Schedule risk modeling in prefabrication housing production

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A B S T R A C T

Every country is dealing with its own housing problems; however, none compares with Hong Kong where housing has always been a major concern as a result of low supply over the past decades. Against the constraints in delivering sufficient houses, prefabrication as a sustainable solution for housing has been increasingly advocated for its potential merits of better quality, construction safety and cleaner built environment. However, schedule delay caused by various risks affected the prefabrication housing production (PHP) in Hong Kong. This problem can be further worsened when the manufacturing sector of PHP has entirely moved to offshore areas in the Pearl River Delta region. This study applies system dynamics to recognize and investigate the potential effect of various risks on the scheduling of prefabrication housing construction projects through the employment of Vensim software package. The simulation results show that schedule risks, namely low information interoperability between different enterprise resource planning systems (LIIBDEPS), logistics information inconsistency due to human errors probability (LIIHEP), Delay of delivery of precast element to site (DDPES), and Design information gap between designer and manufacturer (DIGDM) significantly contribute to the schedule delay in PHP. However, schedule is more sensitive toward LIIBDEPS than for the other three risks, indicating that LIIBDEPS should be monitored and given priority. The system dynamic model serves as an effective tool for quantitatively evaluating the effect of various risks on the schedule of PHP, offering valuable references for managers though comparing simulation results under different risk scenarios, so that potential risks that might lead to schedule delay could be identified and handled in advance.

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1. Introduction

Every country is dealing with its own housing problems, but none compares with Hong Kong where houses have always been a concern to most local citizens for the past several decades. A number of 2,671,900 permanent residential flats were in stock as of the end of 2014, of which 1,496,500 (56%) were private flats, 781,500 (29%) were public rental housing and 393,900 (15%) were subsidized housing (Department, 2015). On the demand side, as of end of December 2015, public rental housing has about 147,000 general applications, and the average waiting time for general applicants was 3.7 years (Authority, 2016). The Hong Kong Housing Authority reiterated an ambitious housing plan to supply 93,400 public housing rental units until 2020 (Authority, 2016). However, Hong Kong is suffering from a series of constraints including safety, time, environmental protection and labor shortages to deliver housing plans. Against this background, prefabricated construction as a solution is envisioned to be increasingly accepted as main construction method in Hong Kong.

Potential benefits cannot be supported without overcoming its inherent drawbacks of fragmentation, discontinuity, and poor interoperability, which raise a range of risks that have adverse influence on the schedule performance of prefabrication housing production (PHP). To help address encountered schedule delay problem in PHP, many excellent researchers have looked into risk-related issues and contributed to the body of knowledge of the management of PHP (Wang et al., 2014, 2015; Li et al., 2016a,b). However, these studies only consider risks from static and isolated
perspectives, despite that these risks are coherently interrelated with each other and might vary along with time. Moreover, most previous research also does not take sufficient consideration into their quantified influence on the schedule of PHP and fail to predict potential delays through simulations (Li et al., 2014a,b; Tam et al., 2007, 2014; Uttam and Le Lann Roos, 2015). To fill the research gap and meet with the practical industry need, this study proposes a dynamic model to assess and simulate potential risks found in four major prefabrication construction processes, employing the system dynamics (SD) method. The objectives of establishing this evaluation model include (1) exploring interactional, interdependent, and complicated relationships underlying the risk factors that have significant influence on the schedule performance of PHP; (2) evaluating and simulating the effect of identified risks on the schedule of PHP; (3) comparing and analyzing the potential effect on the schedule of PHP under different risk scenarios.

2. Research background

2.1. Prefabrication housing production (PHP) in Hong Kong

Most house construction in Hong Kong still applies traditional construction technologies characterized by bamboo scaffolding, cast-in-situ, wet trades, falsework and formwork, fixed jobsites and labor intensive. Though conventionally construction technologies like wet trades and cast in-situ may have their own benefits such as high flexibility to design changes, they have received extensive criticisms. The Construction Industry Review Committee (CIRC) systematically reviews current development in the construction industry in Hong Kong and recommends enhancement measures to raise the quality and performance of local construction. The report, named construct for excellence, critically pointed out the problems surrounding the construction industry of Hong Kong, including but not limited to: disappointing environmental performance, incompetently trained labor force, and poor record of construction site safety. As a result, the wider use of precast components was proposed as a prime measure to enhance the performance of the construction industry in Hong Kong. In comparison with traditional housing production technologies, prefabrication construction has the following benefits: (1) Better on-site construction environment as a result of reductions dust and noise, construction waste (Tam et al., 2015), water and air pollution, (Hong et al., 2016); (2) Compressed construction schedules as the change of the sort of work flow, for instance, allowing foundations being poured on-site for while the precast components are assembled offsite at the same time (Tam and Hao, 2014); (3) Easier for quality control, labor supervision and fewer material deliveries (Li et al., 2016a,b); (4) Fewer losses as a result of misplacement of materials and less requirements for on-site material storage (Lu et al., 2011); and (5) Safer working environment for worker through reducing dangerous operations, e.g., components traditionally constructed on-site at heights or in confined spaces can be fabricated offsite and then hoisted into place using cranes (Ingrao et al., 2014).

2.2. Literature review on prefabrication

Existing research on the management of prefabricated construction (MPC) can be categorized into four parts, namely, vertical relations, benefits, challenges and promoting approaches. Vertical relations are analysed based on the characteristics of MPC: 1) relationships, where buyer-supplier relationships have received wide attention (e.g., Bildsten, 2014; Doran and Giannakis, 2011; Hofman et al., 2009) because of the significant role of suppliers in guaranteeing stable and high-quality supply for production, while client-contractor relationships are also claimed to be important for improving the efficiency of MPC by reducing variations in the on-site installation stage (Doran and Giannakis, 2011); 2) structure, where make-to-order and engineer-to-order are the major strategies adopted in supplying prefabricated products. Make-to-order is usually used for supplying standard or configurable components for production (Cheng et al., 2010) and can provide effective support for the management of logistics chains (Court et al., 2009), while engineer-to-order provides clients with diverse products which are developed according to completely new designs (Gosling and Naim, 2009) and the management process is relatively more difficult due to the complex information flows (Ergen et al., 2007); 3) results, referring to mass customization of the housing sector as a consequence of long-term and efficient development of MPC. Regarding the benefits, the literature points out that effective MPC can help increase the productivity (Demiralp et al., 2012; Sungkon et al., 2015), enhance quality management (Ikonen et al., 2013) and reduce waste generation (Lu and Yuan, 2013). MPC, however, presents significant challenges due to lack of experienced stakeholders (Mao et al., 2014), lack of prefabrication-related skills and knowledge and limited supply capability (Blishmas and Wakefield, 2009), indicating the fragmentation of the supply chains. Some approaches are proposed in order to promote SCM for prefabricated construction, such as information technologies (Cus-Babic et al., 2014), technological innovation (Chiang et al., 2008), planning systems (Bergström and Stehn, 2005), and coordination mechanism (Cus-Babic et al., 2014; Xue et al., 2005). However, although previous studies have contributed to the knowledge base on the management of prefabricated construction, studies on schedule risk-related issues in the implementation of prefabrication are limited. While various risks occur along the whole process of PHP processes and have vital influence on the successful delivery of prefabrication housing projects. Moreover, a consensus on the complexity of risks in prefabrication construction exists because of its characteristics including dynamics, uncertainty, and mutual interaction, while previous research regarding risk management considers risks from a static and isolated perspective. For example, Luu et al. (2009) explored major cause-effect relationships among identified schedule risks through expert interviews; Davis-McDaniel et al. (2013) applied event-fault tree for risk assessment of bridge failure; Kim et al. (2009) described how Bayesian belief network is applied to quantify schedule risks. They considered little about the dynamic changes during the construction period. Moreover, they neglect the fact that interactions between risks are increasing and strengthening along with the prefabrication construction, which increases the difficulty of risk management and leads to project delays (Li et al., 2016a,b). From this aspect, systematic analysis can help managers gain a better understanding of system essence, function, and behavior, as well as interaction with the environment. Therefore, this research adopts the SD method for analyzing and evaluating the potential effect of various risks on the schedule of PHP from the dynamic and mutual interaction perspective, to fill the current research gap and provide a practical tool for simulating schedule variation in prefabrication housing projects.

3. Methodology

Originated by Forrester in the 1960s, SD is a science that emphasizes on the structure of complex systems and the relationship between dynamic behaviors and function based on computer simulation technology and the theory of feedback control (Forrester, 1968). SD has been applied in a wide variety of research fields for macro analysis and management, such as economic development (Meadows et al., 1972; Taubed and Wray, 2006), military system management (Fan et al., 2010; Moffat, 1996), Please cite this article in press as: Li, C.Z., et al., Schedule risk modeling in prefabrication housing production, Journal of Cleaner Production (2016), http://dx.doi.org/10.1016/j.jclepro.2016.11.028
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