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Overlapping design and construction activities and an optimization approach to minimize rework

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Abstract

Construction industry often faces challenge to complete project in minimum possible time. Overlapping design and construction activities with early information from the precedent activities shortens project completion with the expense of rework in downstream design and construction activities. However, the expected amount of rework must be properly quantified to decide on the overlapping strategy. This study presents an integrated framework to overlap design and construction activities using the concepts of upstream evaluation and downstream sensitivity characteristics and develops a simulation model in order to ascertain project performance in terms of total project duration and expected amount of rework. The results indicate that reduction in project duration and expected rework amount vary based on the accuracy of upstream early information and sensitivity of downstream activities. Moreover, unplanned overlapping may not necessarily reduce project duration but may result in excessive design and construction rework which can be very costly. This study also describes a decision-making framework to optimize project schedule with minimal rework. The search for an optimal overlapping strategy is carried out using an Overlapping Strategy Matrix (OSM) with the genetic algorithm (GA) to eliminate unnecessary rework. The proposed optimization method minimizes the expected amount of rework while maintaining the project completion contract date and provides an effective means to decide on the overlapping strategy.

Keywords: Concurrent execution; Design and construction activities; Rework; Project completion; Optimal overlapping strategy; Genetic algorithm

1. Introduction

Reduction in project completion time is an important aspect in today's construction industry. In practice, for most construction projects, design is followed by construction and each of the phases is done by its own team members. This sequential execution lengthens overall project completion time (Blacud et al., 2009) and this approach also suffers problems of buildability and constructability (Alarcón and Mardones, 1998; Lam et al., 2006) as well. Buildability and constructability issues have been addressed in many researches (e.g. Anumba and Evbuomwan, 1996; Faniran et al., 2001; Lam et al., 2006). During the construction phase, difficulties arise due to inconsistencies among drawings and specifications, lack of coordination among specialists, designer with little construction knowledge and non-technical specifications. Various methods have been adopted in order to integrate design and construction such as inviting construction expertise early at the design stage; judging a design based on the buildability score; providing guidelines to implement the concept of constructability and so on (Lam et al., 2006; Song et al., 2009).

On the other hand, in order to reduce overall project completion time, first concurrent engineering was introduced to shorten design project (Krishnan et al. 1997; Smith, 1997; Zheng and Hong-Sen, 2005) and then fast-track method was initiated where some amount of overlap occurs between pairs of design and construction activities (Blacud et al., 2009; Gill et al., 2005; Khoueiry et al., 2013). This overlapping is particularly important for large scale design–build projects. By overlapping, construction begins before design is finalized. However, final design may differ from early design parameters that have been utilized, and thus may cause rework in downstream construction activity. Construction rework is very costly and may adversely impact overall project completion time. As presented in Hwang et al. (2009), rework

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contributes 5% cost overrun of the total construction costs and design error is the source of highest rework cost. Han et al. (2013) also stated similar findings that design error cause up to 79% of rework cost.

Peña-mora and Li (2001) proposed a framework to overlap two sequential activities to minimize the risk of rework in downstream activity using the concept of upstream evolution rate and downstream sensitivity to change in upstream parameter. Blacud et al. (2009) also described a framework of characterizing the sensitivity of downstream construction activities to minimize the risk of construction rework. However, these studies considered only single dependency between one upstream design activity and one downstream construction activity. With multiple dependencies this can be more complicated and the impact of rework on overall project completion is an important consideration in project planning.

Furthermore, in coordinating design and construction, as-built measurement of construction work that serves as feedback input to design is an important consideration (Chua and Song, 2005). Redesign may be necessary in some instances if as-built measurement is overlooked. As argued by Chua and Song, parameters go through evolutionary states from preliminary or conceptual and eventually approved for construction. Construction is the stage of parameter realization and the realized value may be different from what has been designed. If the deviation is out of the allowable tolerance limit, it may adversely affect subsequent design parameters and downstream construction works. However, their study did not explicitly model the subsequent impacts on downstream activities and overall project completion.

This study proposes a framework to overlap design and construction activities incorporating early information sharing in design. Multiple dependencies between activities have been considered while accounting the possibility of rework in downstream activities. Following the framework, a simulation model is developed to quantify the impact on rework for design and construction activities and overall impact on project completion. The study also proposes a framework to search for an optimal strategy of overlapping to minimize the expected amount of rework. The effectiveness of the proposed model has been investigated with an illustrative case example.

2. Overlapping sequential activities

Overlapping design activities is common in engineering project to shorten design completion time. Krishnan et al. (1997) described a detail framework for overlapping strategy for a pair of dependent design activities in product development using the concept of upstream evolution and downstream sensitivity. The term evolution refers to the refinement rate of an upstream generated design parameter from its preliminary form to a final value. With a faster evolution rate more accurate design parameter can be released early so that downstream activity can start early with a low risk of rework. On the other hand, sensitivity is measured by the additional time that is required for rework due to a change in an upstream activity. The lower is the sensitivity to changes in upstream parameter; the less risky it is to begin a downstream activity early and vice versa. Hence, the best overlapping occurs between a fast evolving upstream activity and a low sensitivity downstream activity. Peña-mora and Li (2001) proposed a framework of overlapping where two sequential activities can be overlapped with minimum risk of rework in downstream activity. The overlapping amount was characterized by dividing activities into various intervals in terms of upstream activity's evolution rate and the sensitivity of downstream activity. Bogus et al. (2006) described overlapping strategies with an aim to minimize redesign in downstream activities. Srour et al. (2013) also presented a scheduling model of overlapped design activities based on dependency information.

Nevertheless, design rework differs from construction rework when utilizing early information. Design rework usually involves revision to design calculation or a re-assessment of the design information. On the other hand, construction is a physical activity and it deals with construction materials. Hence construction rework will cause physical rework such as adding more concrete to a foundation or even replacing an existing foundation with a new one. This type of rework is costly and may require long time which in turn delays project completion.

The issue of overlapping construction activities was partially addressed in Blacud et al. (2009). In their study, they focused on the determinants (such as transformation process, lead time, modularity, and interaction of components) that contribute to the sensitivity of construction activities to upstream design changes. Construction activities can be categorized based on these determinants so that sensitivity of the construction activities can be determined to facilitate the overlapping of design and construction. However, the study did not consider the overall impact on project completion and loss of productivity.

The aforementioned studies considered only a single dependency between one upstream design activity and one downstream design/construction activity. Moreover, construction feedback to a design activity has not been properly addressed when design and construction activities are overlapped.

3. Overlapping design and construction activities

This section describes a systematic overlapping strategy to quantify the impact on project completion and loss in productivity considering multiple dependencies between design and construction activities. The overall impact on project completion and loss in productivity depend on the amount of rework that is required for each activity. In such, Blacud et al's (2009) sensitivity parameter is used to determine the amount of rework that may be needed for a construction activity when utilizing early design parameters from upstream design activity. For an activity with low sensitivity to design change, the expected amount of rework will be low and vice versa (see Fig. 1). The worst overlapping will occur between a design activity with slow evolution rate (i.e. there is a high probability that final design will differ from preliminary provided design parameter) and a highly sensitive construction activity. Since construction rework is expensive and may adversely affect project duration, such overlapping should be avoided.