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Optimization of overlapping activities in the design phase of construction projects

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ABSTRACT

A well-known practice to accelerate construction projects is to overlap the design phase activities. For a typical construction project, a number of overlapping strategies exist during the design phase which all can result in timesaving. However, the cost of these strategies varies significantly depending on the total rework and complexity they generate. A favorable overlapping strategy is one that generates the required timesaving at the minimum cost. To find such a strategy, the question "Which activities have to be overlapped and to what extent to reduce the project duration at the minimum cost?" should be answered. This research aimed at answering the question through generating an overlapping optimization algorithm. The algorithm works based on the principles of genetic algorithms (GAs). The algorithm explained in the paper is unique compared to previous algorithms and frameworks available in the literature, as it can optimize multi-path networks and can handle all types of activity dependencies (i.e. finish-to-start, start-to-start, and finish-to-finish). It also takes both critical and non-critical activities into account and follows the critical path if the critical path changes or new critical paths emerge. A computer tool was also developed to run, examine and validate the overlapping optimization algorithm. This paper introduces the algorithm and the computer tool in detail and explains the results of their validation through optimizing a real-world project schedule.

1. Introduction

An effective technique for earlier completion of projects is to overlap the project activities that normally would be performed in sequence. This process can result in rework and increased risk, which raise costs. In the design phase of a typical project, a huge number of overlapping strategies exist, which all can result in the same timesaving. However, the cost of these strategies varies significantly depending on the total amount of rework and complexity they generate. The best strategy is one generating the required timesaving at the minimum cost. To find this strategy, the question "which activities have to be overlapped and to what extent to reduce the project duration at the minimum cost?" should be answered. However, since the number of possible overlapping arrangements can be extremely high, manual methods are not helpful. In addition, available planning and scheduling tools (e.g. Primavera, MS Project) lack the capability to evaluate the cost of overlapping and identify the most favorable overlapping strategy. Therefore, developing a decision support tool capable of finding optimized overlapping strategies is a step toward a new generation of planning and scheduling tools. This paper introduces an overlapping optimization algorithm and its associated computer tool, which fulfill the above need.

The remainder of this paper is structured as follows: A detailed literature review is provided to position this research in the literature. Then the overlapping mechanism is briefly reviewed and the overlapping time–cost trade-off function central to solve the overlapping optimization problem is introduced. Next, the overlapping algorithm and its computerization—the major contribution of this paper—are explained in detail, to allow the work to be reproduced by other researchers. Finally, the results of experiments with the computer tool and the validation process are described.

2. Background

The available literature about overlapping can be categorized into two main areas: product development and project execution. Since the manufacturing industry began to utilize concurrent engineering long ago, the research for overlapping in product development is older and more extensive than that for project execution, particularly construction projects [1]. Several researchers such as Krishnan [2], Loch and Terwiesch [3], Nicoletti and Nicolo [4], Prasad [5] and Terwiesch et al. [6] have investigated the inherent nature of activity overlapping in product development. Roemer et al. [7,8] have tried to determine optimal overlapping policies. Some researchers such as Eppinger [9], Pena-Mora and Li [10], Bogus et al. [11–13] and Blacud et al. [14] have used the models and frameworks developed in product development research studies to develop similar models and frameworks for the construction industry.

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Table 1
Comparative review of the existing major literature.

Researchers	Type of industry		Type of activities		Type of study				Type of overlapping		
	Manufacturing	Construction	Between interdependent activities	Between dependent activities	Individual isolated overlapping	Group of overlaps			Design–design	Design–construction	Construction–construction
						A single chain of activities	Multi-predecessor overlaps	Cascade of overlaps			
Nicoletti and Nicolo (1998)	×		×		×				×		
Krishan et al. (1997)	×			×	×				×		
Eppinger (1997)	×			×	×				×		
Loch and Terwiesch (1998)	×			×	×				×		
Terwiesch et al. (2002)	×		×		×				×		
Pena-Mora and Li (2001)		×		×	×				×	×	×
Bogus et al. (2005)		×		×	×				×		
Blacud et al. (2009)		×		×	×					×	
Roemer et al. (2000, 2004)	×			×		×			×		
Gerk and Qassim (2008)		×		×		×					×
Berthaut et al. (2011a, 2011b)		×		×		×	×		×		
Cho and Hastak (2013)		×		×		×	×		×		
Dehghan and Ruwanpura (2014)		×		×		×	×	×	×		
This Paper		×		×		×	×	×	×		

Table 1, which is adapted from Dehghan and Ruwanpura [1] and further completed, shows a brief comparative review of the existing literature. The next sections provide further details.

2.1. Overlapping in product development

Research by Nicoletti and Nicolo [4] contributes to planning concurrent execution by enhancing information flow between interdependent activities. Loch and Terwiesch [3] and Terwiesch et al. [6] studied the importance of communication and information exchange in concurrent engineering and presented an analytical model to address two questions: 1) how much is the optimal overlap? and 2) how should the overlapped activities be coordinated? The model of concurrent engineering offered by Loch and Terwiesch [3] is more analytical than numerical. In addition, they do not include the cost of rework in their model, which is very important as often the cost of rework is higher than the cost of extra communication.

Information exchange and coordination are the focus of all research performed by Prasad [5], Ha and Porteus [15], Nicoletti and Nicolo [4], Loch and Terwiesch [3] and Terwiesch et al. [6]. Activity characteristics are less investigated in their research. However, other researchers, such as Krishnan et al. [2,16,17] have focused on activity characteristics to find out which activities are the best fit for overlapping. Krishnan et al. [17] introduce and formulate two characteristics for upstream and downstream activities, and use them to determine how activities must be overlapped. The first characteristic is upstream evolution, which refers to how fast the upstream information is refined and finalized. The second characteristic is downstream sensitivity, which refers to how much downstream activity is sensitive to possible changes in upstream activity and how quickly downstream activity can accommodate those changes. The significance of Krishnan's model is that in spite of its simplicity, it is a good representation of real-world practice. The concepts of evolution and sensitivity, and their combination to define different situations for overlapping, make a large contribution to understanding the mechanism of overlapping.

2.2. Overlapping in construction projects

Pena-Mora and Li [10] have conducted a highly contributing study about overlapping in construction projects. They use the concepts of upstream task evolution and downstream task sensitivity formerly developed by Eppinger [9] and Krishnan et al. [17], to generate a framework suitable for construction activities. Instead of the concepts of upstream task evolution and downstream task sensitivity in product development, Pena-Mora and Li considered upstream/downstream production rate, upstream production reliability, and downstream task sensitivity. Their framework provides guidance for any type of overlapping including design–design, design–construction, and construction–construction.

The research by Bogus et al. [11–13] adds more details and more insight to the research by Krishnan et al. [17], but with an orientation toward construction projects. The research is limited to the design phase and considers information dependency between activities. Its results are more useful for design managers to decide subjectively if a pair of activities are suitable for overlapping. Blacud et al. [14] added more to the research of Bogus et al. [12] by expanding the concept of evolution and sensitivity to the construction phase. Blacud et al. [14] studied the overlapping of design activities as predecessor activities with construction activities as successor activities. They focused their research on determining the factors contributing to the sensitivity of construction activities.

Common to all research studies performed by Krishnan et al. [17], Pena-Mora and Li [10], Bogus et al. [12], and Blacud et al. [14] is that they focus on one individual overlap and do not consider the overlapping in the context of a project schedule and with regard to other overlaps. They do not provide any clue to which activities are better to be