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The S-curve for forecasting waste generation in construction projects

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ABSTRACT

Forecasting construction waste generation is the yardstick of any effort by policy-makers, researchers, practitioners and the like to manage construction and demolition (C&D) waste. This paper develops and tests an S-curve model to indicate accumulative waste generation as a project progresses. Using 37,148 disposal records generated from 138 building projects in Hong Kong in four consecutive years from January 2011 to June 2015, a wide range of potential S-curve models are examined, and as a result, the formula that best fits the historical data set is found. The S-curve model is then further linked to project characteristics using artificial neural networks (ANNs) so that it can be used to forecast waste generation in future construction projects. It was found that, among the S-curve models, cumulative logistic distribution is the best formula to fit the historical data. Meanwhile, contract sum, location, public-private nature, and duration can be used to forecast construction waste generation. The study provides contractors with not only an S-curve model to forecast overall waste generation before a project commences, but also with a detailed baseline to benchmark and manage waste during the course of construction. The major contribution of this paper is to the body of knowledge in the field of construction waste generation forecasting. By examining it with an S-curve model, the study elevates construction waste management to a level equivalent to project cost management where the model has already been readily accepted as a standard tool.

1. Introduction

Construction and demolition (C&D) waste, sometimes simply referred to construction waste, constitutes approximately 20–30% of all waste worldwide (Srinivas, 2003). Without proper management of C&D waste can result in severe degradation of the environment (Lu and Tam, 2013; Boiral and Henri, 2012; Coelho and de Brito, 2012). Construction projects, particularly sizable ones, generate a continuous stream of waste that needs to be systematically planned and managed. This is increasingly becoming a normative feature. For example, de Guzmán Báez et al. (2012) reported the Spanish Government's 105/2008 Royal Decree (Ministry of the Presidency, 2008), within which the obligation to develop a waste management plan (WMP) in advance of each construction project is of special interest. The WMP for a project site provides an overall framework for waste management and reduction, and contains key types of waste to be reduced, waste reduction targets, waste reduction programmes, waste disposal procedures, and monitoring and audit (HKEPD, 2009). A WMP is also mandated in economies such as the UK (Brian, 2008) and Hong Kong (HKDB, 2000) for public works projects; failing to consider or comply with it as a legal duty means the commitment of an offense that is punishable by law. In major economies, based on the polluter pays principle, different C&D waste disposal charging schemes have been enacted, whereby contractors are charged with a levy for every ton of waste they dispose of, e.g. in landfills. Nowadays, it is not uncommon for contractors to put the levy in their bids so that part of the extra cost will eventually be transferred to the client. Hence, it is critical that both client and contractors have a relatively symmetric access to the waste generation information to allow the contract to be fairly awarded. During the course of construction, contractors need the

Abbreviations: C&D waste, construction and demolition (C&D) waste; ANNs, artificial neural networks; WMP, waste management plan; CWM, construction waste management; WGR, waste generation rate; MSE, means square error; CWG, construction waste generation; AMSE, average MSE; BP, back-propagation; GA, genetic algorithm.

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information, e.g. to define the size of roll-off containers, the best form of external and internal transport, and all the waste logistics (Nagalli, 2013). Contractors also need to benchmark actual waste generation against the WMP periodically so that appropriate interventions will be introduced when necessary. In short, forecasting the construction waste generation stream as a project progresses is pivotal in any effort to manage C&D waste.

Owing to its immediate material implications to construction waste management (CWM), forecasting the generation of construction waste has become a hot research topic, often under the umbrella of 'quantifying waste generation'. Bergsdal et al. (2007), Lu et al. (2015) and Lu et al. (2016) reported that forecasting C&D waste generation could be at a project level, a regional level, and a national level. The research reported in this paper is focused at the project level, although it could be used for estimation at a regional level, e.g. by aggregating all the construction projects in the region. Wu et al. (2014) reviewed C&D waste quantifying methods from the perspectives of waste generation activity, estimation level, and quantification methodology, and classified them into the following six types: site visit method, waste generation rate method, lifetime analysis method, classification accumulation method, variables modeling method, and other particular methods. Quantifying construction waste generation can be conducted as a post-mortem of completed or ongoing projects, e.g. by conducting on-site investigation (Lu et al., 2011), analyzing waste disposal records (Poon et al., 2004) or material flow (Cochran and Townsend, 2010; Li et al., 2013), but its main thrust is to provide decision-making information for the future.

To provide this decision-making information, it is highly desirable to have a model that can forecast waste generation as the project progresses, or even before the project commences. Notably, de Guzmán Báez et al. (2012) used a linear model to forecast the waste generation stream of Spanish railway projects determined by a few project characteristics, such as length of the railway, and numbers of intersections and underpasses. Cheng and Ma (2013) and Li et al. (2016) analyzed waste generation by investigating detailed design and construction units, e.g. work breakdown structure and bills of quantities. Sáez et al. (2014) described the relationship between accumulation of CDW in terms of weight or volume and durations with linear regression with seven residential building projects. While the foregoing studies sensibly emphasize the importance of investigating detailed units, they fall short of providing a reliable waste generation rate (WGR), wastage levels, or conversion ratios of materials to target products. Readers are thus encouraged to refer to the body of references on WGR, which according to Lu et al. (2011) lies at the core of many efforts for understanding waste management in the construction sector. Katz and Baum (2011) developed a novel methodology to predict the accumulation of construction waste based on field observations. According to Katz and Baum (2011), waste "accumulates in an exponential manner". This is clearly a very rough approximation of the real situation, where the amount of waste tends to decrease towards the end of projects as the finishing trades take over – suggesting a sigmoidal or S-curve to be more appropriate. However, no previous research has attempted to articulate the waste stream in this way.

The Project Management Institute (PMI) (2013) defines an S-curve as a graphic display of cumulative costs, labour hours, percentage of work, or other quantities, plotted against time. The name derives from the S-like shape of the curve (flatter at the beginning and end, and steeper in the middle) produced on a project that starts slowly, accelerates, and then tails off. The S-curve is particularly useful in project cost management. For a project of n activities, the cost accruing at time point t is C_t, and the accumulative cost $\sum_{t=1}^{n} C_t$ for a regular project follows an S-curve as the project progresses. Intuitively, the accumulative waste generated from the project should also follow an S-curve. Once the curve is substantiated, it can be used to estimate the total amount of construction waste generation, even during the preconstruction phase. This information is very useful when contractors place the waste levy in their bids. The S-curve can indicate specific accumulative waste generation at time point t and the information is particularly useful for producing the WMP, e.g. in planning the site area for temporarily storing the waste without conflicting with other trades, or planning the transport for waste disposal. During the construction process, it can be used as a baseline against which actual waste generation can be compared and interventions introduced as necessary.

S-curve is a good tool to describe the accumulation of construction activities against time. However, few studies, if not none, have used this tool to describe construction waste generation. Therefore, construction waste management usually lacks effective planning tools. The primary aim of this paper is to propose and test an S-curve for forecasting construction waste generation by taking advantage of a big data set formed by over five million waste disposal records generated from 9850 projects in Hong Kong from January 2011 to June 2015. It tends to provide contractors with not only an S-curve model to forecast overall waste generation before a project commences, but also with a detailed baseline to benchmark and manage waste during the course of construction. The remainder of this paper is structured into five sections. Subsequent to this first introductory section, the second section provides a literature review of previous studies on the S-curve; the third section provides a detailed description of the methodology, at the core of which is curve fitting by trial and error applied to big data and artificial neural networks (ANNs); the fourth section presents the results and findings; the fifth section discusses the results and findings; and the sixth and final section draws a conclusion and makes suggestions for further related research.

2. The S-curve in project management

The S-curve is a graphic display of cumulative costs, labour hours, percentage of work, or other quantities, plotted against time in a project (PMI, 2013). The shape of the S-curve, normally with a smaller slope at the beginning and near the end and a larger slope in the middle, indicates that progress is slower in initiation and closure of resources but faster when the main work takes place. It is able to reveal the overall project progress in single numbers. Early research works suggested the use of cumulative plots of cost versus time and cumulative value versus time for project control, and emphasized its role in facilitating senior managers to clearly understand the overall financial situation. Cash flow forecasting based on S-curves was further developed with more appreciation of financial management in construction in the early 1970s (e.g. Hardy, 1970; Bromilow and Henderson, 1974; Balkau, 1975). Since then, the use of S-curves has been an enduring research topic for project planning and control, in forecasting cash flows in the pre-construction phase, and as targets to assess the delay of actual progress in the construction stage (Chao and Chien, 2009).

There are some risks in using S-curves to establish the progress target for project control. For example, under the threat of penalty for not meeting forecast values, contractors may speed up non-urgent activities at the expense of critical activities needed to achieve the targets (e.g. Jepson, 1969; Kim and Ballard, 2000). However, it should be noted that S-curves provide a simple and handy tool with which project managers can control projects; and the risks of misusing S-curves can be mitigated to a certain extent by integrating them with other project management approaches, such as milestone planning.