Mathematical and Computer Modelling 57 (2013) 2044–2053

Contents lists available at SciVerse ScienceDirect

Mathematical and Computer Modelling

journal homepage: www.elsevier.com/locate/mcm

A system dynamics model for assessing the impacts of design errors in construction projects

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ARTICLE INFO

Article history:
Received 30 March 2011
Received in revised form 14 June 2011
Accepted 15 June 2011

Keywords:
Design errors
Rework
Design change
Schedule revision
Simulation
Schedule delay
Cost overrun

ABSTRACT

Design errors leading to rework and/or design changes are considered to be the primary contributor to schedule delays and cost overruns in design and construction projects. While design errors are deemed prevalent, most design and construction firms do not measure the number of errors they create, thereby having limited knowledge regarding their mechanism to undermine project performance. To address this, a system dynamics model has been developed to capture the dynamics of design errors and systematically assess their negative impacts. This paper reports on the development of the model, and its application to a university building project. The results indicate that design errors can significantly delay project schedule in spite of continuous schedule recovery actions taken by construction managers. The case study also shows that schedule pressure can propagate the negative impact of design errors to numerous construction activities, including those that are not directly associated with the errors. Finally, the case study confirms that the developed model can more rigorously assess the negative impact of design errors, which is often underestimated by practitioners. Based on these results, it is concluded that the developed model can assist project managers in better understanding the dynamics of design errors and recovering delayed schedule, particularly under schedule pressure.

1. Introduction

Despite advances in construction equipment and management techniques, major schedule delays and substantial cost overruns persist in design and construction projects [1–5]. US General Accounting Office [6] reported that its 20 civil infrastructure projects across 17 states, with estimated total cost ranging from $205 million to $2.6 billion, experienced significant cost overruns ranging from around 40% to 400%. This trend is not limited to projects in the United States. Latham [7] reported that only 70% of projects in the United Kingdom were delivered within 5% of the tender cost and only 38% within 5% of the tender program. Bromilow [8] also claimed that only one-eighth of Australian building contracts were completed within the scheduled completion dates and that the average schedule overrun exceeded 40%. Flyvbjerg et al. [9] analyzed 258 mega-projects undertaken across 20 countries, concluding that cost overruns were found in 90% of these projects; and that such cost escalation is not a new phenomenon, but has persisted over the past 70 years. This broad range of research is evidence that schedule delay and cost overruns are the rule rather than the exception in the construction industry [5].

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0895-7177/$ – see front matter
doi:10.1016/j.mcm.2011.06.039

Rework has been identified as an endemic problem in construction and engineering projects, and a major contributor to schedule delays and cost overruns [10]. Rework has been defined by Love [11] as ''the unnecessary effort of redoing a process or task that was incorrectly implemented the first time''. Rework, on average, contributes to 52% of total cost overrun, and can increase schedule overrun by 22% [10]. It has also been found that 5%–20% of the contract value can be attributed to rework in construction and engineering projects [12,10].

A major contributor to rework is design error. When an error is identified, it often requires rework to be undertaken, which involves additional time and resource expenditure [13,14]. Unfortunately, regardless of an individual's skill level, experience or education, errors may occur at any time due to the physiological and psychological limitations of humans [15]. Reason [16] contends that it is often the most qualified and highly competent individuals that commit errors with the most detrimental consequences. In general, design and construction firms do not measure the number of errors they create and, in particular, they generally fail to undertake appropriate design reviews, verifications and audits [17,18]. Accordingly, errors are often not identified immediately, but tend to transpire after a period of incubation in the system [19]. After some time, these errors are detected and the need for rework is identified, increasing the amount of remaining work [20–22]. The degree of rework required grows when errors remained undetected for longer periods of time [23].

Tsang and Zahra [24] suggest that the causes and effects of errors are not unidirectional or linear, but are reciprocal and looped in their relationships. In the pursuit of error and rework reduction, it is necessary to understand how such relationships emerge and interact with one another [25]. Based on this recognition, this paper aims to develop a system dynamics model to assist in better understanding the complex mechanism of design errors in which they damage project performance.

2. Design errors in construction projects

Human error can be defined as ''the failure of planned actions to achieve their desired goal, where this occurs without some unforeseeable or chance intervention'' [26]. Erroneous decisions made during design can occur due to impaired human cognition [27], particularly when designers experience workplace stress due to schedule and cost pressures [28]. Designers' cognitive processes can propagate throughout projects they work on and the wider organization, and this may increase the occurrence of errors [23]. Designers may omit to: involve others in design decisions, inform others of assumptions made, elicit other's needs and schedules, or understand the history of problem solving in a replicated design [27]. Love et al.'s [29] phenomenological approach proves that the uncertainty and inevitability of error are not perceptions, but are a reality for design consultants, resulting from the exogenous factors influencing their ability to perform tasks effectively. These factors include schedule pressure, design fees, client procurement strategy and skilled labor supply. In practice, many design and construction organizations pay limited attention to errors and the resulting rework or failures that may occur [17,30,25,29]. The size and complexity of a project, the number of professionals involved in its design and construction, and the complexities of procurement and price determination for services contribute to the potential for 'iatrogenic' impairment [23]. Other systemic problems may include lack of design reviews, checks and verifications, re-use of specification and details, unrealistic schedules, understaffing, and lack of project governance [29].

Triggered by these various factors, design errors can significantly lower project performance by generating rework, requiring additional time and resource expenditure. Furthermore, if errors are discovered during construction, additional time and resources may be required for demolition of incorrectly constructed components. Because of this additional time and cost, construction managers tend to avoid rework on problematic activities by modifying designs and specifications [1]. Particularly in highly uncertain circumstances, there is an over-reliance on scope changes to solve problems that may arise during construction, installation and commissioning [23]. However, if impacts of sudden changes in scope or design are not thoroughly assessed, they often induce additional problems by significantly altering project execution sequences and/or resource profiles. Burati et al. [31] found that 79% of rework costs arising in industrial engineering projects were the result of design changes, errors and omissions. Similarly, Love [11] revealed that design change orders resulting in rework can account for as much as 50% of project cost overrun.

Not only do design errors result in rework and/or sudden design change, they are also one of the main reasons for unreliable progress monitoring, which causes recovery actions taken by project managers to be ineffective. Cooper [20] contended that undetected rework is the main driver of discrepancies between real progress and perceived progress. Since project managers take schedule recovery actions based on perceived progress, the effectiveness of recovery actions diminishes as the gap between perceived and real progress widens. This in turn lowers the chances of on-time project completion. As hidden rework is discovered, construction managers realize that real progress is less than they had perceived, and that there is much more work remaining than was perceived. This can cause schedule pressure amongst project managers, inducing latent conditions where further errors are likely.

In an effort to meet a project's schedule completion date, additional resources may be employed; however, such action may lead to a contradictory effect [32]. By exceeding the limits of concurrency, complexity increases and tasks are delayed, particularly when revisions, repairs and rework occur [33]. Pate and Cornell [34] suggests that schedule pressure not only increases the probability of errors occurring (e.g., erroneous execution in the construction stage), but also decreases the chances that they are detected using regular procedures. Design errors that may be deemed minor in nature are likely to be overlooked due to the time that it would invariably take to correct them [23].