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Methodology to Reduce Construction Project Schedule Duration Using Activity Aggregation

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Abstract A methodology to reduce schedule duration of a typically large-scale construction project is proposed and demonstrated. It involves aggregation of simultaneous and repetitive activities identified in a project schedule that was already prepared using a traditional sequencing method. Labor re-allocation and time duration of aggregated activities are used to devise a model for calculating savings in schedule duration. The proposed method is applied to a dry dock construction project. There is a significant reduction in the schedule duration tested for both labor comfort and cost comfort scenarios. The savings in labor comfort case is marginally greater than the savings in cost comfort case. The efficiency of the proposed method seems to depend on the quality of the original schedule upon which the method is applied. It is also found that the frequency of repeated activities within any given management unit, and the variance in duration of those activities, play a key role in choosing and prioritizing activities identified for aggregation purposes.

Keywords Activity aggregation, Schedule duration reduction, Schedule optimization, Simultaneous activities, Repetitive activities

1. Introduction

Construction costs are expected to increase globally by around 3 to 4% every year, which is significant [1]. Construction industry is one of those well-established industries, and yet to fully leverage innovations in processes involved, especially, in project management and related procedures [2]. One of the important aspects of such construction processes is project duration. The latter entity can influence bidding cost and potentially decrease owner-contractor disputes during or after construction [3].

In general, schedule of a project is prepared by giving priority to ease of management of resources such as materials, labor and equipment available. This is applicable irrespective of cost comfort and labor comfort approaches to scheduling. It is referred to as 'traditional method' in this paper. Such scheduling practice need not necessarily consider the influence of activities that occur simultaneously and/or occur repeatedly. In our study, we explore and demonstrate that inclusion of aggregation of such activities can lead to reduction in project duration. The method proposed is based on identification of activities on a higher hierarchy level, segregation of simultaneous activities, and prioritization of activities based on characteristics such as frequency, individual duration and its variance.

A complete construction schedule of a dry dock was used to evaluate the proposed aggregation method. The dry dock is being constructed in an Indian coastal city. The projected cost of the dry dock is 220 million USD.

There are several software packages available for applying and testing the proposed method [4-7]. Microsoft Project was used in this study as it provided satisfactory control over manipulating related variables.

1.1. Structure of Presentation

The structure of this paper is as follows: first, a review of literature is presented. Then, proposed method is explained in detail. This is followed by an analysis of results obtained when the proposed method is applied to dry dock construction scheduling procedure. Finally, conclusions and areas where this method can be further improved are presented.

2. Literature Review

There is an increasing number of infrastructure projects, costing in the order of several million US dollars, in both developed and developing countries [8, 9]. The complexity involved in project management is well documented [10, 11]. The challenges in reducing cost and duration had been well-addressed by researchers in this field [12, 13].

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2.1. Project Duration

There had been several innovative efforts in reducing the project duration. Notable works are by Bogus et al [14] and Srour et al [15]. Bogus et al conducted one of the earliest research works primarily focusing on overlapping sequential activities. Our method focusses on aggregation of activities. Srour et al proposed a methodology for scheduling, also considering overlapping, however, giving more emphasis based on dependency information [15]. We too rely on checking dependency information, even more in-depth, at a very microscopic level. Their studies had some limitations though. First, the efficiency of their method depends on contractor's knowledge and expertise on overlapping and its consequences, which cannot be always relied upon. Our proposed method does not warrant such pre-expertise. In addition, their works deal only with trade-off between time and cost. In our method, we keep the cost as constant and focus on reducing the time, which will eventually reduce cost of the overall project too. Furthermore, large scale or mega projects will have higher frequency of activities with natural precedence relationships, which were not considered in those studies. In our study, we duly incorporate such factors.

2.2. CPM's Effect on Proposed Method

The proposed method is to be applied on an existing schedule already prepared using a traditional method, such as involving use of techniques like Critical Path Method (CPM). Therefore, any inefficiency in the existing schedule may affect the performance of our method. Because, disadvantages and occasional inefficiencies in traditional scheduling principles, including CPM, are well known [16] [17]. For instance, if the duration is overly estimated in an existing schedule, the difference between the project durations of existing and proposed may not be a reliable estimate. If the existing schedule is optimized to its best, then the effect of our proposed method will be truly reflected.

2.3. Role of Repeated Activities

There is scope for reducing schedule duration in a project if it has repeated activities. This had been addressed using qualitative approach [18]. The relation between discontinuous execution of repeated activities and the drop in productivity had also been researched [19]. Our method relies on such presence of repeated activities.

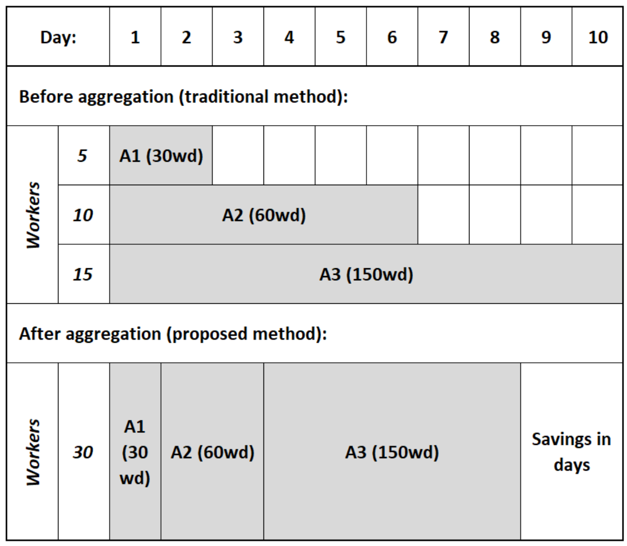
3. Methodology

The method proposed to reduce schedule duration, fundamentally involves re-allocation among activities, satisfying the following requirements:

- The activities should occur simultaneously.
- The activities should be of same nature, for example, either concreting or piling and so on.
- They should not have same duration compared with each other. More the variance in duration of activities, better they would be suitable for aggregation.

Application of the proposed method for a large scale project involving hundreds of activities is described later. Here, the methodology will be explained using a simple case first, as shown in the Figure. 1. The top-most row indicates time scale in days. Two cases are presented namely, 'before aggregation' and 'after aggregation'. The 'before' case involves a traditional scheduling method with no aggregation of any kind. The 'after' case is what is proposed in this study. Each case involves three activities A1, A2 and A3, consuming 5, 10 and 15 workers respectively. Corresponding durations of activities are 2, 6 and 10 days. The worker-day for each activity is presented inside the gray boxes extending along the time scale. The total worker-day amounts to 240 (30+60+150), in both cases.

All the workers in the first case are assigned to one single activity at a time in the second case. This will cause A2 to follow A1, and A3 to follow A2, thereby, reducing the total duration of schedule. Here, the savings in days amount to 2 days (9th and 10th days in the time scale).



A1, A2 and A3 are activities. The unit "wd" represents worker-days.

Figure 1. Basic concept of aggregation - a simple sample case

3.1. Model Formulation

The formula used to derive the savings in schedule duration is given below:

$$D_s = max(d_{i,A}) - (\sum(w_i d_i)_A / \sum w_{i,A}) \quad (1)$$

Where,
D_s = savings in days,
d_i = duration of i^{th} activity in days,
w_i = number of workers allocated for i^{th} activity.

Notation A in the equation corresponds to the traditional method. Applying this equation for the case depicted in Figure. 1, D_s will be 2 days, as shown below.

$$D_s = 10 - ((30+60+150) / (5+10+15))$$

Therefore,
D_s = 2 days,

(as seen in Figure. 1, 9th and 10th days)

Note that the above equation does not affect total worker-days assigned. Everybody in the workforce (allocated for individual activities in the traditional case) is involved in one activity at any time, under the proposed method of scheduling. In the case demonstrated above, it is assumed that activities A1, A2 and A3 start simultaneously (in traditional schedule).

In a large-scale project with hundreds of activities, it is important to identify the activities for which the proposed method can be applied. This requires understanding of some qualitative aspects, described in the following section.

3.2. Aggregation Principles

In a typical project scheduling environment using packages like Microsoft Project, it is necessary to form summary tasks and management units as applicable. Such grouping is explained using a basic example as shown in Figure. 2.

A traditional non-aggregated scheduling process will essentially have so called "basic tasks" and "summary tasks" only. In the aggregation process proposed, a higher grouping named "management unit" is required apart from the basic and summary tasks, as shown in Figure. 2. A management unit is a set of inter-related basic tasks while a summary task is a set of tasks within those basic tasks. The sequence of execution comprises of several management units. In Figure. 2, a summary task in management unit-2 is shown to include three basic tasks; all related to one common objective, which is, the pile cap. Each management unit deals with a unique set of basic tasks as well as summary tasks.

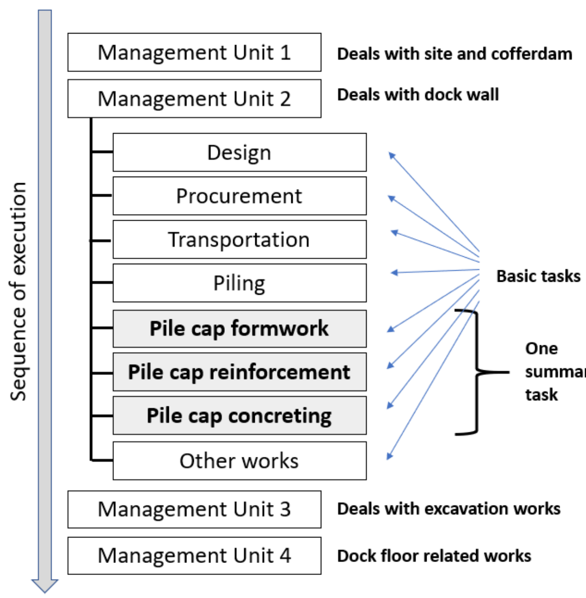


Figure 2. Management units and summary tasks

Once basic activities are grouped under different management units, the sequence of management units cannot be changed. Any change is allowed only within a management unit. This is the basic difference between a traditional sequencing method and the proposed sequencing method. Some advantages are discussed next.

Aggregating a sequence without considering management unit-level segregation will only cause disruption in precedence relationship and hence, a lower effect on schedule duration. Consider a case where there are two major activities namely, wall construction and floor construction. Assume that both activities have a sub-activity named pile cap construction. In traditional sequencing method, pile cap construction activity from both wall and floor construction works may be regarded as suitable candidates for grouping and hence, executing at one shot. However, this is impossible if say, wall construction needs to be completed before floor construction. If wall construction is included in a management unit that precedes another management unit that includes floor construction, there is no possibility of grouping. Because, management units are designed to accommodate sub-activities that are not supposed to be grouped across them.

Allowing a considerable amount of overlapping of activities where applicable, is in practice and is beneficial in reducing schedule duration [14, 15]. However, once management units are defined, there is no need for overlapping; because, management units are separated by discrete precedence relationships only. There is an advantage of reducing delays here, as resources meant for several activities spread over spatially and temporally are allocated to specific individual management units. This can be explained using Figure. 3 where five activities (A, B, C, D and E) are shown.

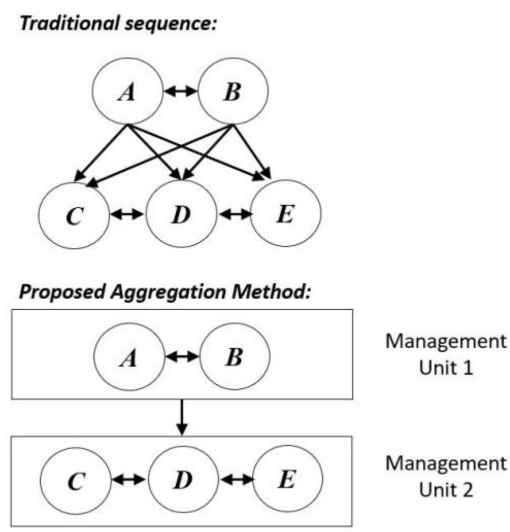


Figure 3. Simplification of precedence relationships

Traditional sequence shows precedence and succession relationships between all the five activities (in Figure. 3). Note that activities C, D and E need the completion of activities A and B. When these activities are aggregated as per the proposed method, and if it results in say two management units, there is only one dependence for management unit 2 (which covers the activities C, D and E).

When this methodology is applied to a construction project with hundreds of activities, there will be a significant reduction in precedence and succession requirements, thereby reducing the complexity involved. Results are in accordance with the expectation, as presented in the following section.

4. Results and Analysis

Method proposed was applied to a large scale scheduling process for a dry dock construction involving around 150 activities spread over 1300 days with an overall cost of around 220 million USD.

The equation (1) was used to determine the reduction in schedule duration. This was done after aggregating suitable activities as explained earlier. Before describing the results obtained, a note on criteria for selection of activities is briefly explained.

4.1. Frequency of Activities and Variation in Durations

In the dry dock case considered, activities had a frequency range of occurrence from 1 to 6. Higher the frequency, better the chance of higher savings after aggregation. However, if repeated activities have no variation in their durations, no savings will occur whether they are done parallelly or serially. Therefore, both the frequency of activity and the variation in duration are required to be considered in choosing candidate activities for aggregation. This is further explained using Figure. 4.

Activities of different types are in the horizontal axis (M4T1, M2T1, and others, in Figure. 4). There are two vertical axes; frequency of an activity on the left side and standard deviation in activity's duration on the right side. Bars represent frequency and line represents standard deviation, across activities. No sorting is applied for any variable here.

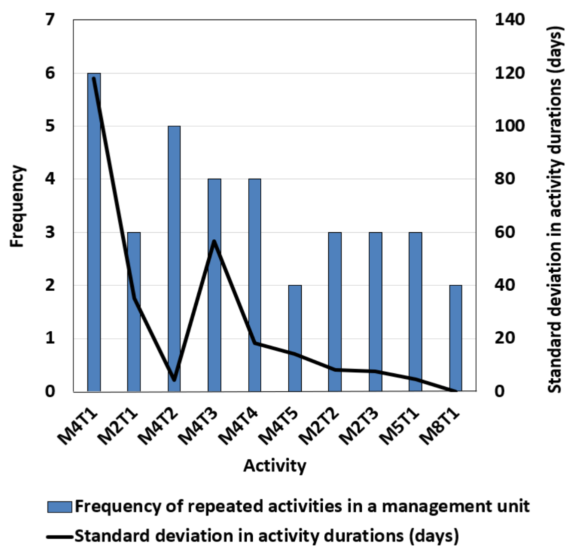


Figure 4. Effect of activity frequency and duration variation

A term 'M4T1' in the horizontal axis represents task type 1 under management unit 4. In the dry dock application case, it stands for bearing pile installation activity. This has a frequency of 6 and a standard deviation of around 120 days in duration (with minimum and maximum durations of 5 and 300 days respectively, showing a high variance). Another term 'M4T2' shows a relatively high frequency and low standard deviation. In the dry dock construction, it corresponds to transportation and mobilization activity. Though it occurs many times (high frequency), its duration seems not to vary much every time. While aggregating, this activity will be ignored or given lower priority because, aggregation will not yield in any significant reduction in duration.

The chart shows only ten activities while the exercise had around 150 activities before aggregation. If there is a limitation in the number of activities to be considered for aggregation, arising out of cost or management constraints, ranking of all the activities based on a weighted value of frequency and variation quantities is recommended. In the present case study, all the activities that had a recurrence (with frequency more than one) were considered irrespective of the variance.

4.2. Analysis of Project Duration Savings

After careful consideration of simultaneously occurring activities, their nature and type, frequency of occurrence and duration of individual activities, equation (1) was applied for the entire project schedule. The results are presented in Figure. 5. Two scheduling cases were considered: labor comfort and cost comfort. This is to make sure our method works in both standard types of scheduling.

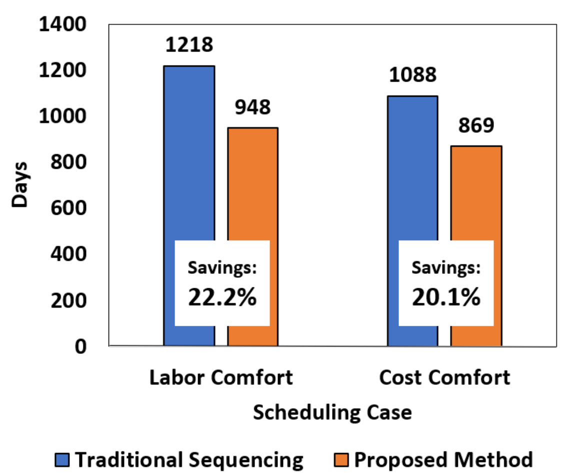


Figure 5. Savings in schedule duration

Number of days calculated in traditional sequencing is compared with results from the proposed method. Under the labor comfort case, the schedule duration reduces from 1218 days to 948 days (a savings of 270 days, which is, 22.2%). Under the cost comfort case, the schedule duration reduces from 1088 days to 869 days (a savings of 219 days, which is, 20.1%).

Note that for traditional sequencing, number of days required for cost comfort case (1088 days) is smaller than that of labor comfort case (1218 days). This is because, it is possible to allocate labor resources in a crunched manner under cost comfort scenario. This leads to simplified precedence relationships and hence, leads to a smaller schedule duration. This particular change in duration should not be considered as a savings because it involves hidden costs of management issues. The real savings is what we can achieve using the proposed method (showed earlier).

Percentage savings achieved under cost comfort case is slightly lower than that of labor comfort case. A possible reason is that, it has reduced number of simultaneous activities and a lower variance in durations of repeated activities. This could have reduced the potential of sufficient aggregation among activities too.

4.3. A Note on Quality of Schedule used for Aggregation

It is known that critical path method (CPM) has its own disadvantages and might lead to an imperfect schedule [16]. For instance, while using CPM, excessive lag durations that accompany some activities might lead to an inefficient schedule. Furthermore, a CPM schedule which is primarily resource-oriented could also readily cause some inefficiency (as we focus on reducing the time than resources required in our method). Therefore, care should be taken to ensure the quality of the schedule for which the method is to be applied.

There can be situations where cumulative reduction of schedule duration related exclusively to aggregated activities may be higher than the reduction in project schedule duration. Because, only those activities present in the critical path can affect the project duration. Within the days saved, a comparison between the savings and cumulative reduction in aggregated activities can be shown as in Figure. 6.

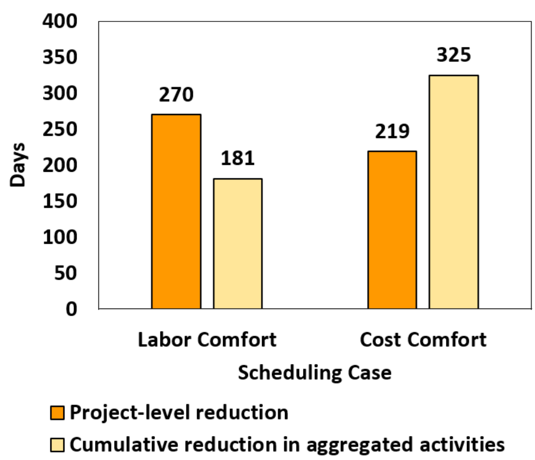


Figure 6. Effect of the quality of schedule used

Project duration savings can be lower or higher than the cumulative savings of individual activities as seen in the Figure. 6. For the labor comfort case, such cumulative value is lower than the value determined by proposed method as seen in the diagram, with 181 and 270 days respectively. However, for the cost comfort scenario, the cumulative savings is higher than the project duration savings. This is not an anomaly. This is expected because, effect of aggregated activities that fall outside the critical path will be nullified automatically.

The effect of a long management unit nullifying the effects of simultaneous smaller management units is shown in Figure. 7, a snapshot from Microsoft Project scheduling work. Note that the management units 5, 6 and 8 in the Figure. 7 are smaller than management units 2 and 4. Any reduction achieved in 5, 6 and 8 will not get reflected in the reduction of project duration.

In Figure. 6, if the cumulative value is lower than the project duration savings estimated, it only reflects that there is further scope of improvement in the original traditional method used for scheduling. In the case of cost comfort, sum of individual savings (325 days) is higher than 219 days derived as project duration savings before. This is acceptable as there is lesser scope of improving the cost comfort schedule, compared to labor comfort schedule. This also leads to another observation that the efficacy of forming management units depends upon the quality of schedule used. The complexity involved in optimizing a schedule using traditional non-aggregating method and its effect are to be further investigated in the future.

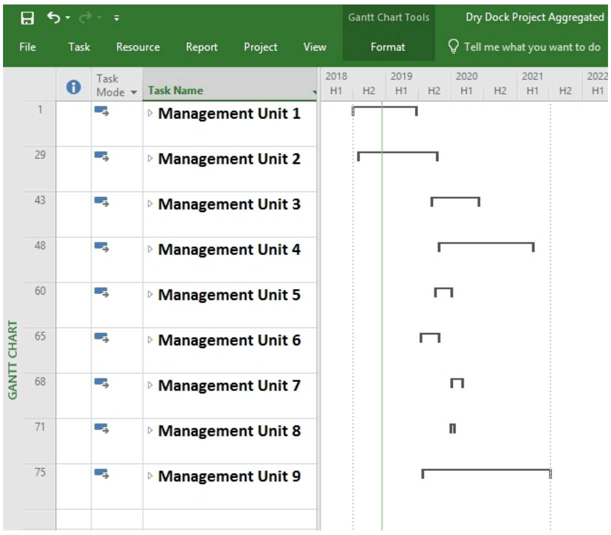


Figure 7. Effect of longer management units

5. Conclusions

A method to reduce the duration of schedule was presented. The model proposed was applied for a large-scale high-cost dry dock construction project. The method involves aggregation of activities that are repetitive and occur simultaneously. Two different approaches to scheduling were considered for evaluation, namely, labor comfort and cost comfort. This was to ensure that the influence of these approaches on the hierarchy of execution of activities has been taken into account explicitly.

There was a reduction of 22.2% and 20.1% in project schedule durations for labor comfort and cost comfort scenarios respectively. There is an added advantage of this method. In both such scenarios, there is a notable reduction in number of activity sequences. Such reduction can result in schedules that are less prone to errors.

Aggregation of activities can also eliminate the issues rising from discontinuous execution of repetitive works. Though the data used was from a typical dry dock construction project, the method can be applied to any large-scale project environments. However, applicability of the method in small scale projects is yet to be explored. Furthermore, our study is based on the assumption that the project involves simultaneous and repetitive activities, a strong management and monitoring practice and the presence of continued availability of equipment. Effect of variations in these variables needs to be investigated and hence recommended for future research.

It is also possible to apply the methodology demonstrated here, to reduce the cost of the project, keeping the time constant (which could be a separate future exercise).

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