INTEGRATING LEAN INTO STORMWATER RUNOFF MANAGEMENT: A THEORETICAL EXPLORATION

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ABSTRACT

The integration of lean production and environmental initiatives are gaining the attention from construction researches looking into areas to improve by assimilating the best of both concepts. Current construction research has proven the effectiveness of lean in reducing both production and environmental waste. However, environmental waste produced by polluted water from construction sites has not received much attention as there is a lack of management tools to deal with this issue. Conventional runoff management focuses more on mitigating the already existing runoff than preventing it from occurring. This research aims to explore the means for preventing and reducing the quantity of site runoff by utilising lean management principles and tools. This research will first identify the links between lean and site runoff by demonstrating the theoretical relationship between both elements. Then, lean management and Low Impact Development (LID) concepts will be explored to cope with both production and environmental waste. Finally, an integrated framework to better manage runoff using lean management principles will be presented. In practice, this framework provides a clearer picture to contractors and government agencies on the preventive measures that could be applied for runoff management.

KEYWORDS

Production Waste, Site runoff, Environmental Waste, Low Impact Development, Flow, Lean Production, Construction Management.

INTRODUCTION

Excessive construction site storm water runoff induces erosion and sediment that poses threat to the natural aquatic ecosystem and the human population. In the U.S., erosion rates from construction accounts for 10% of the nation's overall sediment load, even though construction only occupies 0.007% of the land area (as cited in Burton and Pitt 2002). In New Zealand, major sediment discharge wiped out the trout population from a stream near Auckland (North Shore City Council 2010). Current runoff management based on control has failed to prevent and reduce runoff. To overcome the inadequacies of the current system, an alternative approach called Low Impact Development (LID) has emerged. LID aims to maintain the natural hydrologic

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functions of a site by inhibiting and retaining the runoff (Department of Environmental Resources 1999)

The principles of LID implementation coincided with certain Construction Management (CM) elements. Although both concepts aimed at addressing different issues, there are linkages between them that allows for an integrated runoff management approach. However, it is argued that the potential LID and CM integration can be neglected due to the inefficiencies of the current CM framework (theoretical and practical). Conventional CM may not be able to smooth the process flow that may create delays and waiting between activities. This may create excessive runoff. Lean principles have proven to be beneficial to overcome the current CM limitations. Therefore, lean principles are introduced here to recognise the inefficiencies, to benefit in flow of processes as well as to reduce runoff. So, it is argued that lean can enhance the integration of LID and CM approaches to manage storm water runoff.

Research (Huovila and Koskela 1998; Vieira and Cachadinha 2011; Novak 2012) have been conducted to find out the synergy between lean and the environment, but site runoff issues have yet to receive much attention from the researchers. Hence, this research aims to provide a theoretical framework to manage site runoff by integrating LID and CM that is supported with lean principles. The research question for this study is as follows: Can lean production and storm water runoff management be linked at a conceptual level, in order to reduce runoff waste? This research will identify links between lean and site runoff by demonstrating the theoretical relationship between both elements. Then, lean management and Low Impact Development (LID) concepts are explored to cope with both production and environmental waste. Finally, an integrated framework to better manage runoff using lean management will be presented. The first section of this paper provides an overview of LID, CM and lean. Within this section, LID is being integrated into CM dimensions. The following section explores the assimilation of runoff into lean concept and finally, a management approach in addressing site runoff is provided. This exploratory and conceptual paper is part of a long term study in managing site runoff utilising CM approaches.

LITERATURE REVIEW

Runoff is a by-product of the interaction between land and rainfall. A formal definition of storm water is rainwater that has landed either on the ground, a roof or other impervious areas (Auckland City Council 2009). Storm water runoff may impact the environment through the quantity and quality of water. Increase in water quantity could lead to erosion and sediment that induces flood as well as landslide. Whereas, deteriorating water quality could create non-point source pollution that may affect the habitat and ecosystem of aquatic resources. Primary pollutant embedded within the runoff from construction site is sediment, along with other pollutants such as concrete wash out, construction debris, chemicals, oil and grease, pesticides, solid and sanitary waste (US EPA 2005).

Construction activities often create disturbance to the natural environmental setting thus changing the natural hydrologic cycle (dispersion of precipitation through infiltration, evaporation and transpiration) of a site. Site clearing removes vegetative covers, exposing impervious surfaces that does not allow for retention and infiltration of runoff. Instead of soaking into the ground, runoff due to precipitation will flow across the area in a larger quantity than before.

Conventional storm water runoff management focused on removing runoff from sites as fast as possible via impervious surfaces such as temporary drains which end at a discharge point such as stream. Those practices caused increment in the volume, frequency and rate of discharge while reducing the crucial concentration and travel time. Subsequent problems such as flooding and stream erosion may lead to the necessity for larger capacity of Best Management Practices (BMP) facilities (Low Impact Development Center 2000).

Low Impact Development (LID) is an alternative approach in storm water management that allows the natural hydrologic functions to take place (Department of Environmental Resources 1999). LID is perceived as a long term storm water management system to reduce as well as to improve the quality of runoff from site (Davis 2005). Even though it is a long term approach, the principle of LID, that is to prevent instead of mitigate is beneficial and suited to be applied at construction sites. LID techniques could be categorised into structural and non-structural approach. Structural approaches may require the installation of bio retention, infiltration trenches, wetlands, grass swales and permeable pavements. The prevention approach is known as the non-structural approach that involves site design that creates minimal site disturbance by preserving natural features and reducing impervious areas (Hunter et al. 2010). LID guidelines provided several approaches that could be employed by contractors in preventing runoff during construction. Even though LID and CM are two very different concepts, the requirements for the non-structural approach implementation would be best assisted with proper CM techniques. Therefore, a comprehensive review was done on different LID guidelines (Department of Environmental Resources 1999; Hinman 2005; New Hampshire Department of Environmental Services et al. 2008; Farrar-Nagy 2002) to identify the relevant requirements. The requirements were later categorised into three CM dimensions, as shown in Figure 1.

In order to enhance LID implementation, present CM should be improved. According to Koskela (2000), current theory of project management could not resolve the on-going construction problems of cost, time and quality. Koskela and Howell (2002) revealed that there is a need for a new construction theory due to the flawed existing theory. Current theory of project management is based on the transformation/conversion view that does not acknowledge flows and waste in construction. Production flow is a combination of processing activities (transformation) and flow aspects (inspection, waiting and moving). The common ignorance of the flow aspects may lead to inefficiencies that create waste. Waste is anything that consumes time, resources and space but does not add value to the product. Ohno (1988) defined seven types of waste commonly found in production, as shown in Table 1. In addition to that, Womack and Jones (1996) added goods and services that do not meet customers' needs to the waste list. Common construction is laden with waste that negatively impacts the performance of construction. Several researchers have identified waste and the causes of it in construction (Lee et al. 1999; Polat and Ballard 2004; Rashid and Heravi 2012). In general, the causes of waste identified could be influenced by the 7 flows in construction, identified by Koskela (2000). The 7 important elements for smooth flow in construction are: 1) Previous

Works; 2) Space; 3) Crew; 4) Equipment; 5) Information; 6) Material; and 7) External Condition.

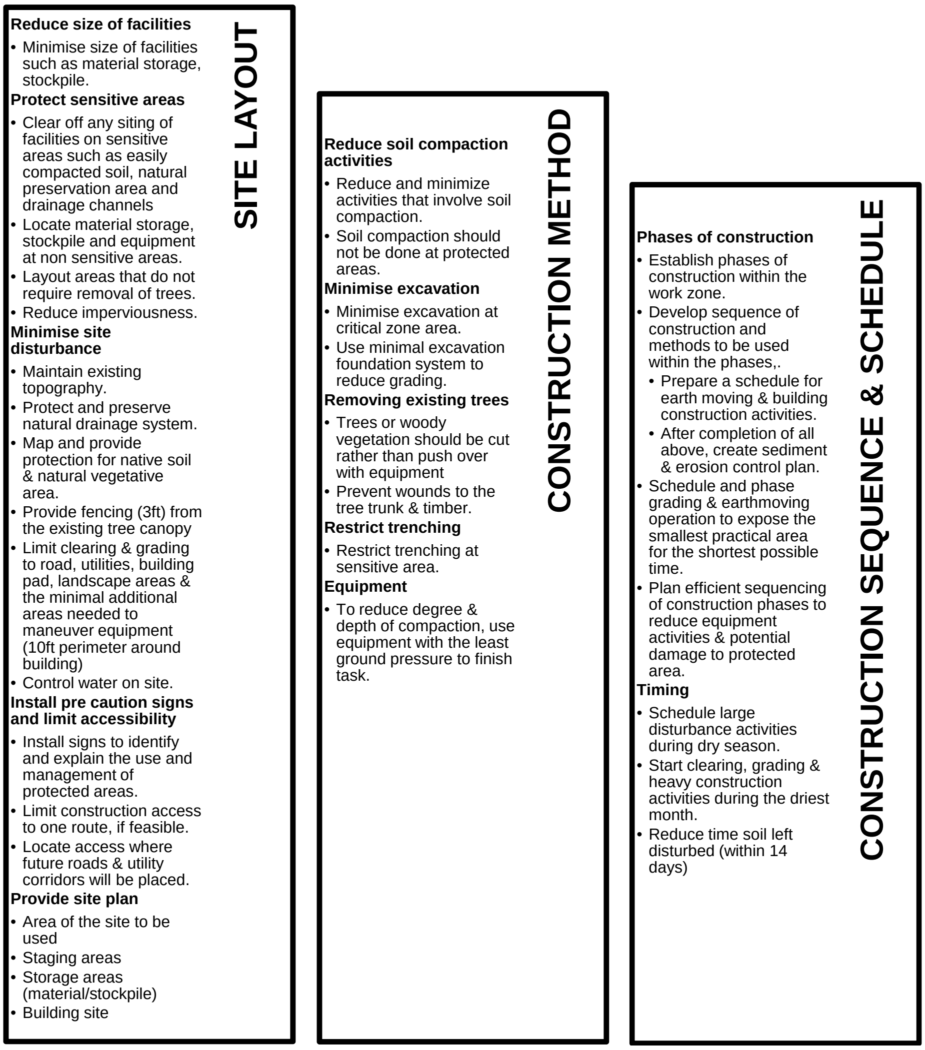

Figure 1: LID Guidelines in Accordance to Construction Management Dimensions Adapted from (Department of Environmental Resources 1999; Hinman 2005; New Hampshire Department of Environmental Services et al. 2008; Farrar-Nagy 2002)

Table 1: Description of Production Waste (Ohno, 1988)

Waste	Elaboration
Overproduction	Produce more than it is required.
Waiting	Waiting of any resources that cause gap and delay between activities
Transportation	Excessive movement of material, equipment, information.
Over processing	Additional steps in processes that are not required.
Inventory	Large number of material in store.
Movement	Unnecessary movement of workers that caused them delays in work.
Defect	Error in process, error in resources, correction and rework.

Inefficiencies in current construction do not only negatively affect the cost, time and quality of a project but also the environment. Generally, lean thinking and environmental efforts are two different concepts, conceived to address different goals respectively. Recent years has brought changes to the application of lean concept, whereby environment is integrated into lean by introducing it as one of the value component of production (i.e.adding it as a new customer) (Horman et al. 2004). Studies were also conducted to establish the synergy between lean construction and sustainability (Huovila and Koskela 1998; Vieira and Cachadinha 2011; Novak 2012). Previously, environmental benefits were found to be a by-product of lean implementation. However, recent years have seen researchers deliberately applying lean concepts to reduce negative environmental impacts (Bae and Kim 2007; Martinez et al. 2009; Nahmens 2009; Carneiro et al. 2012). Adding environmental waste in addition to waste defined by Ohno is beneficial to increase the level of competitiveness and at the same time, environmental waste could be reduced (Wu and Low 2012 ; Rosenbaum et al. 2012) .

THEORETICAL FRAMEWORK

The lean concept incorporates the view of flow and value in addition to the conversion model (Freie and Alarcon 2002). A smooth process flow can increase value to the customer by minimising waste. It may be argued that there is a relationship between the two elements. Hence, inefficiencies in flow of work (Koskela, 2000) may result in production waste (Ohno, 1988). By recognising the mismanagements in flows, production waste could be reduced. This concept is represented in Figure 2.

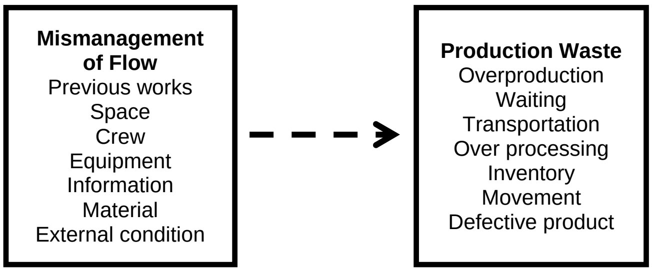

Figure 2: Relationship between Mismanaged Flows and Production Waste Adapted from (Koskela 2000) and (Ohno 1988)

From a construction standpoint, production waste such as waiting times may happen due to the delay of a previous activity, inefficient space allocation, low productivity of a crew, deficient or insufficient equipment, delay in information flow, unavailability of material and external situations such as heavy downpour. Relatively, shortage of material may cause waiting, overproduction of other activities and defective output if less favoured material were used to replace the current unavailable material. The authors claimed that each of the mismanaged flows may affect different production waste and it varies across different projects. According to Viana et al. (2012)'s review on construction waste, the authors can argue that all those waste can be characterised into the traditional production waste. However, waste that was not included in the common production waste is the environmental waste. Environmental waste could be defined as the excessive use of resources that results in affluence released into the air, water or land that may endanger people and also the environment (US EPA 2007). From a lean standpoint, environmental waste does not add value instead increases cost through the excessive consumption of resources. This concept is similar to lean whereby lean waste also does not add value to the customer; in turn it elevates cost and time to the end user. In theory, production waste may cause environmental waste. However, the difficulty in relating both lean and environment is due to the fact that environmental waste is not the focus of improvement in traditional lean management. Table 2 provides the example of relationship between lean waste and how it connects to the environmental waste (US EPA 2007).

Table 2: Example of Relationship between Production and Environmental Waste Adapted from (US EPA 2007)

Production Waste	Environmental impacts	Environmental Waste
Overproduction	Overuse of hazardous materials may result in health hazard	Hazardous waste
Inventory	More energy (lighting, cooling)required for storage area	Excessive consumption of energy
Transportation	Emission from transport	Air pollution, dust
Defects	Raw material and energy consumed but useless	Material and energy waste
Waiting	Energy wasted	Excessive consumption of energy
Over processing	More raw materials consumed	Excessive raw material used
Movement	Unnecessary movement may cause delay to work	Excessive consumption of energy

Similar to other environmental waste, excessive runoff from site is perceived as an environmental waste that needs to be eliminated or prevented. Excessive runoff causes erosion and induces sediment that pollutes water bodies. Water pollution does not add value to the customer and may result in additional cost and time, as the need for erosion and sediment control structures increases. In order to put site runoff into a lean perspective, the main elements of lean needs to be identified and clearly defined to the interest of reducing runoff. The integration of runoff into lean elements is given in Figure 3. The customer in this situation would be the society and environment. The society would expect reduced water pollution while the environment will be less burdened with the negative impact of runoff. In order to make this concept applicable, contractors have to acknowledge the environment as one of the customers in addition to the customer that pays for the output. Waste to the environment should include environmental waste produced such as excessive runoff. The value appreciated by the customer would be the reduced runoff from site that leads to cleaner water for use.

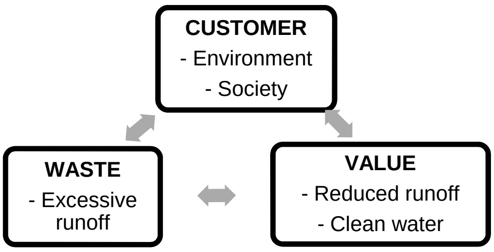

Figure 3: Integration of Runoff into Core Components of Lean Concept

As mentioned, excessive runoff in terms of quantity and quality occurs when runoff flows without resistance on impervious areas. Excessive clearing of site, disturbed soil left for a long duration and excessive compaction are the core problem that induces site runoff. Those factors could be summed as inefficiencies of CM and the stated problem could be eliminated with the use of integrated LID and supported by lean concepts. The interaction between the CM inefficiencies with production and runoff waste is shown in Figure 4. The effect of inefficient CM leads to production waste that generates runoff waste.

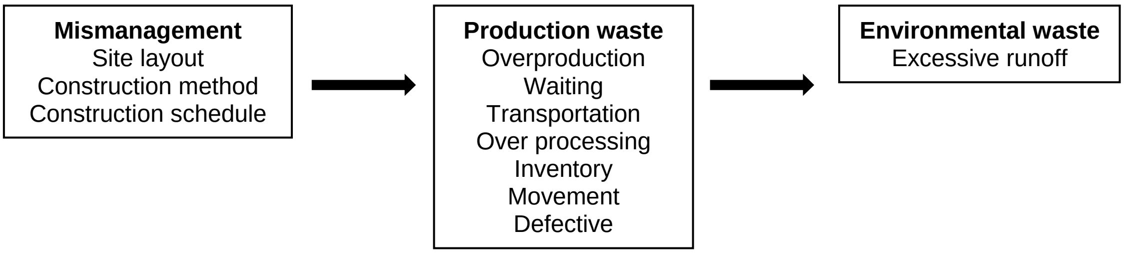

Figure 4: Mismanaged CM elements with Production and Runoff Waste

A comprehensive elaboration on runoff waste in accordance to the production waste is given in Table 4. The elaboration were given under the scope of three construction management elements that affect site runoff, which are site layout, construction method and construction schedule. The possible causes of waste contributors were taken from Koskela (2000)'s 7 flows in construction, assuming that they are mismanaged.

Table 4: Integration between Production with Runoff Waste with Flow

Site Layout Management		
Matters of concern: Position of facilities, Distance between facilities, Size of facilities, Disturbance to natural vegetation & Disturbance to natural topography		
Waste	**Elaboration on waste**	**Possible causes of waste**
Overproduction (resources)	During site clearance, excessive earth removal may require larger stock pile area. Cutting excessive tress and vegetation may lead to larger open land.	Crew, Equipment, Information
Waiting	Long distance between facilities may cause waiting and delay between activities. Hence, may leave soil disturbed. For example: Distance between excavation and soil disposal area.	Space, Crew, Equipment, External condition
Transportation	Huge distance between facilities may cause excessive mobility of equipment and material that may cause soil compaction. Unnecessary movement of equipment. Improper route plan.	Space, Crew, Information
Over processing	Excessive clearance of land such as clearing of natural vegetation and slope cutting.	Crew, Equipment, Information
Inventory	Excessive material may require huge storage area and may cause soil compaction with larger area to be cleared.	Crew, Information, Material, Previous work
Movement	Workers walk between facilities that do not cause physical harm but may cause delay in finishing the work.	Space, Crew, Information
Defect	In efficient position of facilities on sensitive areas such as on infiltration and drainage area.	Crew, Equipment, Information, Space
Selection of Construction Methods		
Matters of concern: Excessive compaction, Choice of heavy equipment, Excessive clearing and grading, Minimise excavation, Method that affects natural water ways & Method of removing trees		
Waste	**Elaboration on waste**	**Possible causes of waste**
Overproduction (work)	Excessive cut of tree and natural vegetation.	Crew, Equipment, Information, Space
Waiting	Choice of method that causes idleness in the process that leads to soil compaction by heavy equipment.	Crew, Equipment
Transportation	Heavy equipment causes compaction. Alternately, choose lower load equipment.	Equipment, Crew, Information
Over processing	Unnecessary compaction, surpass the required	Crew, Equipment, Information

	standard. Excessive clearance and grading. The type of equipment chosen is much heavier than the alternative lighter one.	
Inventory	Material ordered in bulk requires large storage area.	Crew, Material, Space,, Material
Movement	Method that requires unnecessary movement and may cause delay.	Information, Space, Crew
Defect	Error in the method or work that creates damage and may require redo.	Crew, Information, Previous Work, Equipment, External Condition
Construction Schedule and Sequence		
Matters of concern: Land clearing and grading conducted during wet season**,** Construction phasing for minimal exposure**,** Construction sequence to reduce equipment activities**,** Change to natural slope and drainage system		
Waste	**Elaboration on waste**	**Possible causes of waste**
Overproduction	Work that finished earlier than planned may cause soil to be bare before the next contractor takes over. Planned clearance of the whole site without doing phasing. Excessive cut of slope or grading that creates compaction and extra soil to be disposed.	Previous work, Crew, Information, Space, Equipment
Waiting	Improper planning and sequence of work that creates gap between activities. Improper allocation of resources that creates lag between works.	Crew, Equipment, Information, Previous Works, Material, External Condition, Space
Transportation	Excessive movement of equipment due to inefficient resources planning.	Crew, Information, Equipment, Space, Material
Over processing	Excessive clearance of slope and drainage	Information, Crew
Inventory	Improper scheduling that creates work and material in store.	Crew, Information, Material, Previous Work
Movement	Unnecessary movement that causes delay	Information, Crew
Defective product	Inefficient schedule and sequence. For example, conducting land clearance and grading during rainy season.	Crew, Information, External Condition, Previous Work, Equipment

CONCLUSION

LID, CM and lean are three different concepts, conceived to address different issues independently. A conceptual connection was drawn to link LID, CM and lean to improve the performance of site runoff management. This paper provided a new perspective in relating production and runoff waste. It enables practitioners to understand the inefficiencies in production flow and how it creates a negative impact on the runoff. Hence, practitioners can improve the performance of both production and runoff by referring to the suggested management approaches. In general, the framework produced here could be used as a methodology to address other environmental concerns (carbon emission, noise pollution, solid waste, etc.), in replacement of runoff as a subject. This paper provided a new perspective to manage environmental issues by improving the current inefficiencies in production. The limitation of this research is acknowledged with the lack of practical application and verification. Further research will be conducted to verify the validity of the current framework. Case studies will be carried out to identify the causes of inefficiencies in production and the inherent relationship with runoff by the use of Value Stream Mapping (VSM) in combination with Building Information Modelling (BIM).

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