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Lean-based clean earthworks operation

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ABSTRACT

Earthworks operation occupies only a short period of the total project duration but comes with a high cost, mainly due to the use of heavy machineries and skilled operators. Regardless of the short duration, negative effect of the operation on the environment is detrimental, especially from the perspective of site sediment pollution. However, the current body of knowledge lacks improvement strategies that could enable simultaneous enhancement of the production and environmental factors during the operation period. Due to that, this study aims to seamlessly improve the production (time and cost) and environmental (site sediment pollution) variables by applying the concept of lean production towards achieving a cleaner earthworks operation. As a result, a lean based methodology has been proposed by using case study approach that combines different data collection methods (interview, observation, site document). Findings of the study suggest that lean enables clean. Positive improvements have been observed in terms of time and cost reduction by 42.7% and 24.9% respectively. The environmental factor, Rainfall Erosivity is reduced by 41.8%, consequently reducing the risk of soil erosion and sediment production. Ultimately, the proposed methodology could seamlessly improve both dimensions of production and environment at its source, which satisfies the aim for cleaner earthworks operation.

1. Introduction

Earthwork operation takes place during the early stages of construction where it involves land clearing and grading for a short period of time. Regardless of the short duration of occupation, the environmental threat is detrimental, especially from the aspect of water pollution with sediment as the pollutant (Ooshaksaraie et al., 2009; Taylor and Field, 2007). Therefore, earthwork is a critical work stage that requires proper management because an uncontrolled cleared site could result in sediment pollution (Brown and Caraco, 1997). Sediment pollution could create chains of other problems such as damage to the aquatic ecosystem, health risk to the people and unnecessary cost and resources for remedial works (Harbor, 1999). Conventionally, the risk of sediment pollution during construction has been kept under control using end-of-pipe approaches by allocating erosion and sediment control facilities, e.g. mulches and sediment pond (NZTA, 2010). Those control facilities do come with additional cost and time to be installed (Shaver, 2000). Besides the downside on the production variables of time and cost, treating the already produced pollutant is supposed to be the last approach in terms of environmental management (Hamner, 1996).

Control at source concept such as Cleaner Production (CP) proposes an alternative approach to manage environmental issues by preventing or limiting the occurrence of the pollutant (UNEP, 1996). CP functions to increase productivity through the efficient use of resources while promoting better environmental performance through source reduction and emission (Kjaerheim, 2005; Cabello Eras et al., 2013). Even though CP has provided the basis for improving both dimensions of production and environment, the environmentally driven concept still lacks prescriptive techniques to address the operational inefficiencies in production. It is common for CP to rely on technological changes (Neto et al., 2013) but fundamentally, CP is not all about technology and should start from the basis of improving the current processes through elimination of its operational inefficiencies. On the other hand, LP has been established primarily to improve the performance of operations from the production aspect and has been long-practiced to improve the production processes in various sectors (Womack et al., 1990). Lean has also been proven to benefit in terms of the environment whether as a coincidence or planned benefit. In regards to that, lean is believed to enhance clean (Cobra et al., 2015; Queiroz et al., 2015).

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1.1. Research aim and objective

This study aims to adopt the principles of Lean Production into the concept of Cleaner Production in order to improve the production (time and cost) and environmental (site sediment pollution) variables of earthworks operation. In this study, the term Cleaner Production will be used interchangeably with 'clean' while the term Lean Production will be used interchangeably with 'lean'. The objective of this study is to develop a practical lean-based methodology to enhance the functions of clean in an earthworks operation with the environmental focus on site induced sediment pollution. For this study, the developed methodology will be known as lean-clean.

2. The production and environmental issues of earthworks operation

The production factor of time has been hailed as a crucial variable in earthworks because this operation sets the rhythm for subsequent activities (Fu, 2013). The operation also acquires a relatively high cost in comparison to the time spent on the work, due to the heavy dependence on machineries and skilled operators (Kang et al., 2009). Hence, it is common for productivity to be the subject of interest among the industry players and researches who seek to improve the earthworks operation (Martinez, 1998; Dawood et al., 2010). Previously, the productivity studies have focused on the traditional aspects of construction which are time, cost and quality without relating it to the environment.

However, the current scenario differs due to progressions that have been made towards integrating environment as part of the studies conducted to improve the performance of earthwork operations. For example, Golzarpoor et al. (2013) have provided a synergistic approach that combines the production and environmental factors in determining the cost, fuel and energy usage and carbon emission from the earthwork operations. González and Echaveguren (2012) and Capony et al. (2012) have also conducted similar research using discrete event simulation and GPS technology respectively. However, most of the studies have concentrated on the common issues of air and carbon emission with least regards for site sediment pollution. Typically, the environmental issue of site sediment pollution has long been treated in isolation from the production aspect (Lewis and Hajji, 2012). According to Belayutham and González (2015), the independent treatment of the aforementioned variables of production and sediment pollution will cause contractors to exert imbalance efforts in addressing the different variables. In this case, the environmental issue is commonly being side-lined. Hence, this study intents to identify a common ground between the production and environmental (site sediment pollution) variables of earthworks operation that allows both aspects to be managed seamlessly through the adoption of Lean Production.

2.1. Lean production and earthworks operation

Lean Production (LP) is a manufacturing-based production management philosophy that has been applied in construction with the term lean construction (Koskela, 2000). The application of lean in earthworks for construction projects could be categorized as pure lean or technologically infused lean-approaches (Belayutham and González, 2015). For pure lean approaches, Fidler and Betts (2008) and Kaiser and Zikas (2009) have used lean tools and principles to stabilize and improve the efficiencies of the earthwork's movement, increase equipment utilization, cost reduction and optimize labor resources. For improvements done with the help of technology, Dawood et al. (2010) have produced an interactive visual lean system for earthwork operations planning to achieve transparency, reduce complexity, waste and positive project time. Similarly, Kemppainen et al. (2004) have used two optimization algorithms to assist in finding the most cost-efficient schedule and mass haul alternatives that ultimately increased the functions of the Last Planner System in Finland's construction industry. Meanwhile, Kirchbach et al. (2014) have presented 'digital kanban', a system supported by machine sensory and information technology that embraces lean principles for optimized earthwork productivity. Most works have been done to apply lean to improve the earthworks' production factor, with little effort found to enhance the environmental variable, specifically sediment pollution.

Nonetheless, LP has been combined with green in recent years as the focus on sustainability soars within the construction industry. The relevance has been established as the environmental impact of production processes could be traced back to its inefficiencies (Cabello Eras et al., 2013). The call to integrate lean with the environment has been intense with researches from different industries advocating for the move (Bergmiler and McWright, 2009; Martínez et al., 2009; Lapinski et al., 2006). However, the green-lean integration might not necessarily address the issue of 'source reduction' or prevention per se as the term green represents a more general perspective of managing the environmental effect (Baines et al., 2012). As an example in construction, green construction could involve strategies such as using energy-efficient equipment and recycling of waste that has already been produced (Govenor, 2008), rather than to prevent the occurrence of waste at the first instance. In addition to that, it is rather difficult to distinguish a specific definition for green as the term is broad and could relay different meaning to different person (Zaini and Endut, 2014). Therefore, this study intents to utilize a specific 'control at source' environmental concept, which is Cleaner Production (CP), that has a clear definition of scope for application so that an orderly method of implementation could be proposed.

2.2. Cleaner Production and earthworks operation

Cleaner Production (CP) is "the continuous application of an integrated preventive environmental strategy applied to processes, products and services to increase the overall efficiency to reduce risks to humans and the environment" (UNEP, 1996). CP functions to increase production's productivity through efficient use of the resources and to promote better environmental performance through source reduction (Kjaerheim, 2005; Cabello Eras et al., 2013). The emphasis is to prevent the production of pollution rather than to depend on the end-of-pipe systems where pollutants are being treated after it has been produced (Huisingh and Bass, 1991).

A bibliographic study by Giacchetti and Aguiar (2015) on the term CP using the Scopus database found that journal with significant prevalence on this subject is the Journal of Cleaner Production. Therefore, literature search for CP in regards to earthworks operation has been conducted in the CP focused journal. The search in the aforementioned journal using the term 'earthworks' has resulted in 43 returns. Within the 43 results, only 2 articles (Belayutham et al., 2016a, 2016b) have discussed particularly on the environmental aspect of site induced water pollution (sediment pollution). From the articles, only 1 article has integrated the use of lean towards cleaner earthworks operation. However, the article has only focused on the off-site related administrative inefficiencies (Belayutham et al., 2016a). Besides that, most of the other earthworks related studies have focused on other environmental variables such as carbon emission (Trani et al., 2016), greenhouse gas emission (Barandica et al., 2013), energy consumption (Cabello Eras