Optimized Acceleration of Repetitive Construction Projects

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Purpose The purpose of this paper is to present an improved algorithm for optimized acceleration of repetitive construction projects. **Method** Through a set of iterative steps this algorithm identifies the least costly method that would put a project back on track, while maintaining crew work continuity. The algorithm divides each activity into segments and identifies the segments that would shorten project duration if accelerated. For these identified segments, the ones with the lowest cost slope are selected and cued for acceleration. Through the proposed segmentation of activities this algorithm provides better focusing of allocated additional resources, thus resulting in more cost-efficient acceleration plans. The algorithm is implemented in a spreadsheet application, which helps automate calculations, yet allows users to fine-tune the algorithm to fit the project conditions at hand. The algorithm allows users to select among different acceleration strategies such as working overtime, working double shifts, working weekends, employing more productive crews, work stoppage for converging activities and intentional work breaks. **Results & Discussion** The developed algorithm is applied to a case study drawn from literature in order to illustrate its basic features and demonstrate its accuracy. The results obtained, when compared to those reported for the case considered, demonstrate the ability to accelerate this project in while utilising fewer resources.

Keywords: *management & social issues, repetitive projects, acceleration, linear scheduling*

INTRODUCTION

In many cases contractors and/or owners find themselves challenged by having to accelerate a repetitive project. This challenge is difficult for two main reasons, primarily because the need for such a decision implies that the project is already running behind the required ending date, which increases the pressure on involved parties, and secondarily because accelerating a project implies enduring additional costs that are not accounted for in projects' original budgets. These facts highlight the need for a reliable tool that would aid project managers in selecting the right action to accelerate a project at least cost in a timely manner.

Repetitive construction projects are identified as construction projects formed of recurring units, each unit consisting of a number of sequential activities. This unique nature paves the way for making considerable savings on time and cost by maintaining the continuity for crews and different resources involved in this class of projects. Maintaining work continuity offers many benefits such as maintaining a constant workforce by reducing firing and hiring of labour, retaining skilled labour, maximizing use of learning curve effect and minimizing equipment idle time[7]. However, maintaining continuity forms an additional constraint when planning and managing a repetitive project. Consequently, using traditional scheduling and planning tools and techniques to manage repetitive projects has been widely criticized[12]. This calls for developing special tools and techniques to properly manage every aspect of a repetitive project. The research at hand presents a unit based acceleration technique for repetitive construction projects. There are two main uses for the presented technique: it can be used to shorten a project's planned duration if the project is scheduled to end after a specific deadline, or it can be used as a part of a control procedure when a project runs behind schedule, to reduce or eliminate schedule overruns.

IDENTIFYING ACTIVITIES TO ACCELERATE

Recognizing the right activity to accelerate in a repetitive project is key step towards successful project acceleration. Accelerating the wrong activity will lead to spending more money without any effect on a projects duration, or to spending more money than needed. In traditional projects (i.e. non-repetitive) such a decision is made easier by shortening activities on the critical path[11], where priority for activity crashing is set based on their respective cost slope (i.e. the added direct cost per unit of time reduction). Consequently, crashing any activity on this path would shorten the projects duration. This remains valid until that critical path is no longer the longest path in the network. Things are different in repetitive projects, as many alternatives exist in literature for identifying which activities control a repetitive project's duration. Two well-known methods to identify the critical activities controlling a repetitive projects total duration are "Controlling Activity Path" for schedules built using Linear Scheduling Model (LSM)[4], and "Controlling Sequence" for schedules built using Repetitive Scheduling Method (RSM)[6]. Many comparisons have been made between these two methods highlighting advantages and disadvantages of both methods. Although both successfully identify critical activities, both techniques only account for sequential activities with constant production rates, therefore limiting their practical use[10].

Although in the context of this research Linear Scheduling Model (LSM) was used to represent schedules, a different technique was used to identify which activities to accelerate than targeting the controlling activities defined earlier[6]. The technique adopted in this research is a modified version of the technique proposed by Hassanein and Moselhi[8]. In their technique, identification of critical activities was set based on activities' least alignment with their successors. As the case in all repetitive projects scheduling techniques, when a successor activity has a higher rate than its predecessor, its starting time is determined by backward calculations based on the predecessor activity ending time. Consequently, reducing the duration of a least aligned predecessor will advance its ending time, thus enabling an earlier start for its successor. Figure 1, shows an example of a repetitive project's schedule, and shows how accelerating the least aligned activity would lead to shortening project duration. The proposed modification in this research is that the identification of the least aligned activity is performed for each unit separately. So instead of identifying an activity to be accelerated throughout all units, the activity to be accelerated is identified for each unit separately.

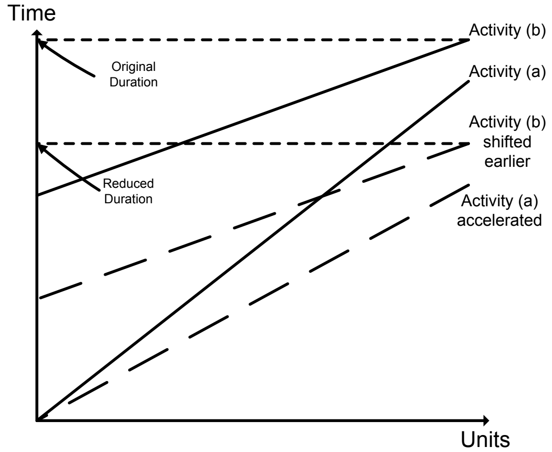

Fig.1. Effect of Acceleration on a Repetitive Schedule

ACCELERATING STRATEGIES

There are common accelerating strategies project managers often use when accelerating repetitive projects. Acceleration strategies that are extracted from literature and included in the scope of this research mostly depend on increasing the man hours assigned to the activity. This can be done by choosing one of the following strategies: (1) working overtime; (2) working double shifts; (3) working weekends and (4) employing more productive crews[8]. These strategies aim at increasing the assigned man-hours to each activity; enabling the activity to be completed in shorter duration. Clearly each of the acceleration strategies stated above comes with associated costs. Examples of these associated costs are increased direct costs as in labor wages and equipment running costs, and indirect costs in the form of increased supervision and loss of productivity due to congestion in case of increased crews size[1]. On the other hand, as projects' total duration decreases, indirect costs also decrease. Two additional strategies are also considered, namely: (5) relaxing activities[3] and (6) introducing intentional work breaks[13]. Those two strategies can have the effect of decreasing projects total duration only if applied to converging activities. As can be seen in Figure 2, converging activities are activities having a higher rate than their predecessor and a lower rate than their successor. By relaxing a converging activity's rate or introducing an intentional break it can start earlier, and its successor can start earlier. Relaxing an activity might cost less money as it leads to assigning fewer resources, however it might cost more. For example relaxing an activity could mean increased renting period for equipment and increased supervision man hours. Similarly introducing intentional breaks comes at an increased cost, especially in equipment extensive projects like highway projects as rented or procured equipment would be left idle on site. The associated costs leave strategies (5) and (6) less likely to be chosen by a project manager to accelerate a project; however, they are included as options in the proposed algorithm.

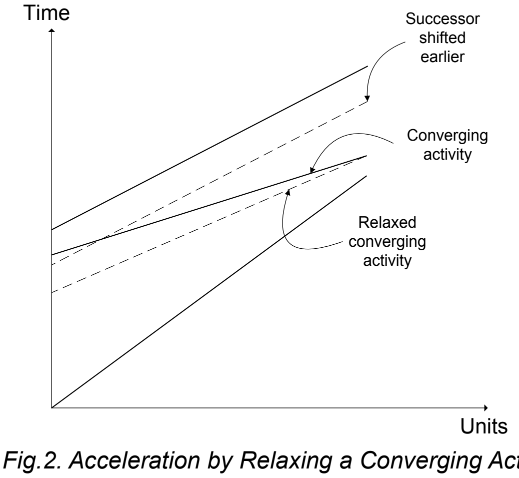

Fig.2. Acceleration by Relaxing a Converging Activity

Previous repetitive projects acceleration techniques chose a critical activity to accelerate throughout all units. For example chose to accelerate activity “earthwork” for every kilometre throughout a highway construction projects. This might be the correct choice in some cases where units are all typical. Typical units mean that for each activity all units have the same quantity and that crews and equipment have same productivity throughout all units. This leads to a repetitive schedule formed of activities represented by straight lines with a different slope for each line. Once an activity is identified to be less aligned with its successor or predecessor (i.e. critical), it will continue to be less aligned through all units. This is identified as a special case. The general case is that projects consist of non-typical units. Non-typical units have different quantities for the same activity, and utilize crews and equipment operating at different productivities. Repetitive projects schedules consisting of non-typical activities are represented by broken lines with varying slopes for each unit. An example of which can be seen in Figure 3. This general case makes it unlikely that the least aligned activity will be the same throughout all units. The presented algorithm in this research identifies the least aligned activity separately for each unit. By doing so, two main benefits are realized. Firstly, needed duration shortening can be achieved using less accelerating resources, as these excess resources were previously assigned to non-critical portions of the identified activity, thus not reducing total project duration. Secondly, it helps avoid productivity loss due to assigning too many overtime hours, as literature shows that maintaining a 1 hour per day of overtime for 4 weeks, results in a 16% less efficient process than keeping regular working hours for 4 weeks[8].

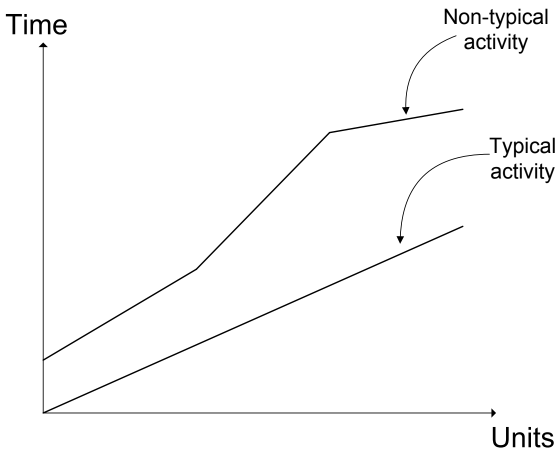

Fig.3. Typical and Non-typical Activities

PROPOSED METHOD

The proposed acceleration technique aims at identifying which activities of a repetitive project to accelerate and which accelerating strategy to be used to accelerate them. The starting point is a repetitive project scheduled in LSM, and having a duration that needs to be shortened. As explained earlier, the priority in acceleration is for the activity that is least aligned with its successor. Identifying the least aligned activity is done using a technique similar to minimum moment algorithm used for resource leveling[9]. It operates by calculating the areas trapped between lines representing successive activities, then calculating the moment these areas cause around a centerline. Less aligned activities result in bigger areas with bigger eccentricities, hence resulting in bigger moments, and vice versa. One of the modifications introduced in this research is that the alignment calculations are carried out for each unit separately instead of the whole project. Although this requires more calculations, yet it allows choosing less costly acceleration strategies.

A deeper look at the algorithm at hand reveals that considering each unit separately has a weakness. This approach would identify the criticality of an activity based only on the productivity of the assigned crew, regardless of the number of crews working on the same activity in other units. For example if 3 crews are assigned to an activity each producing 1 unit per day, their total productivity is 3 units per day. Comparing each activity’s rate and neglecting the global perspective that includes the number of assigned crews would identify this activity to be more critical than an activity assigned to a single crew producing 2 units per day, although clearly the later activity progresses at a slower rate. To address this issue the equations for calculating areas and their moment around the center line had to be modified to include also the number of crews, which enables correctly conveying the rate of an activity according to the productivity and number of crews assigned. The algorithm outlined in Figure 4 along with the following equations demonstrates how to identify the least aligned activity in a repetitive project is formulated. The activity with the largest value for Ω is the least aligned activity.

$Area_{(i)} = L.Side_{(i)} + R.Side_{(i)} / 2$

$L.Side_{(i)} = S_{(i)} - S_{(i-1)}$

$R.Side_{(i)} = [F_{(i)} - F_{(i-1)}] - [D_{(i)}(n-1)/n] + [D_{(i-1)}(n'-1)/n']$

If $L.Side_{(i)} > R.Side_{(i)}$

$C_{(i)}=(L.Side_{(i)}+2 \times R.Side_{(i)}) / [3(L.Side_{(i)}+R.Side)_{(i)}]$

$e_{(i)} = C_{(i)} - 0.5$

If $L.Side_{(i)} > R.Side_{(i)}$

$C_{(i)}=(R.Side_{(i)}+2 \times L.Side_{(i)}) / [3(R.Side_{(i)}+L.Side_{(i)})]$

$e_{(i)} = 0.5 - C_{(i)}$

$\Omega_{(i)} = Area_{(i)} \times e_{(i)} - Area_{(i+1)} \times e_{(i+1)}$

Where

- **$Area_{(i)}$** is the area between activity (i) and (i -1)
- **$S_{(i)}$** is the start time of activity (i)
- **$S_{(i-1)}$** is the start time of activity (i-1)
- **$F_{(i)}$** is the end time of activity (i)

- **$F_{(i-1)}$** is the end time of activity (i-1)
- **$D_{(i)}$** is the duration of activity (i)
- **$D_{(i-1)}$** is the duration of activity (i-1)
- **n** is the number of crews assigned to activity (i)
- **n'** is the number of crews assigned to activity (i-1)
- **$C_{(i)}$** is the distance between the area's edge to the area's center of gravity
- **$e_{(i)}$** is the eccentricity of the center of gravity to the center line of area (i)
- Ω(i) is the value reflecting the degree of misalignment of activity (i)

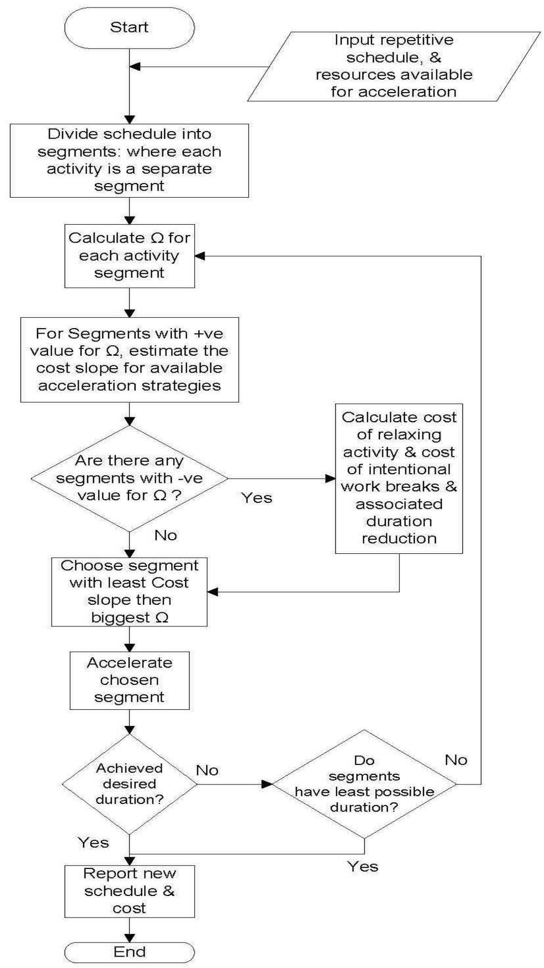

Fig.4. Proposed Algorithm

As shown in Figure 5, Ω is calculated for each activity for each unit separately, to identify the least aligned activity for each unit. Activities with negative values of Ω are converging activities. These activities are considered for acceleration through relaxing their rate or applying intentional work stoppages. After identifying which activity to accelerate, now the acceleration strategy has to be carefully selected. This research bases the strategy selection on the least associated costs. Here it is up to the project manager to provide the cost of each acceleration strategy in the form of cost per hour or cost of intentional work stoppage. Then this cost is translated into a cost slope for each strategy, where each strategy cost is in the form of cost per day of duration reduction. The priority in selecting which segment to accelerate is for the least cost slope. In case there is more than one segment with the same cost slope, the second priority is for the activity with the largest Ω value.

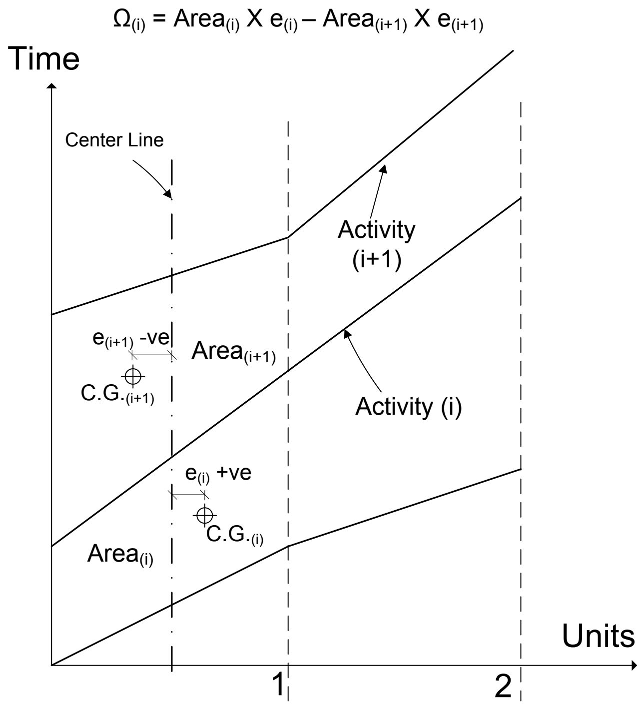

Fig.5. Identifying Least Aligned Activities

The formulated model was implemented in a spread sheet application that automates all calculations. The application accepts projects initial schedule, along with activities quantities and crews rates. It automatically runs all calculations and identifies the activity nominated for acceleration in each segment. As the user responds to the identified nominations and assigns acceleration resources, the application continuously re-identifies the next activity to be accelerated in each segment, until the required duration reduction is achieved.

CASE STUDY

The developed algorithm was applied to a case study drawn from literature to demonstrate its basic features. The case study presented in literature[2] is a 15 Km three-lane highway project, consisting of 5 repetitive activities. These activities, in their order of precedence, are: (1) cut and chip trees; (2) grub and remove stumps; (3) excavation; (4) base; and (5) paving, and all precedence relations are finish to start, with no lag time. The project is divided into 15 segments of equal lengths, each is 1km. This project includes typical activities and non-typical activities. Typical activities are (4) base and (5) paving, as they have same quantities for each unit and same crew productivity for different crews. While activities (1) cut and chip trees, (2) grub and remove stumps and (3) excavation are non-typical activities, as their quantities change from one unit to another and also their different crews have different productivities. The included activities are all sequential except for activity (3) excavation; this activity is non-sequential as its starts by units 4 to 1, then units 5 to 15. The original project data can be found in literature[2], the initial schedule had a normal duration of 83 days.

When Hassanein and Moselhi[7] applied their acceleration technique, the goal was to accelerate the project to end it in 77 days. And they only considered working overtime hours as an acceleration strategy, and the cost of overtime hours was considered the same for different crews. So the case study was mainly about identifying which activities to accelerate. Their acceleration technique achieved the required end date by accelerating activities "grub and remove stumps" and "excavation" throughout all units, by adding three and two hours of overtime per day respectively. The total of the assigned overtime hours mounts up to 75 hours.

The algorithm proposed in this research was then applied to the selected case study. The original schedule was input to the developed spreadsheet application. The spreadsheet automatically identifies the critical activities to be considered for acceleration for each respective unit. Additional overtime hours were added to the identified activities. Automatically the schedule was updated and the new critical activity segments were identified and additional overtime hours were added in an iterative manner, taking into consideration the limit of available overtime hours for each crew. The final 80 days duration schedule was achieved by the combination of overtime hours displayed in Table 1.

Table 1: Added Overtime Hours

	Cut and chip trees		Grub & remove stumps		Excavation		Base		Paving	
Unit	Over-time	New Duration	Over-time	New Duration	Over-time	New Duration	Over-time	New Duration	Over-time	New Duration
1	3	4	-	3	3	6	-	10	-	8
2	3	4	-	3	2	4	-	8	-	8
3	2	6	-	4	3	6	-	10	-	8
4	-	4	-	3	3	5	-	10	-	8
5	-	6	-	5	-	6	-	10	-	8
6	-	8	-	6	-	7	-	10	-	8
7	3	10	3	7	-	6	-	10	-	8
8	1	8	3	5	-	5	-	10	-	8
9	-	7	-	4	3	6	-	10	-	8
10	-	7	2	4	-	5	-	10	-	8
11	-	6	-	5	3	6	-	10	-	8
12	-	4	-	3	2	4	-	8	-	8
13	-	4	-	2	2	4	-	8	-	8
14	-	4	-	3	3	6	-	10	-	8
15	-	4	-	3	2	4	-	8	-	8

Table 2 shows the original duration and results of both acceleration methods. It can be seen that the modified acceleration algorithm presented in this research achieved the same duration reduction by assigning 46 instead of 75 overtime hours, thus significantly reducing acceleration costs.

Table 2: Comparison of Results

Schedule	Duration	Total Overtime Hours
Original Schedule by Elrayes[2]	83	-
Acceleration by Hassanein and Moselhi[8]	77	75
Modified unit based acceleration	77	46

CONCLUDING REMARKS

An improved algorithm for optimized unit-based acceleration of repetitive construction projects was presented. The presented algorithm can accommodate typical and non-typical activities, and sequential and non-sequential activities. The automated spreadsheet application presented makes using the algorithm very simple and straightforward, and allows users to fine tune the algorithm to fit any project conditions at hand. The presented method selects from six available alternatives for project acceleration while maintaining resource continuity. The demonstrated application to a case study showed how the presented works well for accelerating construction of repetitive projects; yielding –for the case study- the same accelerated project duration while using less additional resources.

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