Real-time Schedule Control

Shabtai Isaac[a]

[a]Department of Structural Engineering, Ben Gurion University of the Negev, Israel
E-mail: isaacsh@bgu.ac.il

Abstract –

Numerous previous studies have dealt with the use of automated technologies for on-site, real-time data collection to support construction project control. Most of these studies are based on the assumption, that the collected data can be compared with planning data to identify deviations and implement control actions. However, construction scheduling often focuses on pre-construction forecasting and logistics processes that are carried out by middle management. In contrast, the execution proper is governed by informal short-term scheduling, performed ad-hoc by site management. This reality creates discrepancies between the data provided by automated monitoring technologies and the information that can be obtained from project schedules, in terms of their granularity, scope and underlying assumptions. The aim of this paper is to review existing scheduling methods, and compare their outputs with the data provided by automated monitoring technologies. Ways are proposed in which scheduling methods can be enriched in order to better support monitoring and control processes.

Keywords –

Scheduling; Monitoring; Control; Real-time Data Collection

1 Introduction

These instructions will enable you to prepare your manuscript in an electronic format, ready for submission and peer review. It is therefore essential that these instructions be carefully followed. It is not widely known that Gantt charts, which are currently primarily used in construction projects for displaying schedules, were originally developed as monitoring tools – designed for supervisors to quickly know where production stood relative to the plan, and identify causes for reduced productivity. Regarding schedules, Gantt in fact warned: "Many shops have a very nice schedule system; they plan their work beautifully—at least, it looks very pretty on paper; but they have no means of finding out whether those schedules are lived up to or not. Usually they are not" [1]. This will not come as a surprise to practitioners involved in the management of construction projects, which typically suffer from significant deviations from their planned schedules [2, 3, 4]. However, Gantt's warning does not seem to have had much of an impact on those who use the chart that he developed for pre-project scheduling, given the prevalent gap between the scheduling that has been carried out offsite and the actual on-site execution management.

In many construction projects schedule control processes are implemented to identify the delays that occur, and reduce their impact on the project. Schedule control processes usually involve the following four steps:

1. A comparison of the actual performance on the construction site with the planned schedule
2. An identification of any differences between the actual and planned performance
3. An identification of those deviations that are likely to affect the date at which the project will be completed
4. The execution of controlling actions for the deviations identified in step 3.

However, such control processes, and the consequent updating of the project schedule, are often carried out manually, and thus infrequently and at a significant delay from when deviations actually occur. Consequently, many studies have focused on the use of automated tracking technologies to provide project management with detailed data on the actual progress in a project in real time, including the locations and production rates of different activities. Various technologies can be used for such a purpose, including global positioning system (GPS), radio frequency identification (RFID), 3D cameras and laser scanners [e.g. 5, 6, 7, 8]. Models have also been developed to convert automatically collected data into information regarding the project performance, which could then be compared with the project plan for the identification of deviations [9].

However, questions remain on how exactly automatically collected data should be compared with data from the schedule, in order to allow project management to implement control actions such as correcting and replanning the schedule. In particular, it is unclear how the real-time monitoring data can be synchronized with planning data in terms of the granularity of the data, and the frequency at which it is provided. While the monitoring data can be collected in real-time, the scheduling data is, at best, accurate at a daily level. In practice, there is often a significant gap between the formal schedules prepared for construction projects prior to their execution, and the informal short-term planning performed by site management, which is often not well documented [10, 11].

The differences between formal schedules in construction projects, the informal methods used for onsite execution planning, and the detailed data that can be provided by automated data collection technologies, raise the question how scheduling practices should be adjusted to allow project management to fully utilize the real-time monitoring data for schedule control. This paper discusses how the current scheduling methods can be changed to support effective, real-time schedule control.

2 Existing Methods for Schedule Monitoring and Control

Many practitioners currently rely for the monitoring and updating of the schedule on the same methods that they use to define the schedule. Most use the Critical Path Method (CPM) for this purpose. However, traditional CPM network analysis has a number of limitations, which have been dealt with in numerous previous studies. These limitations include the inability to model continuous and simultaneous work flows of teams on the construction site, which need to be taken into account in case of overlapping, interdependent activities [12, 13]. Location-based scheduling methods have been developed to take into account the location of work on the site to avoid conflicts between overlapping activities [14]. However, these methods are limited to a novel visual representation of the activities, and are all defined using the same precedence diagram that is used in CPM,

Another important limitation of CPM and other traditional project scheduling methods is the assumption of unlimited resource availability, and the unexpected delays that often occur in projects due to insufficient resources [15]. A large number of methods have consequently been proposed to solve the resource-constrained construction scheduling problem. But despite these shortcomings of CPM and other traditional scheduling methods, few studies have addressed the basic precedence diagram that is used in all these methods. By using the same constructs and relationships as the existing activity network model, the effectiveness of alternative solutions that have been proposed so far has therefore been limited.

While most practitioners use for schedule control the same methods that they use for planning the schedule, some methods have been developed especially for this purpose. Earned Value Management (EVM) has been put forward as an alternative to the frequent updating of project schedules. EVM supports project control by forecasting the final project cost. The use of EVM to predict the final project duration has been found to be less reliable, since the EVM schedule indicators fail when projects continue execution past the planned end date [16]. Consequently, an extension to EVM, called earned schedule (ES), has been developed which uses time-based indicators for schedule performance. However, the reliability of ES has been criticized as well, since it fails to differentiate between critical and non-critical activities [17].

In the context of this study, both EVM and ES can be regarded as high-level approaches, based on a set of macro level indicators, which facilitate a simpler control process than detailed network analysis [18]. However, such an approach contradicts the need for a detailed schedule analysis when real-time data is used for schedule control, which addresses individual activities and continuously updates the status of the current critical path,. Similar to CPM and other planning methods, EVM and ES are thus not sufficient for real-time tracking and control of construction activities.

3 Proposed Approach

This paper discusses possible extensions to the existing precedence diagram used for project scheduling, to provide improved support for real-time schedule control. The precedence diagram used to produce construction schedules represents the relationships between the activities in the project network model. It is proposed that schedule control could be supported by adding new control points and milestones to the precedence diagram.

3.1 Control Points

Currently, only the start and finish points of an activity are represented in precedence diagrams. Accordingly, only four types of relationships between activities can be defined: finish-to-start (FS), start-to-start (SS), finish-to-finish (FF), and start-to-finish (SF) relationships [19]. These types are often insufficient for monitoring activities in real-time. Additional types of constructs and relationships are required for real-time control, given the granularity of the monitoring data and the frequency at which it is provided.

A solution for this can be to add internal control points to the definition of activities in schedules, in addition to their endpoints. For many activities in construction projects specific points in time can be defined as control points during the execution of an activity, so that an alert is provided when the activity reaches such a point. Those activities can be divided into discrete sections, such as apartments or floors. Naturally, the sections into which an activity is divided can differ in size when these sections represent different work-zones, and the size of these zones accurately represented in the schedule.

The mid-activity control points are differentiated from the start and finish of activities. Such control points can enable carefully tracking the status of activities, and the identification of deviations that occur as the activity is being executed. Currently, solutions for identifying deviations from such midpoints when they occur, and adjusting the execution of other planned activities accordingly, are mostly informal. Once the internal control points of two activities that are interdependent and overlapping have been defined, temporal relationships can be defined between those points in order to identify the implications of a deviation at a specific control point (Figure 1) [20]. For example, a time buffer that needs to be maintained between repetitive activities could be defined, and any change in the status of this buffer due to variations in the production rates of the activities identified in real-time.

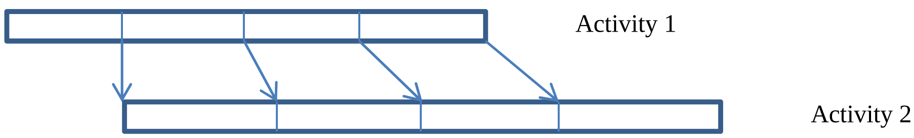

Figure 1: Temporal relationships between internal control points of activities

Internal control points can also be used for the management of limited resources, and when the allocation of those resources needs to be changed during the execution of an activity. Often, simultaneous activities in projects need to share limited resources such as equipment and manpower, and the project management reallocates those resources among the activities at certain points in their execution (Figure 2). Currently, there is no formal way to incorporate such requirements in schedules, to ensure that delays are taken into account when they occur. Internal control points can be used for this purpose as well.

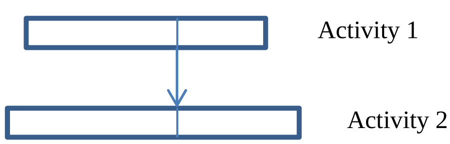

Figure 2: Reallocation of resources at control points

3.2 Milestones for Non-critical Activities

To control project execution, milestones can be defined as additional control points to provide an alert when a delay in a non-critical activity exceeds the free float (Figure 3). Float is currently considered to be a by-product of the CPM computation, and is often ignored in the daily planning and control of projects. In fact, it is not directly represented in most Gantt charts, and consumption of the float usually becomes evident only after the occurrence of delays in non-critical activities that exceeded the float. As a result, the critical path frequently changes in a ways that are not anticipated.

The status of milestones can automatically monitored, and used to help the project manager prevent delays from exceeding the free float and activities becoming critical. The milestones allow the project manager to identify potentially critical paths, and track the available float on them at any moment in the project. While the use of such control points does not directly resolve the question of who owns the float, it does increase the control the project manager has over its allocation and use. In those cases in which the project manager deems the slack between two activities to be insufficient in light of the uncertainties and risks involved in those activities, the float can be increased and the milestones adjusted accordingly, while ensuring that these don't violate technical or safety requirements that are reflected in maximum relationships.

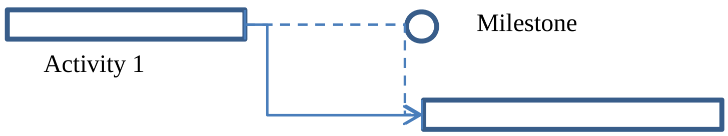

Figure 3: Milestone for non-critical activity (Activity 1)

3.3 Control Actions

Control actions are carried out in order to track and compare the actual progress with the planned progress using the predefined control points. When possible, the control actions make use of project buffers to absorb the impact of deviations from the schedule. Buffers are a gap between the (required) minimal and (actual) defined attributes of an activity. To this end, resources such as time, equipment and manpower are often allocated in the project plan beyond the minimum required for the planned activities. This is done to protect the activity from variability in other activities which produce or use the same resource, and upon which the first activity is therefore dependent. Several types of buffers are used in project plans [21]:

a. Inventory buffers consist of stocks of materials and finished components, and of plan buffers – backlogs of work for crews that are used to ensure reliable workflows [12].
b. Contingencies consist of time buffers (extra time allotted for activities) and reserve funds in the budget.
c. Capacity buffers consist of excess space, manpower and equipment capacities allocated for activities.

In order to carry out a quantitative assessment of the possible magnitude of the impact of a deviation that has been detected, and the consequent controlling action required to cope with this deviation, the status of buffers in the project has to be monitored, and the fraction of the deviation that can or should be absorbed by these buffers has to be assessed. Since the size of buffers that can be used to absorb the impact of changes may vary during a project, depending on external factors, it has to be continuously monitored in real time. In some cases, additional information has to be manually collected for this purpose, since project team members may have tacit knowledge regarding the actual buffers, when these are not explicitly known. For example, a sub-contractor can probably assess how much additional work he can carry out in the project.

4 Discussion and Further Research

To summarize, it is proposed that current scheduling methods can be changed to support effective, real-time schedule control, using automatically collected monitoring data, in the following way:

1. Additional control points are added to the project activity network. These include internal mid-activity points, and milestones for non-critical activities. New relationships are defined between those points to detect the implications of a deviation in one activity for other related activities in the project.
2. Deviations are automatically detected, in real time, at the control points that have been defined. This ensures that monitoring is carried out at any point that is important for project management, and not just at the end-points of activities.
3. The current status of buffers in the project is tracked, in order to detect the remaining slack, and consequently the control actions that can be taken.
4. Appropriate control actions are initiated to make use of available buffers in order to absorb the impact of deviations that have occurred and adjust the schedule. This will prevent a deviation from the project goals, in terms of the date of delivery and overall cost.

Further research is currently being conducted in order to develop new mathematical definitions that will allow the addition of the proposed control points to the precedence diagram, and to develop algorithms for updating the schedule in accordance with the data that is automatically collected.

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