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A LEAN APPROACH TO MANAGE PRODUCTION AND ENVIRONMENTAL PERFORMANCE OF EARTHWORK OPERATION

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ABSTRACT

Earthworks comprise of only a small number of activities, equipment and personnel but relatively large percentage of the total construction cost. Uncontrolled earthworks could increase risk to the environment, especially water pollution. Both production (time, cost and quality) and environmental measures are critical during earthworks and should be managed and improved holistically. Past researches have established the applicability of lean to improve the performance of production and environment in construction. However, limited results were shown for earthwork operations. Most lean based studies on earthworks focused on production planning and increasing productivity of the operation, neglecting the environmental emissions, particularly water pollution. Therefore, this paper aims to simultaneously improve the production and environmental performance (water pollution) of earthwork operations through the application of lean production. Thus, lean tools were used to recognize current production and environmental inefficiencies within an earthwork operation. Then, improvement strategies will be proposed in combination with common construction management practices such as site layout management and time planning to reduce and eliminate waste. The research findings could potentially provide direct production and environmental benefits to the construction industry as well as a safe and conducive setting to the public during construction.

KEYWORDS

Earthwork, production, environmental sustainability, lean construction, water pollution.

INTRODUCTION

Earthwork operation involves mass clearance and movements of earth around and outside construction site. This operation is critical as the resulting performance of this preliminary process may 'make or break' the following processes (Fu, 2013). Production (time, cost, quality) performance has commonly been the measure of

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success for this operation, over the environment (Lewis and Hajji, 2012). The imbalanced treatments of both criteria tend to push contractors to address one more than the other (Taylor and Field, 2007). However, the relation between production and environment could be closer than perceived. Earthwork operation involves the stripping of land cover that induces damaging processes e.g., excessive runoff, erosion and sediment, that increases the risk of water pollution. Apart from topography and geographical aspects, production factors such as time could also determine the severity of the damaging processes (Brown and Caraco, 1997). The common end-of-pipe system (silt trap, sediment pond) could only mitigate the resulting damages and do not prevent the occurrence in the first place. Allegedly, prevention strategies such as construction phasing are a better option in comparison to the mitigation approach (Brown and Caraco, 1997). The prevention strategies do involve strategizing the production factors, especially time, to minimize processes of excessive runoff, erosion and sediment production. In order to improve the production factors, lean production has progressively being used to enhance productivity in many areas including earthwork operation (Fidler and Betts, 2008). However, the vague link between production and environment has caused lean efforts to undermine the inclusion of the environmental dimension, which includes water pollution. Therefore, this research aims to simultaneously improve the production and environmental performance (water pollution) of earthwork operations through the application of lean production.

LITERATURE REVIEW

Earthwork has been plagued with productivity issues, consequently igniting interest among researches who are seeking to improve this construction operation (Martinez, 1998; Dawood, et al., 2010). Earthwork's progression is crucial in the development of a project because it determines, to a large extent, the proper flow of work for the following activities (Fu, 2013) that affects the time factor in a project. Furthermore, the requirements for expensive heavy equipment and skilled manpower involve major cost in a project. Earthwork has an influential effect on the overall success of a construction project but the uncertain and highly variable environment makes the success hard to achieve (Kirchbach, Bregenhorn, and Gehbauer, 2012). Various factors could affect the performance of an earthwork operation e.g., types of soil, haul road, site access point, location of borrow pit, construction method and equipment availability (Martinez, 1998). In addition to that, weather, operator's experience, haul distance and gradient, schedule restriction and conflict with other activities/ obstructions could also dampen an operation's performance (Christian and Xie, 1996; Martinez, 1998).

Earthwork only occupies short time period of a whole construction but the potential risk and threat to the environment is great through large scale of clearing and grubbing operations (Taylor and Field, 2007; Ooshaksaraie, et al., 2009). A calculated Universal Soil Loss Equation (USLE) figure for a cleared earthwork site reveals an estimated 16.14 tons of sediment production, in comparison to the pre-earthwork yield of 3.20 tons (Pain, 2014). If a cleared site is left uncontrolled and mismanaged, severe soil erosion and sediment production could take place, leading to water pollution (Ooshaksaraie, et al., 2009). Mass grading creates two critical variables i.e., time and size of area exposed, that should be well managed to minimize the negative effects of site clearance (Brown and Caraco, 1997; Pain, 2014).

Commonly, the environmental problems arising from earthwork operation has been treated in isolation from production (Lewis and Hajji, 2012). The independent treatment creates segregated efforts that may trigger the notion of one more important than the other. Hence, to mitigate this situation, mutual benefits by integrating production and environment should be demonstrated. Works have been done to integrate both the elements of production and environment in earthwork. Lewis and Hajji (2012) and Golzarpoor, et al. (2013) have provided a synergistic approach that combines production and environmental factors to determine the cost, fuel, energy and emission from earthwork operations. Gonzalez and Echaveguren (2012) and Capony, et al. (2012) also conducted similar research using discrete event simulation and GPS technology respectively. However, most of the studies concentrated on the issue of air and carbon emission with least regards for water pollution. Therefore, this research attempts to fill the knowledge gap by managing environmental issue of earthwork, from the standpoint of water pollution that also benefits the production.

LEAN EARTHWORK

In the area of earthwork, most lean approaches have been utilized to improve work production, whereby the approaches could be categorized under pure lean and technologically infused lean approach. For pure lean approach, Fidler and Betts (2008) and Kaiser and Zikas (2009) have used lean tools and principles to stabilize and improve the efficiency of the earthwork movements, increase equipment utilization, reduce cost and optimize labor resources. For improvements done with the help of the technological system, Dawood, et al. (2010) produced an interactive visual lean system for earthwork operations planning to achieve transparency, reduce complexity, waste and project time. Similarly, Kemppainen, et al. (2004) used two optimization algorithms to find the most cost-efficient schedule and mass haul alternatives that ultimately increased the functions of Last Planner system in Finland's construction industry. Kirchbach, et al. (2014) presented 'digital kanban', a system supported by machine sensory and IT that embraces the lean principles for an optimized earthwork productivity. Most studies applied lean to improve earthworks' production with little effort found to enhance the environmental variable.

LEAN AND ENVIRONMENT

Lean philosophy and environmental sustainability are two different concepts, conceived to address different goals. Pioneered in the manufacturing sector, lean approach has been widely credited for its potential to improve the production aspect of the industry. On the other hand, environmental sustainability is focused on reducing environmental impacts such as energy usage and greenhouse gas emission amongst others (Miller, et al., 2010). Despite the differences, Carneiro, et al. (2012) and Belayutham and Gonzalez (2013) suggested for both philosophies to be used complementarily. This is supported by benefits shown from growing amount of works on the integration of lean and environment in various sectors. Bergmiller and McWright (2009) found that manufacturing plants that implement lean in their production system tend to be greener than other common manufacturing plants. For a home manufacturing plant, the utilization of lean tools have increased process efficiency and reduced material wastage (Nahmens, 2009). Lean philosophy has also simultaneously improved the production and carbon efficiency in a precast concrete production (Wu and Low, 2012). In construction, Huovila and Koskela (1998) proposed to combine lean construction with sustainability objectives to eliminate material waste, minimize resource depletion and pollution.

RESEARCH METHODOLOGY

This paper displays a combination of theory and practical aspects of lean approach to enhance the production and environmental performance of an earthwork operation. Descriptions on the research methods employed to define the different aspects of Lean Earthwork Framework is shown in Table 1.

Table 1: Research Methods

Lean Earthwork Framework Aspects	Research Method	Details of Research Method
Step 1: Value	Literature Review	
Step 2: Value Stream	Literature Review Document analysis Observation Interviews	Literature review: Journal, conference, books, electronic articles, thesis. Observation: One earthwork site, one month duration.
Step 3: Flow	Interview Observation Document analysis	Interviews: Four earthwork contractors with an average of 15 years working experience.
Step 4: Pull	Interview Observation	Document analysis: Daily site diary.
Step 5: Continuous Improvement	Interview	

LEAN EARTHWORK FRAMEWORK

This framework will encompass the application of the five principles (value, value stream, flow, pull and continuous improvement) of lean thinking by Womack, et al. (1990) to enhance the earthwork operation. Using earthwork as an example, this framework could potentially be adapted to improve other operations, in line with the vast applicability of lean across different industries and sectors (Huovila and Koskela, 1998; Bergmiller and McWright, 2009; Nahmens, 2009; Wu and Low, 2012).

STEP 1: VALUE

Lean tools: SIPOC and 5 Whys

In an earthwork operation, the production and environmental variables have been dealt in isolation without considering the overall view on how it could relate, complement and impact each other. Therefore, to improve both variables simultaneously, point of similarities should first be established by deciding the value of the operation. For earthwork, the value from production and environmental perspective (water pollution) can be distinguished by identifying customers' voice using the SIPOC (Supplier-Input-Process-Output-Customer) tool, as shown in Figure 1. In general, customer is the recipient of the output from a process. Two outputs are involved e.g., production and environmental output, that needs to satisfy a set of different customers and requirements.

Supplier	Input	Process		Output	Customer	Requirements
• Earthwork Contractor	• Equipment • Skilled workers	Earthwork Operation Cut → Haul → Fill	PRODUCTION	• Graded earth • RL Platform	• Client • Next contractor	• Timely delivery • Within budget • Accepted quality
• Design engineer	• Earthwork plan • Erosion & Sediment Control plan		ENVIRONMENT	Land surface transformation • Excessive runoff • Erosion and sediment	• Receiving environment and its surroundings	• Clean water • Reduced emission to water body

Figure 1: SIPOC for Earthwork Operation

From Figure 1, there are no clear similarities shown between the customers' requirements (value) for production and environment (water pollution). Hence, a further derivation is required to find the point of similarity. To do so, a lean technique called 5 whys was used to derive potential factors that could affect the achievement of the value. 5 whys is a lean technique used to identify the root cause of a problem. The question why a problem exists is being asked and the answer is written below the aforementioned problem and the procedure will be repeated five times. The derivation could potentially provide a point of similarity, consequently providing one common value to be considered for both the production and environment (water pollution).

The derivation of the 5 whys for both variables have been conducted with the support of literature, shown in Figure 2. The factors derived for water pollution were taken from literatures (Shaver, et al., 2007; Kaufman, 2000; Brown and Caraco, 1997). Similar method was applied to identify the factors for earthwork production inefficiencies (Christian and Xie, 1996; Martinez, 1998). From Figure 2, time is identified as the point of similarity since both aspects of production and environment are affected by time. Time shortening of the earthwork operation could eliminate time overruns as well as reducing the number of rainfall incidents, consequently minimizing the risk of water pollution. Throughput time is recognized as the most utilized measurement factor to understand movement in processes (Koskela, 1992).

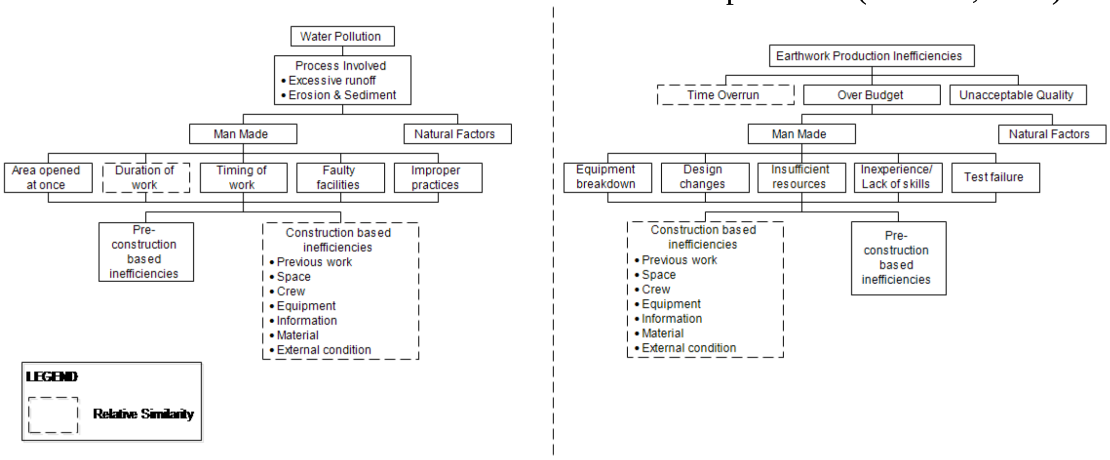

Figure 2: Point of similarity between earthwork production and environment

This step has provided a theoretical integration of value (time) to simultaneously improve the production and environment (water pollution) variables in an earthwork operation. For the purpose of this paper, it is presumed that the following lean steps to improve the time factor will benefit both the production and environment (water pollution).

STEP 2: VALUE STREAM

Lean tool: Gemba, Value Stream Map (VSM)

VSM was used to portray the current processes involved in the earthwork operation and comprised of three main processes which are cut, haul and fill. The main processes involved in an earthwork operation were earlier defined by Martinez (1998). In order to further derive the performance metrics of the operation, productivity scale for the operation should first be understood. Earthwork productivity could be measured with volume of earth per unit of time (m^3/t). Therefore, the flowing unit in this operation is m^3 of earth. In order to portray the details of earthwork in a VSM, data for the required indicators are shown in Table 2 (NZQA, 2015):

Table 2: Measured Indicators

Indicators	Measurement	Indicators	Measurement	Indicators	Measurement
Start day	Month/ day	Finish time	Hour/ mins.	No. of workers	No.
Finish day	Month/ day	Non-working days	Day	No. of trips	No.
Start time	Hour/ mins.	Distance travelled	m	No. of equipment	No.

From the indicators, production factors e.g., lead and cycle time, haul and return time, average haul distance, idle time, productive time, break time and output per day can be calculated. Current VSM based on the aforementioned processes and indicators is shown in Figure 3. The map details the progression of processes involved in one cycle of operation. After discussion with the site engineer, it is agreed that a single cycle of work would best be represented by 10 unloads to portray the earth movement with its related equipment. Therefore, 1 cycle = 10 unloads of earth.

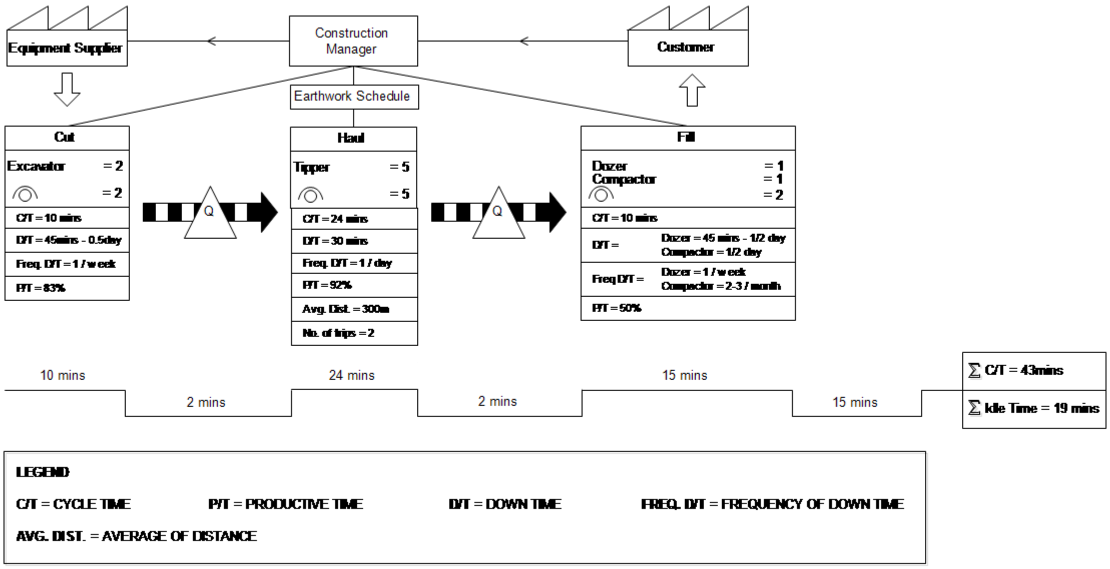

Figure 3: Current Map for Earthwork Operation

In this VSM, the use of lead and cycle time is aligned with the definition by Hopp and Spearman (2008) whereby, lead time is the maximum allowable cycle time for a job whilst cycle time is the average time for a job to go through a line. The reduction in lead time will shorten the period of operation, consequently reducing the risk for water pollution inducing processes i.e., excessive runoff, erosion and sedimentation due to rainfall.

STEP 3: FLOW

Lean tools: Root cause analysis

Figure 3 illustrates the process flow that shows VA (cycle) and NVA (idle) times when earth was not being worked on. The percentage of NVA (idle) time is 30.6% of the total lead time of 62 minutes. A large portion of the idle time (15 minutes) was found at the fill area where the dumped soil was not being worked on till it reaches 10 unload. Even though the idle time did not cause congestion to other work sections, the two idling machineries (dozer and compactor) represent waste in resources. A smaller portion of the total idle time can be seen at the cut area with 2 minutes idle time as the excavator waits for the tipper. In serving 5 tippers for a return haul trip of 12 minutes/ tipper, the excavator will have 2 minutes of idle time. Even though the figure seems small, cumulatively it could reach up to 40 minutes per day with a total loss of 280 m^3 soil.

Besides the obvious idle time waste, cycle time may also disguise some major flaw within the site practices, causing cycle time to be longer than necessary. An ideal cycle time is usually provided by the manufacturer but could vary due to different factors mentioned by Martinez (1998). Interviews were conducted among site personnel. From the interview, major contributing factors are given below, positioned from highest to lowest frequencies:

Frequent --> *Occasionally*

Machine breakdown; Weather (rain); Underground services

In addition, respondents were also asked about practice related factors that could affect the earthwork cycle time and productivity. The factors are given as follows:

- Skill and experience of the equipment operator is really important where the difference between experienced and less experienced ones could result in shortages of approximately 20 m^3 /day or 3 trips of tipper.
- At the cut section, the position and turning point/ swivel degree of the excavator creates differences in time and efficiency. Smaller swivel point is much efficient than large swivel points.
- At the fill section, cycle time increases when tipper unload soil far from the dozer. Common improper practices can also be found with compactors where vibrators were not activated in attempt to reduce cost. Non-vibrated compactor could cause a longer cycle time besides further damages such as failed compaction test that leads to unnecessary halt of the operation.

Hence, various reasons could be traced back in attempt to identify the root cause including some of the factors proposed by Koskela (1992), e.g., crew, equipment, information, external condition and previous work.

STEP 4: PULL

Lean tool: Just in Time (JIT)

The current processes (Fig. 3) are linked to each other using the traditional push system. Earth will be loaded by excavator into the tipper, which then will pass it on to the fill section. The push system created an overloading on tippers as there were insufficient tippers to satisfy the excavator's supply, consequently creating waiting period for the excavator. Mismatch happens when push is being applied without matching the availability of tipper, resulting in 2 minutes idle time per cycle for the excavator. The JIT technique allows contractors to critically plan their equipment usage, productivity and distance travelled in order to smooth the work flow.

STEP 5: CONTINUOUS IMPROVEMENT

Lean tool: Future map VSM, Kaizen

For this paper, the future map will not be drawn but suggestions for improvement are provided to increase the productivity of the operation, consequently resulting in shorter time and reduced risk of water pollution. In order to improve the current processes, the ill practices identified during the observation and interview should be eliminated (Refer Step 3: Flow).

For future improvements, earthwork planning should be done in conjunction with construction planning elements e.g., site layout, schedule and method. Proper site layout planning could enable the shortest haulage distance between process locations. Integration with construction schedule allows work sequences that do not necessitate the clearance of site at one go. This technique of construction phasing also promotes the preventive measures of water pollution as land will only be cleared when it is ready to be worked on. This could potentially be one of the strategies to manage the idle time found at the fill section. Schedule could be strategized for the fill section to be worked only once a day. Meanwhile, the dozer could be used to clear areas bit by bit, without the common whole site clearance. This strategy could eliminate the prior site clearance time (3 months for the site studied) as well as eliminating the idle time. This strategy provides mutual benefits for production and the environment (water pollution) since land will not be left open for long due to shorter operation period.

CONCLUSION

In an earthwork operation, the production variables (time, cost, quality) has often been the emphasis without realizing the potential harm the environmental aspect could have on production, if the latter is not being managed well. This research has illustrated the application of lean to simultaneously improve the production and environmental (water pollution) variables in an earthwork operation. A theoretical framework was drawn at Step 1 (value) to show essential link between both variables that could encourage contractors in working towards similar goal. The practical demonstration of certain lean tools at Step 2 (value stream) and Step 3 (flow) enables construction team to identify deficiencies in current workflow that affects the production rate and risk towards water pollution. The solutions proposed at Step 4 (pull) and Step 5 (continuous improvement) when being integrated with construction planning elements at initial work stages could produce a production and environmental friendly construction plan. Academically, the framework has filled the knowledge gap to integrate lean with the environment (water pollution), which was previously absent. A longer duration of study could provide a more comprehensive picture on the productivity of the operation. Future research will well benefit the construction industry when parts of this research are integrated with IT systems such as Building Information Modelling (BIM). BIM features such as what-if scenarios allow the generation of an optimal construction plan in terms of space, resource and time availability that benefits both production and environment (water pollution).

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