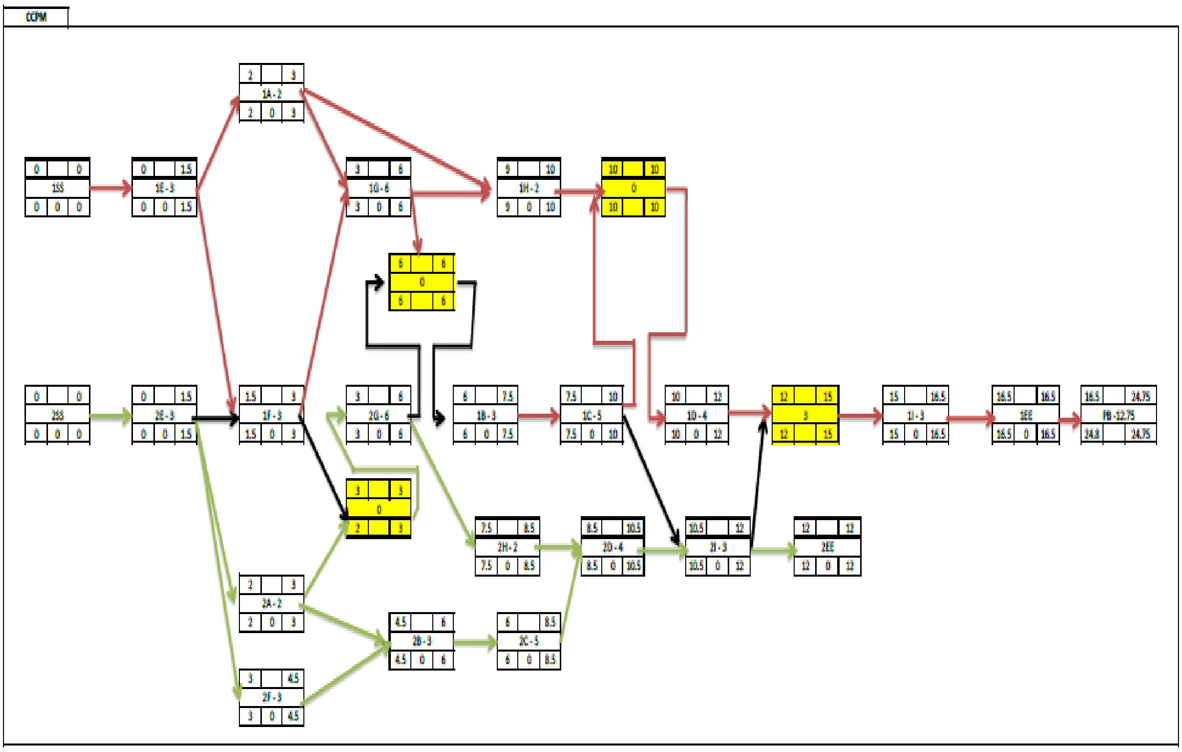

Table 2. Multi Project Resource Allocation Table – Scenario 2

Current Activity			E			F			A			B			G			H			C			D			I			
Pre. Act. EFT			0			3			0			5			6			12			9			14			18			
																											14			
(1)	(2)	(3)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(a)	(b)	(c)	(4)
1	LB	0	0	1	0	3	1	0							6	1	0													20
2	LB	0	0	1	0	3	1	0							6	1	0										20	1	0	23
3	LB	0	0	1	0	3	1	0							6	1	0				Act G of Proj 1									27
4	LB	0	0	1	0	3	1	0							6	1	0													27
5	LB	0							0	1	3				5	1	1													20
6	LB	0							0	1	3				5	1	1													20
7	LB	3				3	1	0				6	1	0							9	1	0							14
8	LB	3				3	1	0				6	1	0							9	1	0							14
9	LB	3				3	1	0				6	1	0							9	1	0							14
10	LB	3				3	1	0				6	1	0							9	1	0							14
11	LB	3							3	1	0				5	1	1	12	1	0				14	1	0	18	1	2	23
12	LB	3							3	1	0				5	1	1	12	1	0				14	1	0	18	1	2	23
1	EX	0	0	1	0				3	1	0							5	1	7				14	1	0				24
2	EX	0	0	1	0				3	1	0							5	1	7										14
1	MC	0				0	1	3				6	1	6													15	1	5	23
2	MC	3				3	1	0				6	1	0													9	1	11	23
1	ST	17																									17	1	3	23
1	FM	0				0	1	3				6	1	6																15
2	FM	3				3	1	0				6	1	0																9
EST			0			3			3			6			6			12			9			14			20			

7. RESULTS AND DISCUSSIONS

Scheduling as per case 1, leads to a multi-project schedule in which both projects together are completed in 43 days. Scheduling as per case 2 leads to schedule where it takes 24.75 days for the first project and 12 days for the second one to complete. It has to be noted here that in both cases, only one feeder buffer of 3 days is added to the schedule at the end where a non-critical chain meets the critical chain. As per the concept of critical chain, feeder buffers should be added to all the junctions of non-critical and critical chains. The provision for the same is shown in case 2 where in the number of buffering days required can be filled up at the highlighted buffering boxes by the project manager in the due course of the project depending upon the progress and probable uncertainties. The same can be extended to case 1 also. With regards to substitution of resources, the resource EX was a very critical whose substitution would have had a very positive impact on early completion of projects. This study has used two similar projects [7] for multi-project scheduling, though the same logic could be extended to two different projects. However, the difference in them should not be great since two completely different projects cannot be a part of a programme. The resource utilization graphs are shown in the figures 3 and 4.

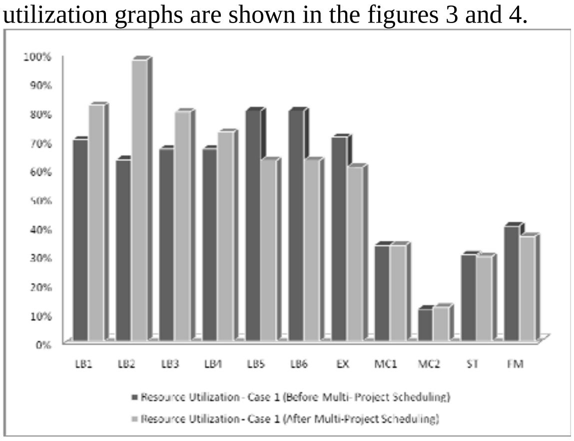

Figure 3. Resource utilization – Scenario 1

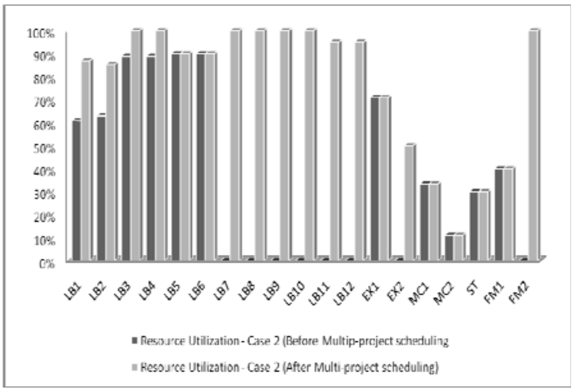

Figure 4. Resource Utilization – Scenario 2

Resource Name	Avbl (Days)	Used (Days)	Utilize%
LB1	20	14	70%
LB2	27	17	63%
LB3	27	18	67%
LB4	27	18	67%
LB5	20	16	80%
LB6	20	16	80%
EX	24	17	71%
MC1	27	9	33%
MC2	27	3	11%
ST	10	3	30%
FM	15	6	40%

Table 3. Initial Resource Utilization %

Resource Name	Avbl (Days)	Used (Days)	Utilize%
LB1	44	36	82%
LB2	44	43	98%
LB3	44	35	80%
LB4	51	37	73%
LB5	51	32	63%
LB6	51	32	63%
EX	48	29	60%
MC1	51	17	33%
MC2	51	6	12%
ST	34	10	29%
FM	33	12	36%

Table 4. Resource Utilization % - scenario 1

Resource Name	Resource Availability	Utilization	%
LB1	23	20	87%
LB2	27	23	85%
LB3	27	27	100%
LB4	27	27	100%
LB5	20	18	90%
LB6	20	18	90%
LB7	11	11	100%
LB8	11	11	100%
LB9	11	11	100%
LB10	11	11	100%
LB11	20	19	95%
LB12	20	19	95%
EX1	24	17	71%
EX2	14	7	50%
MC1	27	9	33%
MC2	27	3	11%
ST	10	3	30%
FM1	15	6	40%
FM2	6	6	100%

Table 5. Resource Utilization % - scenario 2

8. CONCLUSIONS AND FURTHER SCOPE

The paper basically tries to develop a robust schedule for multi-project management with a focus on increasing the utilization of resources through sharing and substitution. The two cases of scheduling depicted here can be used under two different scenarios, that is, scenario 1, when there are constraints on mobilizing resources and scenario 2, when there is no constraint on mobilizing resources and also the project must be completed as early as possible. Transportation models could be set up to study the influence of distance and transit time of resources when they are shifted from one project site to the other. For monitoring the project as it progresses, the fever chart concept (CCPM) can be put to use. Another advantage of this method is that we have two kinds of schedule, one CCPM based and the other usual CPM based, (instead of a purely CCPM based schedule) which would help the project manager to be comfortable since he may be new to the fairly recent concept of CCPM.

Further scope of this work can be to extend the algorithm to larger projects for which computer programming based solutions can be developed. Further, this paper only identifies the potential resources for substitution, but does not focus on practicality of the substitution given the safety, quality and cost considerations which can be an area for further work. Cost parameters can also be assigned to decide on the cost effectiveness of the method selected. There is a lot of future scope in integrating both the CCPM and CPM scheduling techniques to better utilize the best in both - simplicity of CPM and reliability of CCPM.

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