Journal of Cleaner Production 103 (2015) 275–285

Contents lists available at ScienceDirect

Journal of Cleaner Production

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

Integrated CO_2, cost, and schedule management system for building construction projects using the earned value management theory

Jimin Kim [a], Choongwan Koo [a], Chan-Joong Kim [b], Taehoon Hong [a,*], Hyo Seon Park [a]

[a] Department of Architectural Engineering, Yonsei University, Seoul 120-749, Republic of Korea
[b] Parsons Brinckerhoff, Seoul 135-763, Republic of Korea

ARTICLE INFO

Article history:
Received 4 October 2013
Received in revised form
5 March 2014
Accepted 10 May 2014
Available online 21 May 2014

Keywords:
Earned value management system
Building construction phase
CO_2 emissions
Elemental breakdown structure
Control account

ABSTRACT

Although the construction phase in a building's life cycle is relatively very short, the density of the CO_2 emissions in the construction phase is very higher than that in the other phases (i.e., operations and maintenance phase). However, there was little research on scheduling, monitoring, evaluating and forecasting CO_2 emissions based on the construction schedule. To address this challenge, this research aimed to develop an integrated CO_2, cost and schedule management (ICCSM) system for building construction projects using the earned value management theory. The proposed ICCSM system consisted of five steps: (i) definition of the project scope and organization; (ii) project planning and scheduling; (iii) estimation and budgeting of the CO_2 emissions and construction costs; (iv) establishment and weighting of the project performance measurement baseline; and (v) monitoring and forecasting of the project performance. The case study showed that the ICCSM system can evaluate and forecast the project performance earlier and more accurately, based on the construction schedule, (i) when integrated weighting was implemented, the project performance can be estimated faster (i.e., one day earlier); and (ii) when $0.8 \times$ (cost performance index) $+ 0.2 \times$ (schedule performance index) was implemented as the index for calculating an estimate at completion, the project performance can be more accurately predicted (i.e., error rate $= -0.24\%$). The ICCSM system could allow a project manager to monitor and forecast CO_2 emissions and costs based on the construction schedule, simultaneously.

1. Introduction

The world has adopted the United Nations Framework Convention on Climate Change to prevent global warming, and in 1997, the 3rd Conference of the Parties announced the Kyoto Protocol. The South Korean government declared that it would reduce the country's CO_2 emissions by up to 30% below the business-as-usual projections (Hong et al., 2012a, 2012b). Meanwhile, it was analyzed that 22.7% of CO_2 emissions were produced in the construction phase (which included the materials manufacturing stage, the materials transportation stage, and the on-site construction stage), and 71.7%, in the operations and maintenance phase. Considering the life cycle period by phase, the density of the CO_2 emissions in the construction phase was very higher than that in the operations and maintenance phase (Chantrelle et al., 2011; Ortiz et al., 2010). Also, a considerable amount of fossil fuel was consumed by the construction industry in South Korea (The 18th Korean Congress, 2012). Subsequently, various studies have focused on the CO_2 emissions in the construction phase, which were calculated based on the criteria presented by the International Standards Organization/Technical Committee 207 (ISO/TC 207) (AIA, 2010; Bilec et al., 2010; Cucek et al., 2012; De Benedetto and Klemes, 2009a; Downie et al., 2013; Evans et al., 2009; Jun et al., 2011; Kellenberger and Althaus, 2009; Kim and Lee, 2009). However, there was no research on scheduling, monitoring, evaluating and forecasting CO_2 emissions based on the construction schedule. In other words, the previous studies only focused on (i) assessing the CO_2 emissions of whole buildings or assemblies at the pre-construction phase, and (ii) assessing the CO_2 emissions in the construction phase based on the types of transportation equipment and on-site construction equipment.

First, several studies have assessed the CO_2 emissions of whole buildings or assemblies at the pre-construction phase based on the structure type, flat type and construction method of a building.

* Corresponding author. Tel.: +82 2 2123 5788; fax: +82 2 2248 0382.
E-mail addresses: cookie6249@yonsei.ac.kr (J. Kim), cwkoo@yonsei.ac.kr (C. Koo), kim.cj@pbworld.com (C.-J. Kim), hong7@yonsei.ac.kr (T. Hong), hspark@yonsei.ac.kr (H.S. Park).

http://dx.doi.org/10.1016/j.jclepro.2014.05.031
0959-6526/

With wood, steel and concrete as structural assemblies, analyses have been conducted on the energy and greenhouse gas emissions in the construction phase (Cole, 1998; Guggemos and Harvath, 2005; Xing et al., 2008) and another studies focused on assessing the CO_2 emissions based on the structural strength of concrete (Hong et al., 2012c; Tae et al., 2011a). Some studies compared flat types of commercial buildings and residential buildings in terms of the CO_2 emissions (Guggemos and Horvath, 2006; Shin et al., 2011; Tae et al., 2011b). Others assessed the CO_2 emissions according to the construction method such as implementation of various energy-saving techniques (Hong et al., 2012d, 2012e; Kim et al., 2012; Lee et al., 2012). According to the construction method in the pre-design stage, the decision support model which was capable of assessing the economic and environmental impact of a project was developed (Hong et al., 2012f, 2014a; Moon et al., 2014).

Second, various studies have assessed the CO_2 emissions in the construction phase based on the types of transportation equipment and on-site construction equipment. CO_2 emissions and engine data from construction vehicles and equipment in a real construction site were collected and analyzed (Frey et al., 2007, 2008). Then challenges to the quantification of emissions of non-road construction vehicles and the associated government regulations and incentives were introduced (EPA, 2004a, 2004b, 2005, 2013a, 2013b; Lewis et al., 2009a, 2009b).

As mentioned above, most of the previous studies have focused on assessing the CO_2 emissions of entire buildings or assemblies at the pre-construction phase, but not on scheduling, monitoring, evaluating and forecasting CO_2 emissions based on the construction schedule in the construction phase. To address this challenge, this research aimed to develop an integrated CO_2, cost, and schedule management (ICCSM) system for building construction projects using the earned value management theory. Especially, this study focused on the economic and environmental impact assessment in the construction phase, which included the materials manufacturing stage, the materials transportation stage, and the on-site construction stage. To achieve this, environmental impact was assessed using the "product-level life cycle assessment (LCA) method" that is one of the four-level methods (i.e., material-level, product-level, building-level, and industry-level). It can be calculated from all the input and output materials in the process of manufacturing a final product. When a quantity takeoff of the product is completed, the amount of the output from each component of the product can be determined (AIA, 2010). Also, this study implemented the "process-based LCA method" as "a cradle-to-gate approach" for assessing the environmental load from the material manufacturing to the on-site construction in the building project. The "process-based LCA method" is one of the two methods to conduct an LCA that is focused on a specific product rather than a sector (Hong et al., 2014a).

The proposed ICCSM system has four specializations: (i) scheduling, monitoring, evaluating and forecasting of CO_2 emissions and construction costs based on the construction schedule; (ii) use of the control account based on the elemental breakdown structure; (iii) calculation of the integrated progress rate through implementation of the weighting of each CO_2 emission, cost or schedule; and (iv) use of a system with a user-friendly interface that allows the final decision-maker to intuitively determine CO_2 emissions and construction costs based on the construction schedule.

2. Research framework

This research aims to develop an ICCSM system for building construction projects using the earned value management theory. It was conducted in five steps (refer to Fig. 1). The '(A)' and '(B)' of Fig. 1 refer to the planning phase and the implementation phase, respectively.

First, the project scope and organization were defined. Using the work breakdown structure (WBS), the CO_2 breakdown structure and the cost breakdown structure, the project was divided into detailed elements. The elements were defined as the control accounts that could be used to schedule the project. Second, the planning and scheduling of the project were conducted. The schedule manager planned the master schedule to comprehensively estimate all resources, including both time and materials. The project was scheduled by establishing the relationship among the control accounts. To reflect the actual situation and increase the reliability of the developed system, the schedule information was established using the probabilistic approach. The project durations on each control account were calculated with the critical path method (CPM) and program evaluation and review technique (PERT) method. Third, the CO_2 emissions and construction cost were estimated and budgeted based on the control accounts. Toward this end, the construction phase was divided into three stages: the materials manufacturing stage; the materials transportation stage; and the on-site construction stage. For each stage, the CO_2 emissions and construction cost were estimated. Fourth, the performance measurement baseline was established based on the schedule information, CO_2 emissions and construction cost for each control account. To improve the precision of the system, control account-based weights were used. Fifth, the project performance was monitored using the measuring element and the analysis element. The final CO_2 emissions and construction costs were forecasted using the projection element.

3. Development of the ICCSM system

3.1. Step 1: definition of the project scope and organization

Depending on the objective of the final end-user, the project scope is defined and the level of detail of WBS is determined. Based on those, a control account can be established, which will result in the basic unit of the proposed ICCSM system for the performance measurement of CO_2 emissions, construction costs and schedules (Halpin and Leland, 1992; NASA, 2010).

Based on the elemental breakdown structure (e.g., the formwork, concrete and steel bar), the control account was set, and the quantities of the different control accounts were summed up. As shown in Fig. S1 of the supplementary data, for example, each floor consists of three control accounts (i.e., tower corewall, perimeter slab (A), and perimeter slab (B)). Also, each control account consists of three activities (i.e., the concrete, formwork and steel bar). Finally, each activity consists of the CO_2 package and the cost package which included the materials manufacturing stage, the materials transportation stage, and the on-site construction stage. The project management is enabled by determining the quantity of the control accounts based on the construction schedule.

3.2. Step 2: project planning and scheduling

The project can be planned and scheduled using CPM and PERT. Toward this end, the information on the preceding task and the duration of each control account should be established. Since the duration has frequency fluctuations in an actual construction site and its trend is uncertain, it is reasonable to use a stochastic value, not a deterministic value (Han et al., 2008). In a construction project where there is insufficient information with which to calculate the duration, a triangular or beta distribution can be used (Hong and Hastak, 2007). Meanwhile, the CPM method can be used based on the preceding task and the duration of each control account (Halpin and Leland, 1992; NASA, 2010; Won et al., 2001).