Waste Management 32 (2012) 521–531

Contents lists available at SciVerse ScienceDirect

Waste Management

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

A dynamic model for assessing the effects of management strategies on the reduction of construction and demolition waste

Hongping Yuan [a], Abdol R. Chini [b], Yujie Lu [c,d,*], Liyin Shen [e]

[a] School of Economics and Management, Southwest Jiaotong University, Chengdu, China
[b] Rinker School of Building Construction, University of Florida, FL, USA
[c] School of Economics and Management, Tongji University, Shanghai 200092, China
[d] Department of Civil & Environmental Engineering, University of Maryland, MD, USA
[e] Department of Building and Real Estate, The Hong Kong Polytechnic University, Hong Kong

ARTICLE INFO

Article history:
Received 26 May 2011
Accepted 10 November 2011
Available online 23 December 2011

Keywords:
Construction and demolition waste
System dynamics
Management strategy
Waste reduction

ABSTRACT

During the past few decades, construction and demolition (C&D) waste has received increasing attention from construction practitioners and researchers worldwide. A plethora of research regarding C&D waste management has been published in various academic journals. However, it has been determined that existing studies with respect to C&D waste reduction are mainly carried out from a static perspective, without considering the dynamic and interdependent nature of the whole waste reduction system. This might lead to misunderstanding about the actual effect of implementing any waste reduction strategies. Therefore, this research proposes a model that can serve as a decision support tool for projecting C&D waste reduction in line with the waste management situation of a given construction project, and more importantly, as a platform for simulating effects of various management strategies on C&D waste reduction. The research is conducted using system dynamics methodology, which is a systematic approach that deals with the complexity – interrelationships and dynamics – of any social, economic and managerial system. The dynamic model integrates major variables that affect C&D waste reduction. In this paper, seven causal loop diagrams that can deepen understanding about the feedback relationships underlying C&D waste reduction system are firstly presented. Then a stock-flow diagram is formulated by using software for system dynamics modeling. Finally, a case study is used to illustrate the validation and application of the proposed model. Results of the case study not only built confidence in the model so that it can be used for quantitative analysis, but also assessed and compared the effect of three designed policy scenarios on C&D waste reduction. One major contribution of this study is the development of a dynamic model for evaluating C&D waste reduction strategies under various scenarios, so that best management strategies could be identified before being implemented in practice.

1. Introduction

It is widely acknowledged that the construction industry is not environmentally friendly. Construction activities not only consume a large amount of natural resources, materials and energy, but also generate unacceptable level of solid waste. Kulatunga et al. (2006) reported that the construction sector consumes 25% of virgin wood and 40% of raw stone, gravel and sand used globally every year; and around 40% of materials are used by construction work. The production and manufacture of building components, along with the construction process itself, involves the extraction and movement of 6 billion tons of basic materials annually, or 40% of extracted materials in the US (Kibert and Ries, 2009). In addition, the US construction industry contributes to a large amount of waste to the municipal solid waste stream. Building related construction and demolition (C&D) waste in the US was estimated to be 143 million metric tons (Chini and Bruening, 2005). Wang et al. (2010) mentioned that construction activities in China consume approximately 40% of total natural resources and around 40% of energy.

Faced with the large amount of C&D waste, since the 1980s, continuous research efforts have been devoted to figure out how to minimize the generation of C&D waste in order to reduce associated adverse impacts during construction and demolition of building structures. It has been determined that previous studies have investigated a wide range of topics under the umbrella of C&D waste management, ranging from C&D waste reduction, recycling, to waste disposal. It is also worth pointing out that among them, investigation into the problem of how to reduce the generation of C&D waste in different contexts has been attracting notable

* Corresponding author. Address: School of Economics and Management, Tongji University, Shanghai, China.

E-mail addresses: hpyuan2005@gmail.com (H. Yuan), lyj0415@gmail.com (Y. Lu).

0956-053X/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.wasman.2011.11.006

attention. A probable explanation is that C&D waste reduction is the highest priority among all waste management options, encompassing reduction, recycling and disposal (Peng et al., 1997). Specifically, existing studies in relation to C&D waste reduction can be roughly categorized into four themes, including: (1) barriers to implement C&D waste reduction; (2) strategies for promoting C&D waste reduction practices; (3) major stakeholders' attitudes/behavior toward C&D waste reduction; and (4) benchmarking C&D waste management performance through measuring and comparing waste generation rate (WGR). For example, according to Chini (2007), reducing C&D waste and increasing use of recycled materials in the US are driven by higher landfill costs, greater product acceptance, and government recycling mandates. Favorable in-service experience with recycled materials and development of specifications and guidelines for their use are necessary for recycled materials acceptance. Yuan et al. (2011) carried out a study to explore major obstacles to implement C&D waste management in China. The findings reveal 16 obstacles that affect the implementation of C&D waste management in China, which would be useful information for further developing strategies to deal with the problem. By using Ajzen's "theory of planned behavior", Teo and Loosemore (2001) examined the attitudinal forces that shape operatives' attitudes toward C&D waste reduction. Later, a theory of waste behavior is proposed to help managers understand and improve operatives' attitudes and behavior toward waste. Furthermore, some researchers concentrate their work on measuring C&D waste through various methods, including direct observation (Formoso et al., 2002), comparing contractors' records (Skoyles, 1976), sorting and weighing the waste materials on site (Bossink and Brouwers, 1996), and truck load records (Poon et al., 2001a), aiming to benchmark different C&D waste management practices and possibly compare these practices through the indicator WGR.

On the other hand, management measures to reduce C&D waste at the project level have also attracted widespread attention. Previous studies have suggested some major variables affecting the overall effect of C&D waste reduction, including: design change, investment in C&D waste management, government regulation, site space for performing waste management, low-waste construction technology, and waste management culture within an organization. Particularly, the design change occurring during construction is perceived as one of the most significant sources resulting in C&D waste because Osmani et al. (2008) estimated that around 33% of on-site waste is related to project design. It is stated by Osmani et al. (2008) and Chen et al. (2002) that investment in C&D waste management can help promote C&D waste management through employing waste management workers, purchasing equipments and/or machines for waste minimization, and improving workers' skills of waste management. Government regulations also play a critical role in C&D waste reduction by developing and fostering the regulatory environment for waste reduction (Karavezyris, 2007). Site space for performing waste management activities is regarded as a significant variable by Wang et al. (2010) as without a space layout pre-planned, the temporary placement of sorting facilities and implementation of waste management activities might disarrange other construction activities. Previous studies, such as (Jaillon et al., 2009; Esin and Cosgun, 2007), have acknowledged the potentials of low-waste construction technologies, such as prefabrication and modular structure in buildings, for reducing C&D waste. Furthermore, findings from Yuan and Shen (2011) and Teo and Loosemore (2001) demonstrated that it is crucial to take the attitudes of major practitioners into consideration when seeking a workable solution for reducing waste.

In recent years, some studies have attempted to deal with C&D waste reduction from a *different* perspective – viewing the whole C&D waste process as a system. Just as stated by Seadon (2010): "the conventional waste management approach is that waste generation, collection and disposal systems are planned as independent operations. However, all these are very closely interlinked and each component can influence the other." In this regard, considering C&D waste reduction independently could not properly unveil how a specific waste reduction strategy will affect or be affected by other elements within the C&D waste reduction system. Although this broader view increases the difficulty of managing waste, requiring an approach that handles complexity, it is exciting to see that attempts have been made to address a kind of system complexity through systematic approaches, such as system dynamics. For instance, Hao et al. (2007) developed a simulation model based on system dynamics for strategic planning of C&D waste in Hong Kong by incorporating the relationship of major activities inherently involved in C&D waste management. They claimed that such a simulation model would have the potential to assist decision-makers to better understand the complexity of information and processes involved in managing C&D waste throughout a project's lifecycle. Later, this approach was adopted by Wang and Yuan (2009) for constructing a model to simulate the C&D waste management system in China. Both studies suggest that system dynamics is of great potential to be applied to deal with the complexity – interrelationships and dynamics – of C&D waste management systems. Nevertheless, their models are all proposed at the regional level, attempting to evaluate and propose management strategies for C&D waste reduction in a given region.

The main aim of this study is to examine the effects of management strategies on C&D waste reduction at the project level with the aid of system dynamics approach. In this study, *C&D waste reduction* refers to the activity carried out in the phases of project design and building construction for preventing the generation of C&D waste. The major variables affecting waste reduction in construction projects, which were reviewed previously, involve: design change, investment in C&D waste management, government regulation, site space for performing waste management, low-waste construction technology, and waste management culture within an organization. The detailed objective of the research presented here is twofold: first, to incorporate the nature of dynamics of C&D waste management system into the modeling process that are not easily measureable, but are vital to descriptions of C&D waste reduction; second, to use the dynamic model for management strategies analysis under various scenarios. It is expected that the identified variables associated with C&D waste reduction and their interrelationships could deepen major stakeholders' understanding about C&D waste reduction. Meanwhile, the proposed model would enable decision-makers to examine the effect of a particular management strategy before implementing it in practice so that the best strategies can be identified.

2. System dynamics methodology

Originated by Forrester (1958), system dynamics is especially designed for dealing with large-scale and complex systems. Forrester (1961) initially defined system dynamics as "the investigation of the information-feedback characteristics of (managed) systems and the use of models for the design of improved organizational form and guiding policy". The basic principle of system dynamics is to understand how the main objects within a specific system interact with each other. Therefore, the purpose of applying system dynamics is to facilitate understanding of the relationship between the behavior of a system over time and its underlying structure and decision rules (Wolstenholme, 1990).

In recent years, system dynamics has been extensively applied across a wide range of disciplines, such as strategic management (Warren, 2005), managing overlapped iterative product development (Lin et al., 2008), agricultural project sustainability (Saysel et al.,