

# DEVELOPING AN UNCERTAINTY ANALYSIS MODEL FOR OFF-SITE BUILDING PRODUCTION

MEHRDAD ARASHPOUR and RON WAKEFIELD

*School of Property, Construction and Project Management, RMIT University, Melbourne,  
Australia*

The hybrid use of off-site and on-site processes in construction projects has increased significantly over the past decade. The analysis and management of uncertainty in hybrid projects is not a trivial task as workflow variability in off-site and on-site operations can interact and amplify one another. The aim of this paper is to analyze various drivers of uncertainty such as high levels of project complexity, risk seeking behaviors, unavailability of resources, and combined variability in hybrid projects. Production data of two Australian construction companies were collected and utilized in modeling uncertainty. Findings show the significant effect of uncertainty drivers on project plan reliability and the necessity of an adequate uncertainty analysis and management in hybrid projects. The results of this study enhance the knowledge about management of hybrid projects and have the potential to improve the way construction companies deal with uncertainty in project environments.

*Keywords:* Construction management, Delays and rework, Hybrid projects, Plan reliability, Simulation and optimization, Site built processes, Workflow analysis.

## 1 INTRODUCTION

Off-site production offers important benefits to construction projects. These benefits include but are not limited to reduced direct cost of labor and building components (Arashpour, Shabanikia *et al.* 2012), better quality of production in a controlled environment (Chan, Yuen *et al.* 2015), and lower rates of worksite accidents (Blismas, Wakefield *et al.* 2010). Off-site construction, however, can cause complexity in management of projects especially when paired with on-site construction activities. So called hybrid projects are prone to deviations from project plans (Yoon and Ventura 2002), increased uncertainty (De Meyer, Loch *et al.* 2002), and resource constraints (Fang, Marle *et al.* 2013).

Increasingly construction companies use both off-site and site-built elements in their projects and a holistic analysis of uncertainty is required to increase project plan reliability in hybrid projects (Arashpour, Wakefield *et al.* 2014a). However, methodical research on this matter is sparse in the construction literature (Rashki, Miri *et al.* 2014).

In order to bridge this gap, this study uses an empirical research approach to analyze the impact of uncertainty and complexity on hybrid construction projects. For this purpose, off-site and on-site construction activities in two large Australian construction companies were investigated. Research findings show meaningful relationships between project plan reliability (*PPR*) and characteristics of hybrid projects, namely level of

project complexity, risk seeking attitudes of project participants, resource constraints, and combined uncertainty in off-site and on-site construction activities.

## 2 COMPLEX AND UNCERTAIN CONTEXT OF HYBRID CONSTRUCTION PROJECTS

Previous research has shown that project size and elements of context increase project complexity results in a decreasing level of project plan reliability (Saha, Hardie *et al.* 2013, Arashpour and Arashpour 2015a). In order to analyze the impact of project size on level of project plan reliability (**PPR**), actual data from the two hybrid construction projects were utilized in 20 simulation experiments with various levels of work quantities. As opposed to the traditional planning and control techniques such as PERT, normal/Beta distributions were not the sole representatives of on-site and off-site activities. Therefore, randomness in activity durations and rework processes was reflected by fitting the optimum probability distributions to the collected real-world data. The goodness of fit was tested using Chi-Square test, Anderson-Darling (A-D) test, and Kolmogorov-Smirnov (K-S) test. Discrete event simulation (DES) experiments were run for 100 times to achieve a confidence level of 99% with all standard errors within 0.5%. Results of simulation experiments have been illustrated in Figure 1.

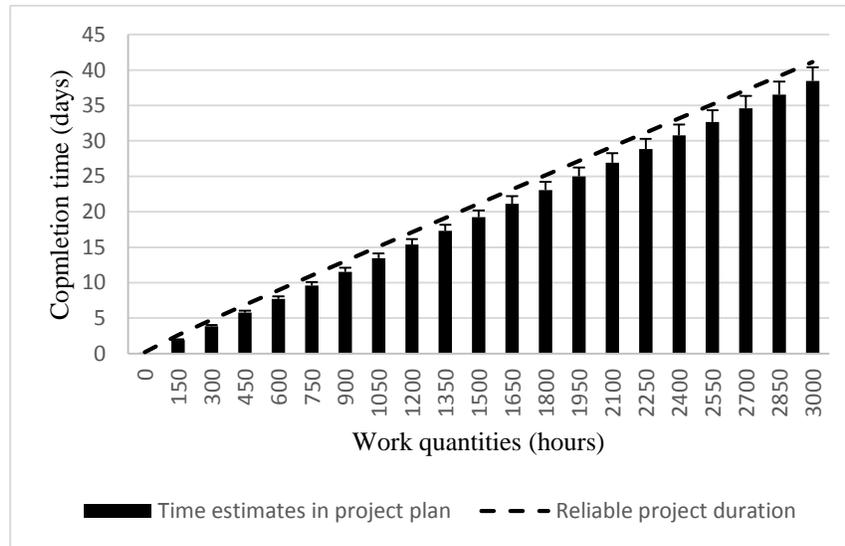


Figure 1. Impact of work quantities and project complexity on completion times.

As can be seen in Figure 2, increasing project work quantities and complexity result in a linear increase in completion times. Understandably, dedicating more resources to project will not necessarily change the situation as there are many activities with fixed-time durations, such as pouring and curing concrete, that cannot be crashed beyond a certain point. That is why reliable completion time (dashed line in Figure 2) is always longer than estimated completion time in project plans (vertical bars). More importantly, time gap between the two is more when large work quantities are involved (complex projects). This is in line with findings in our site observations in the two construction

companies where growth in hybrid project size and work quantities intensified pair and group interconnection of tasks within and between groups of on-site and off-site activities, resulting in lengthened completion times and deviations from project plans. These findings are consistent with those of Saha and Hardie (2008), and Arashpour, Wakefield *et al.* (2013b).

### 3 LEVEL OF RESOURCE AVAILABILITY IN HYBRID CONSTRUCTION PROJECTS

Resource constraints have a significant impact on project duration (Arashpour, Wakefield *et al.* 2015b). In hybrid projects, there are different constraints on project resources in on-site and off-site environments. In off-site construction, equipment and materials are the critical resources and labors (machine operators) are often dedicated resources to the production side of hybrid projects (Arashpour, Wakefield *et al.* 2014b). In on-site project activities, however, subcontractors and skilled labors are critical resources for timely completions (Loosemore and Andonakis 2007, Tam, Shen *et al.* 2011, Manu, Ankrah *et al.* 2013). Interestingly, even within a construction company with several running projects, there may be competition among building supervisors to attract on-demand resources, such as skilled carpenters, to their own project (Laslo and Goldberg 2008).

The observations in the two companies revealed the same pattern for critical resources in off-site and on-site project activities. Figure 2 illustrates the actual completion times associated with different levels of resource availability in hybrid projects.

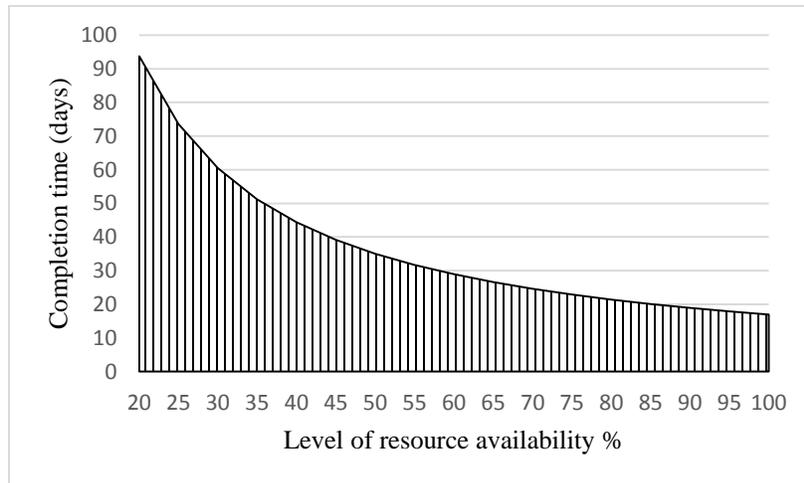


Figure 2. Impact of resource availability on completion times.

The reason behind decreased completion time, and thus reduced risk of delays with regard to the project plan, is that availability of required resources increases the workflow continuity in hybrid projects. In fact, relaxation of resource constraints can reduce risks

of both late completions and low plan reliability in hybrid projects. This is consistent with findings of Ahern, Leavy *et al.* (2014) and Arashpour, Wakefield *et al.* (2015c).

#### 4 CONCLUSION

Prior work has documented the effects of uncertainty on off-site construction activities (Saha 2008, Arashpour, Wakefield *et al.* 2013c). However, these studies have not focused on hybrid construction projects where on-site and off-site activities are concurrently in progress. In this study, two large Australian commercial builders were chosen and their production processes were investigated.

Results of the empirical analysis show that uncertainty in hybrid projects is mainly driven by large work quantities, risk seeking attitudes of project participants, unavailability of resources, and variability of workflow in off-site and on-site activities. These findings extend those of Arashpour, Wakefield *et al.* (2013a), confirming that uncertainty is an important characteristic of hybrid construction projects and needs to be analyzed and managed properly.

This work contributes to the body of knowledge in the field of construction engineering and management by analyzing major contributors to uncertainty in hybrid projects. The findings have great potential to improve performance and productivity in hybrid projects and assist construction companies to find the most cost-effective way of managing their off-site and on-site project activities.

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