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Benchmarking construction waste management performance using big data

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ABSTRACT

The waste generation rate (WGR) is usually used as a key performance indicator (KPI) to benchmark construction waste management (CWM) performance, with a view to improving the performance continuously. However, existing researches, for different reasons, only investigated a relatively small amount of construction projects, whose WGRs cannot be confidently accepted as KPIs. This study develops a set of more reliable KPIs/WGRs using an available big dataset on CWM in Hong Kong. By mining the 2,212,026 waste disposal records generated from 5764 projects in two consecutive years of 2011 and 2012, the WGRs/KPIs are revisited and refined. Demolition is found the most wasteful works. New building, and maintenance and renovation (M&R) works individually produce the least waste amount but by accumulating all M&R works, their contribution to the total amount of construction waste could be phenomenal. Based on the more reliable WGRs from the big data, CWM performance benchmarks for different categories of projects are set up. A contractor can benchmark its CWM performance against its counterparts or its past performance as 'Good', 'Average', and 'Not-so-good', and thus identify better CWM practices that induce superior performance. Based on the benchmarks, the government may consider setting up a WGR-step toll system to encourage those 'Not-so-good' contractors to perform well in the future, and initiate incentives to the companies conducting 'Good' projects to spur better CWM performance. Overall, the WGRs derived from the big data and more robust analyses provide a very powerful and handy tool for CWM.

1. Introduction

Construction waste is defined as the waste that arises from construction, renovation, and demolition activities (Kofoworola and Gheewala, 2009). It may also include surplus and damaged products and materials arising in the course of construction work or used temporarily during the process of on-site activities (Roche and Hegarty, 2006). Sometimes, the terms 'construction waste' and 'C&D waste' are used interchangeably (Lu et al., 2015) and this is also the case in this paper. The Hong Kong Environmental Protection Department (EPD, 2014a) categorizes construction waste into two main types. They are inert construction waste (ICW), which are materials with stable chemical properties (e.g. soil, earth, silt, bricks, blocks, rocks and concrete), and non-inert construction waste (non-ICW) such as timber, bamboo, and paper board and other organic materials. ICW is suitable for public fill works, e.g. site formation and land reclamation, while non-ICW depletes land resources and contaminates surrounding environment after it is disposed of at landfills (Poon, 2007; Lu, 2013; Lu and Yuan, 2013; Yuan et al., 2013; Yuan, 2011). There are some hazardous wastes, such as asbestos and contaminated soil, that arise from construction works but in many countries they are not classified as construction waste (Mou, 2008) and therefore are not considered in this paper. With the increasing embracement of sustainable development, it is highly important to take measures to mitigate the waste generation from the construction industry.

Waste generation rate (WGR) has been broadly used as an indicator to measure CWM performance (Bossink and Brouwers, 1996; Mcdonald and Smithers, 1998; Formoso et al., 2002; Tam et al., 2007; Lu et al., 2011). It can be used as key performance indicators (KPIs), based on which contractors can benchmark their CWM performance and in turn identify the best practice that can seek for continuous improvement. Previous studies on WGRs, which adopted research methods, for instance, literature review, case studies, interviews, site inspections and questionnaire survey,

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provided subjective and limited understanding of the performances (Formoso et al., 2002; Lu et al., 2011; Lin, 2006; Tam et al., 2007; Gangolells et al., 2014). Most of the studies on CWM performance (measured by WGR) have a relatively small sample or sampled relatively small sites due to the difficulties involved in conducting a survey on large-scale projects over a relatively long period of time (Katz and Baum, 2011; Lu et al., 2011). As a consequence, these WGRs reportedly ranged from one study to another without any form of reliability. Results of such studies thus cannot be utilized with a high level of confidence as yardsticks for benchmarking.

The aim of this study is to develop a set of more reliable KPIs/WGRs by making use of a big dataset that has been collected in the past years. Complying to the Law of Large Numbers (LLN), the average of the results obtained from a large number of trials should tend to become convergent to a certain value as more trials are performed (Sen and Singer, 1994). The representative WGRs of non-ICW and ICW for different categories of construction works are identified to measure the CWM performance that epitomizes each category. Benchmarks are set to compare the performance of construction projects with various natures of waste generation. The introduction is followed by a detailed review of KPIs, WGRs, big data, and data mining. Based on the review, detailed research design was put forward in Section 3. The process of analyzing the collected big dataset is presented in Section 4. Accordingly, the results and relevant implications are discussed in Section 5. Suggestions for enhancing the CWM are raised for policy-makers, contractors, researchers and other stakeholders in Section 6.

2. Literature review

2.1. Benchmarking based on key performance indicators (KPIs)

In recent decades, the construction industry has become increasingly competitive. In order to gain competitive advantages, construction companies are pursuing an approach to assessing the management performance. Benchmarking was introduced as a continuous process of improving performance in a systematic and logical way by measuring products, services, and practices by learning from the best to make targeted improvements (Camp, 1989). Benchmarking systems are targeted for development in the construction industry in a few countries via typically analyzing the performance of a system based on a set of key performance indicators (KPIs) (Horta et al., 2009; Cheung, 2010). KPIs represent a set of metrics measuring how well a system performs an operational, tactical or strategic activity, which are the most critical for the current and future success of the system (Parmenter, 2007; Eckerson, 2006). An organization can benchmark its performance by taking the results of its KPIs and comparing these with the performance of their counterparts or with its own past performance as appropriate (Thomas and Thomas, 2008). Therefore, KPIs not only serve as early warning signs that give decision-makers information to reduce uncertainty, but are also expected to indicate what measures should be taken to make sustained improvement in efficiency and quality (Kerzner, 2011).

Researchers have attached their attentions to KPIs in benchmarking performance of CWM. For example, Lin et al. (2011) measured the success of construction projects through benchmarking the performance with the identified KPIs. Hegazy and Hegazy (2012) produced a benchmarking model based on financial KPIs for construction companies to benchmark and evaluate their business performance at the corporate level in the UK. Horta et al. (2009) tried to benchmark the performance assessment of the construction industry by integrating KPIs and data development analysis. More frequently, benchmarking with KPIs also exists in pursuing the success of CWM. Through studying the construction waste generated in a number of hotel projects, Ball and Taleb (2011) found that the benchmarks in existing CWM legislation need to be amended. In measuring waste management performance in the construction industry, waste generation rates (WGRs) are usually replaceable by the KPIs.

2.2. WGRs as KPIs

It has become the tide that construction industry measures performance of CWM with various data collection approaches by focusing on different KPIs, mainly found expressions in waste amount and WGRs. At early time, the method is to quantify construction waste amount, and digging out the causes of construction waste generation (Bossink and Brouwers, 1996). Poon et al. (2004a) also quantified waste amount and found the major causes of waste materials were improper preparation, handling, misuse, and incorrect processing. There are certain existing studies using WGRs as the KPIs for measuring the performance of CWM of individual construction projects. To this end, WGRs becomes the KPI of CWM in this study. Formoso et al. (2002) examined waste management in Brazil through estimating WGRs, which were waste percentage of purchased materials by weight. Poon et al. (2004b) measured the WGR with the volume of waste generated per gross floor area (GFA), which is probably the most frequently used KPI in the literature. WGR is also regarded as an important indicator for successful implementation of an integrated construction waste management plan (Bakshan et al., 2015).

In previous studies, diversified research methods were adopted to acquire the data to measure WGRs. Lin (2006) adopted the neural network method to measure the WGRs for the construction of factory and residential buildings in Taiwan. Interviewing waste manager is also a method for collecting data for calculating WGRs of some projects (Tam et al., 2007). Lu et al. (2011) examined the waste management effectiveness in a typical city, Shenzhen, China by focusing on WGRs of different materials from several construction sites. Visual inspection, tape measurement, and truckload records were used in the study of Poon et al. (2004b). However, these existing studies usually investigate WGRs with a small scale of data, which therefore cannot identify common rules and generalize their findings to other cases. With the help of convenient data collection and large record, big data and data mining are becoming possible to advance the research on WGRs.

2.3. Big data and data mining

Big data is defined as things one can do at a large scale that cannot be done at a smaller one, to extract new insights or create new forms of value, in ways that change markets, organizations, the relationship between citizens and governments, and more (Mayer-Schönberger and Cukier, 2013). People tend to accept the definition that was asserted by IBM that big data has data volume, velocity and variety (three Vs) (Zikopoulos and Eaton, 2011). Volume is the quantities of terabytes, records, transactions, tables, or files; velocity finds expression in batch, near time, real time and streams; and variety can be structured, unstructured, semi-structured and a combination of them (Russom, 2011). Big data could be strategically used as a raw material and a vital input to create a new form of value in living, working, science and industry (Mayer-Schönberger and Cukier, 2013). Its value is found in finance and insurance industries, government, companies of computers and other electronic products, construction industries and others (Brown et al., 2011). Chen et al. (2012) studied how to better serve the needs of business decision-makers by emerging big data, managers and others. Howe et al. (2008) assert big data analytics would become the mainstream of the future research in bio-curation.