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Incorporating rework into construction schedule analysis

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ABSTRACT

Rework has been a primary cause of cost and schedule overruns in large construction projects. While several research efforts have analyzed the causes and effects of rework and provided guidelines to reduce rework, almost no research exists to analyze the impact of rework timing and quantity on schedule delays and to support decisions on cost effective recovery. This research presents a quantitative mechanism for schedule analysis considering rework. The mechanism has three aspects: (1) a new schedule representation of rework magnitude as negative percentage complete for affected activities, documented on the specific date on which the rework is detected; (2) a modified daily-windows delay analysis to apportion project delays among the responsible parties; and (3) an optimization technique for determining the least costly corrective action strategy that recovers project delays. The proposed approach is applied to a case study to demonstrate its ability to consider rework impact, in combination with other progress events by other project parties. This research offers an innovative quantitative approach to consider rework timing and amount in delay analysis and corrective action optimization.

1. Introduction

Rework is a serious problem facing large and complex construction projects, particularly industrial projects that involve multiple parties such as contractors, suppliers, and trades. In such a complex environment where many activities by many parties take place simultaneously, often errors, omissions, and misunderstandings cause undesirable outcomes that have to be reworked. Rework, thus, has been defined as the effort of re-doing a process or activity that was incorrectly implemented the first time [22]. In literature, the term "rework" has been related to other terms such as "quality deviations" [5], "non-conformance" [1,3], "defects" [17], and "quality failures" [4]. Since rework can occur at different stages in the project life cycle, the term "field rework" has been clarified not to incorporate change orders or off-site fabrication errors [8].

Various researchers have studied rework from different perspectives such as rework cycle, root causes, and impact on project performance [19]. [7] introduced the concept of the rework cycle in projects, where the rework itself is not done properly, thus requiring further rework in a recursive cycle that can extend project duration far beyond what is originally conceived. This concept becomes important to the understanding of the interactions among various project factors including rework, which can be studied using system dynamics tools [24]. With respect to root causes, several studies and surveys were conducted to identify and classify the root causes of rework such as [21]; [25]; [6]; [28]; [5]; [23]; [8]; [20]; [26] and [16]. Almost all studies reported that rework plays a major role in cost and schedule overruns. They identified the main root causes of rework as: errors, omissions, failures, damages, poor leadership, poor communication, and ineffective decision-making. The survey of [21], for example, reported the direct and indirect costs of rework observed in various contract types and identified rework causes related to the design team, client, site management, and subcontractors. Among the various project types, industrial projects have been reported by [16] to exercise the most cost increase due to rework.

With respect to the impact of rework on project performance, various researchers reported observations from case studies, surveys, and interviews among professionals. A summary of the rework cost reported in various studies is shown in Fig. 1. With most studies analyzing rework-related cost performance, [16] recommended conducting further studies on rework impact on schedule performance. The direct costs of rework, however, have been reported to be in excess of 15% of the contract value [4,19]. Using a survey of 115 civil infrastructure projects, it was revealed that the following five significant predictors accounted for 25% of the variance in total rework cost: (1) ineffective use of information technologies; (2) excessive client involvement in the project; (3) lack of clearly defined working procedures; (4) changes made at the request of the client; and (5) insufficient changes initiated by the

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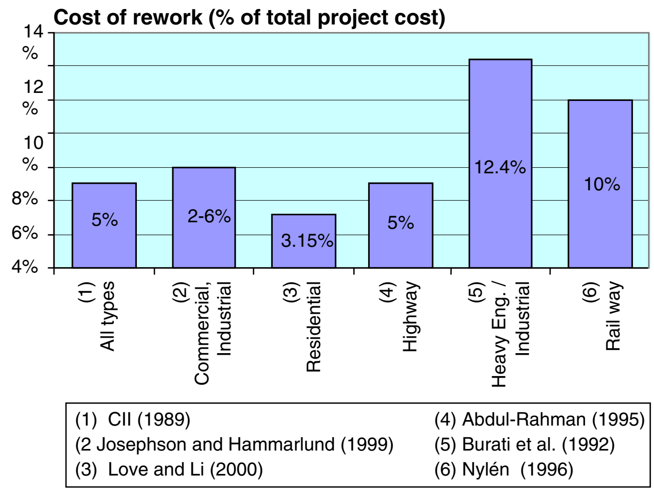

Fig. 1. Cost impacts of rework reported in various studies.

contractor to improve quality [19]. Since many rework causes emanate from the design phase, effective design management has been reported as a key to reducing rework [21]. Research undertaken by [29] who examined 161 projects revealed that 'design changes' accounted for 50% of rework costs incurred in projects.

Based on the above discussion, rework clearly has a huge impact on the ability of construction projects to meet their time and cost constraints. While the various studies in the literature help in recognizing the impact of rework and its root causes, no approach has been proposed to incorporate rework within current scheduling and project control tools. The primary objective of this research is to propose a quantitative mechanism for incorporating rework into existing scheduling tools to clearly represent the evolution of progress events directly on the schedule, calculate a revised project duration, consider rework in project delay analysis, and help in devising cost-effective corrective actions. The research first discusses various ways that rework can affect activities and several strategies to accelerate the project to recover schedule delays. Afterwards, the paper introduces a proposed approach for rework representation, schedule analysis, and corrective action optimization. A case study is then used to demonstrate the proposed approach and, its advantages, and future improvements.

2. Rework Impact on the Schedule

Depending on the construction schedule, there are several situations by which a rework event can impact the project activities, completion, and resource use. Four specific cases, from a simple to a more involved case, are defined as follows:

a) Rework on a single activity, without resource constraints: In this case, if the affected activity is non-critical, the activity float can absorb the additional time needed to do the rework (if such additional time is within the activity total float). On the other hand, if the affected activity is critical, the amount of time it takes to do the rework constitutes a project delay (if no acceleration is done for the remaining part of the activity).
b) Rework on a single activity, with resource constraints: a more practical case for rework impact on a schedule is when the project has limited resources. In this case, even if the activity is non-critical, the amount of time to do the rework will extend the activity duration, thus may cause a resource over allocation that, when resolved, may also lead to project delay.
c) General rework case: in this general case, a rework situation affects multiple activities. For example, when a concrete column needs to be redone because of misalignment, rework becomes necessary in other related activities such as formwork, steel, and concrete. In this general case also, the schedule may have some activities experiencing various events such as contractor slow progress, acceleration, or weather problems. Therefore, rework becomes a documented progress event that combines with all others to impact the project time, cost, and resource use.

Based on this discussion, for a contractor to quantitatively analyse the impact of rework on the project schedule, the following three steps are necessary:

1. Record all progress events, including rework, and calculate the expected project delay;
2. Accurately analyze the project delay to identify the number of days attributed to each party's actions (contractor, owner, or neither); then
3. Analyze various acceleration options to determine the least costly action to recover the contractor's own delay.

In terms of progress recording, this research extends the earlier research of [14] that represents the progress evolution of the project on a daily basis (calculated from the start and finish dates) for each activity (Fig. 2). The activities are thus represented not as long bars (as in commercial software) but as a group of adjacent cells, each is one day, making up the duration of the activity. This bar chart representation, thus, records not only the daily progress, but also the party responsible for any daily event such as work stops and their reasons / documents, etc. As shown in Fig. 2, if an activity is stopped for owner-related reasons (e.g., late approval of drawings), an "O" is shown on that day. In the same manner, if the delay is contractor-related (e.g., using slow resources), a "C" is shown. In the case of events that are not attributable to the owner or contractor (e.g., weather), an "N" is shown. If an event occurs due to concurrent actions of several parties, then a combination of these three letters is shown (e.g., "O + N" or "O + C"), with the reasons recorded as comments in the related cells. This representation can therefore be extended to record rework events and facilitate its related calculations.

It is important to note that this research assumes that all data related to resources, costs, delays, rework, and responsible parties can be collected and recorded. While data collection is not part of the paper's scope, the data can be obtained (to a good level of detail) from site reports, which can be daily, weekly, or monthly. With the absence of a detailed procedure for analyzing the impact of this data on the schedule and on corrective actions, the paper's focus is on developing an analysis procedure that can produce as accurate results as the level of information available.

As mentioned earlier, delay analysis is an important step in determining the amount of time that needs to be shortened from

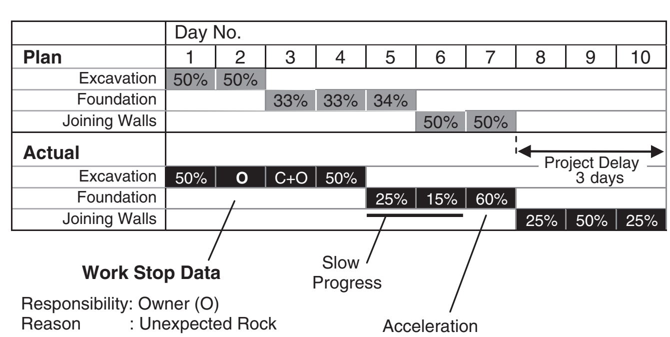

Fig. 2. Progress recording.