GREEN-LEAN APPROACH FOR ASSESSING ENVIRONMENTAL AND PRODUCTION WASTE IN CONSTRUCTION

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ABSTRACT

Sustainability research in construction has been focused on the design and operation stages of projects. However, the production stage has received not much attention. Current sustainable construction approaches exhibit a disconnect between environmental and production waste management in projects. To overcome these limitations, an approach based on green building and lean production principles is proposed in this paper. Thus, a lean tool named Value Stream Mapping (VSM) is adapted to simultaneously assess environmental and production waste over the production stage of construction projects. This paper reports the application of the proposed "green-lean" approach in the construction of a hospital as a case study, analyzing the structural concrete work stage. The main findings showed the ability of the approach to find out the sources of environmental/productive waste, quantify them, and suggest reduction strategies. This also demonstrated the effectiveness of the proposed "green-lean" approach for improving the sustainable performance of projects.

KEY WORDS

Green Building, Lean Production, Sustainability, Value Stream Mapping, Waste.

INTRODUCTION

Construction has historically been one of the industries with the poorest performance in the use of resources, productivity, and management of pollution. The inherent peculiarities of this industry are often presented as excuses for these deficiencies (Nam & Tatum 1988). The traditional construction management concepts, which perceive a production system as a series of isolated processes converting inputs into outputs, are often blamed as the root causes of such problems. This view fails to acknowledge the existence of flows between the processes which do not necessarily represent conversions, this leads to non-optimal flows and to a growth of the non-value adding activities. Furthermore, there is also little concern on the client's needs and requirements (Koskela 2000).

In the last 20 years, the Lean Construction community has been devoted to improving the production performance of construction and engineering projects by understanding the production nature of projects (González et al. 2008). On the other

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hand, the environmental performance of projects has become a significant concern in the past decade, resulting in the development of the Green Building philosophy (Kibert 1994). However, the improvements achieved in construction from these “Lean” and “Green” approaches have been prevented because the productive and the environmental performance of projects have been constantly treated in isolation (Martínez et al. 2009; González and Echaveguren 2012). According to the United States Environmental Protection Agency (EPA 2007a), the performance improvement of production systems can lead to the reduction of environmental waste and vice versa. Currently, the construction industry is not taking advantage of the synergy between Lean and Green initiatives. However, there is evidence on the potential benefits of using an integrated “green-lean” approach to manage construction projects (Bae and Kim 2007; Martínez et al. 2009; Rueff and Cachandinha 2011). Therefore, we argue that a more integrated management approach based on Lean Construction and Green Building is needed to effectively cope with the productive and environmental performance of projects.

Sustainability is a concept that covers the environmental, the economic and the social dimensions of any human activity (World Commission on Environment and Development 1987). However, the Sustainable Construction or Green Building initiatives are often designed from an environmental standpoint, neglecting the economic dimension. In practice, this means that they do not consider the production management aspect of projects (Martínez et al. 2009; González and Echaveguren 2012). In addition, most of these initiatives are focused on the design and operation stages of the project lifecycle, which overlook the construction and deconstruction stages (Forbes et al. 2004).

The Value Stream Mapping (VSM) technique has efficiently accomplished the integration of both production and environmental goals in one management approach for the manufacturing industry (EPA 2007a). VSM is a lean technique that was originally applied in manufacturing to deal with production problems (Rother and Shook 2003). Then, VSM was adapted to manage environmental problems in manufacturing using a green approach (EPA 2007a). Therefore, we argue that the VSM provides a green-lean approach for managing the production systems, simultaneously accomplishing both production and environmental goals.

This paper was based on the research by Rosenbaum (2012). It developed a green-lean approach for construction (Martínez et al. 2009) using VSM. The VSM has been implemented by other researchers in construction (Arbulu and Tommelein 2002; Fontanini and Pichi 2004; Pasqualini and Zawislak 2005; Rueff and Cachandinha 2011; Yu et al. 2009, among others). However, some conceptual and practical VSM modifications in order to appropriately analyze both production and environmental goals were necessary. This research was conducted in the construction site of a medical center project in Santiago, Chile. The project was studied during the structural concrete work stage, for a two months-period. This represents a seminal experience in construction as the VSM technique was implemented to explicitly analyze the environmental dimension into fundamental execution activities on-site.

CASE STUDY

The construction of a 35,000 m^2 medical center in Santiago, Chile was selected as case study. A general contractor (GC) was in charge of the execution of this US$ 100 million project. The GC managed several specialized subcontractors such as piping, formwork and rebar installation. The project has five separate buildings and this research was limited to a physical boundary defined by the main building's limits.

PRELIMINARY DECISIONS AND DEFINITION OF CONSTRUCTION VSM INDICATORS

VSM sees production as a flow that needs to be defined. In manufacturing, these flowing units are well defined products (at different assembly stages) passing by different processes. However, construction elements are not alike. Therefore, the units flowing through a value stream will depend on the analyzed construction element. The construction elements analyzed in this research were: columns, walls, slabs, foundations and slabs on grade, although only walls have been reported in this article. For walls, the units flowing through the value stream will be square meters (m^2) of each element type.

Calculating the amount of inventory in construction is difficult, because the units on hold are not stored in one place, but they are spread out on the site. Besides, they cannot be simply counted, but they have to be somehow measured. In this research, the amount of inventory was estimated by making velocity diagrams between two consecutive and dependent activities. Then, the average difference between the cumulative progresses of them was calculated. The inventory time was estimated as the average waiting time that each of the measured units spent in inventory.

Several indicators were used to elaborate the value stream maps. Some of them were replicated from traditional VSM in manufacturing, while others were added/suggested to address particular issues considered relevant to analyze construction processes. The most relevant indicators are presented on Table 1.

Most indicators were obtained from the data collected by monitoring the different activities involved in the value stream. However, waste indicators required a slightly different approach. Concrete waste was estimated by comparing the volume of concrete contained in a mixer truck and the volume of the elements to be filled with concrete. For metal and wood materials, direct observation or visual inspection of the waste was carried out. The total waste generated was estimated as the accumulated disposed material and compared to the total material needed (see Figure 1).

Finally, the fuel waste estimate was calculated by comparing the total time the concrete pump was running with the time when the pump was effectively pumping concrete. Fuel waste was considered to be the consumption when the engine was idle.

All indicators are presented in the maps per flow unit. They provide production and environmental information for one unit flowing through the entire value stream. The flow unit for walls corresponds to the contour section of the element. If concrete pouring for a 100 m2 wall has a duration D=1 hr, in the map D=0.01hr/m2.

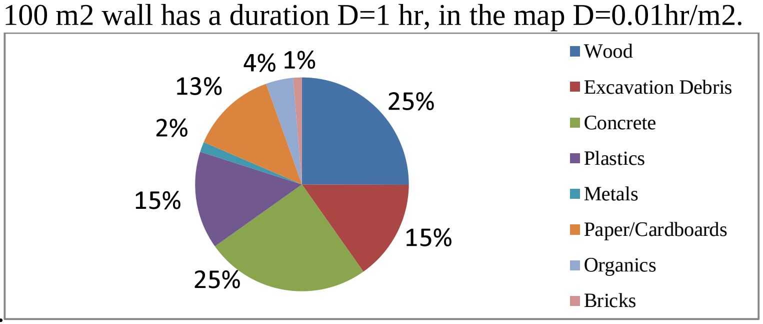

Figure 1: Waste Classification.

Table 1: Indicators.

Name	ABV	Unit	Meaning
Identification	ID	-	Element's identification according to its location (WBS).
Duration	D	Min.	Duration of activities. Measures the time invested on activities.
Setup Time Percentage	STP	%	The percentage of setup time over the duration of a given activity.
Up Time Percentage	UTP	%	The percentage of time where contributory workb is been made over the duration of a given activity. This measures the effective use of time.
Contributory Work Index	CWI	%	The bi-dimensional percentage of time and workers assigned to the activity in which contribution is being made. This measures the effective use of the work crew.
Time of Inventory	TI	Hrs.	The waiting time of an element being processed by the next activity. This measures non value-adding times.
Performance	P	$\frac{Dim.}{worker-hours}$	The progress obtained by a determined amount of worker-hours. Measures the work crews' efficiency.
Cycle Time	CT	Days	The total amount of time that takes to process one flow unit.
Value-adding time	VT	Days	The sum of all value-adding times in the value stream.
Value-adding Percentage	VP	%	The percentage of value-adding time over the cycle time.
Metal Waste	MW	$\frac{Kg}{Dim.}$	Amount of metal wasted in comparison to the amount needed.
Metal Waste Percent	$MW_{\%}$	%	Metal waste shown as a percentage.
Concrete Waste	CW	$\frac{m3}{Dim}$	Amount of concrete wasted in comparison to the amount needed.
Concrete Waste Percent	$CW_{\%}$	%	Concrete waste shown as a percentage.
Wood Waste	WW	$\frac{Kg}{Dim.}$	Amount of wood wasted in comparison to the amount needed.
Fuel Waste	FW	$\frac{Lts.}{Dim.}$	Amount of fuel wasted in comparison to the amount needed.
Fuel Waste Percent	$FW_{\%}$	%	Fuel waste shown as a percentage.
Landfill Diversion	LD	%	Percentage of waste diverted from landfill disposal.
Just in Time Percentage	JTP	%	Percentage completed on schedule, also shows early and late percentages.
Inventory	I	Dim.	Amount of inventory.

THE CURRENT STATE MAP

The indicators were calculated using the procedures described in the previous sections. Then, maps for the current state of the value stream were elaborated (see Figure 2). Environmental indicators are shown in italic so they can be easily distinguished.

The data obtained and current state maps were validated with the opinion of different experts involved in the project. They were constantly interviewed to make sure that the maps were a reliable representation of the construction site.

The maps were analyzed to diagnose the current state of the wall elements value stream. Several problems were identified and they are described next.

Process Variability: there is evidence of great variability in the duration, performance and UTP indicators. Maps show only average values but great dispersion was observed. For example, for rebars installation, the duration has a coefficient of variation of 52% with a mean of 19 min/m2 and a range of 8 to 36 min/m2. It was observed that activities that were processed in a continuous way achieved considerably lower duration than the average stipulated on the maps. On the other hand, a large amount of activities were performed in a discontinuous way. For example, when rebars were installed in a wall, it was very common to observe that workers installed the vertical bars but not the horizontal ones until the last minute.

Human Resource Management Difficulties: The CWI indicator shows that the human resources management of the subcontractors is significantly better than the general contractor. For instance, for rebar installation, the CWI is 85%, this activity is performed by a subcontractor. But for concrete pouring, which is self-performed by the general contractor, the CWI is only 65%. The low level of this indicator can be explained by a number of factors: the arrival of supplies was often delayed and as a result the workers were idle; crews were oversized and this generated congestion among workers; crews were not sure about what to do or how to perform the work; and workers experienced excessive unauthorized detentions.

Large Inventories: Several activities produced large amounts of inventory that accumulated. For instance, the rebar spacers installation showed an average of 351 m2 of inventory (equivalent to 3 wall sections approximately). These accumulated units were spread out through the site and exposed to damage by the elements, equipment, or the work of nearby activities.

Value Stream Sync: One very important aspect of a value stream is the synchronization with the client's demands. Commonly these demands are related to quality, safety, cost and schedule. Although the first three were not measured, some problems were apparent by the on-site observation. Quality errors and defects often occurred. Schedule accomplishment is indicated by JTP. Graphs show a trend to finish activities later than scheduled.

Low Value-Adding Percentage: VP indicates that only 33% of cycle time is being used to add value to the product. The rest of the time is being wasted mostly in waiting time.

Material Resources Supply: One of the largest problems experienced was the suppliers' unreliability to meet the schedule. Managers stated that this created lots of delays, variability and lowered performance in general.

Planning and Control Issues: Many of the problems listed above were related to planning and control difficulties. The main problem was the short term focus of planning and the perception of the processes as a series of single transformation activities. Construction managers spent time preparing documents related to planning and control tools such as the Last Planner System and its indicators (PPC and RNC), S curves and Gantt charts; however, they were barely used.

Waste Management: All waste generated on-site was disposed on landfills. LD indicates 0% diversion and the waste indicators show high inefficiency of materials and energy usage. Concrete orders were constantly overestimated so a lot of material was returned to be disposed on the pre-mix plant. Wood was used for barriers, formwork finishing and supporting structures, and it was treated as disposable, with a WW of 0.7 Kg/m2. Metal waste indicates 3 kg/m2 wasted. The fuel indicator shows that 25% of total fuel consumed was wasted due to the concrete pump was unnecessarily kept running.

Site Sustainability: Excavation material was piled up on-site and exposed to wind erosion. This generated a large amount of suspended particles (dust) that negatively affected the workers' health. There was also a high level of inefficiency in water usage. It was observed that this was particularly problematic for the construction of slabs on grade.

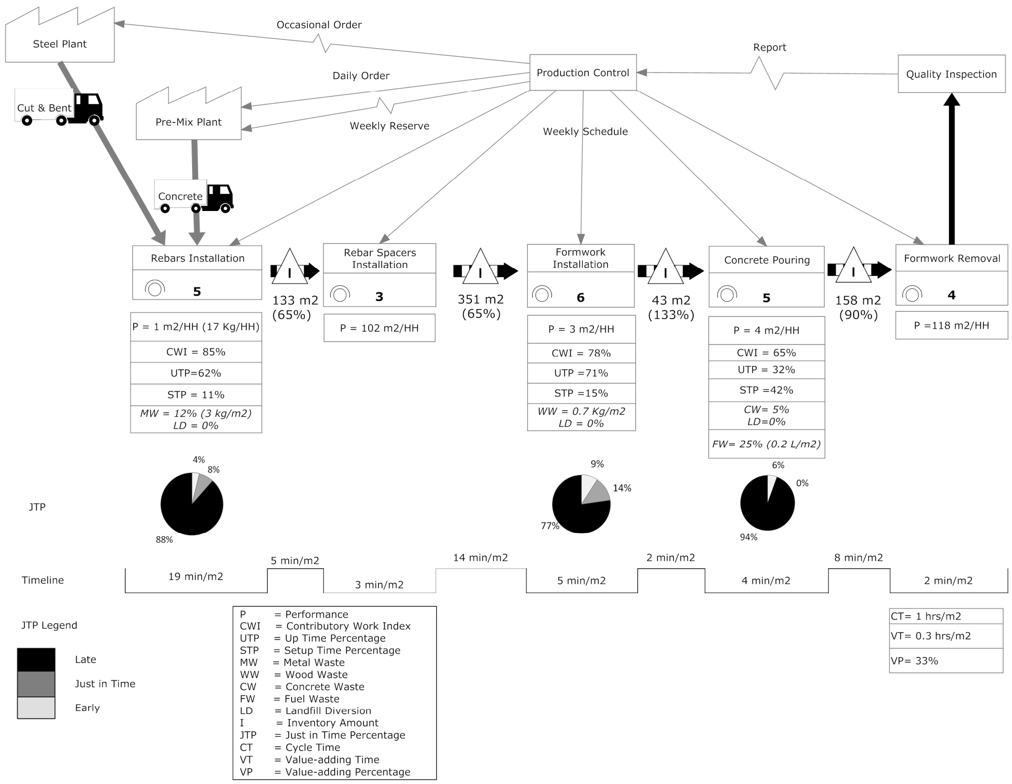

Figure 2: Map of the current state for the walls value stream.

THE FUTURE STATE MAPS

New indicators were estimated based on experience and expert judgment in order to achieve a desirable future state of the production system. Thus, modifications in the flow of products and information were made. The future state map for the walls value stream is presented in Figure 3. Note that changes in the indicators from the current state are presented in bold characters so they can be easily identified.

Merging Activities: It is recommended to merge activities when possible, in order to create a continuous flow between them and eliminate unnecessary inventories. Note that the activities for rebar and spacer' installation are shown as a single activity in Figure 3. In the current state the rebar's installation is performed by a specific crew and the spacers' installation is performed later by a second crew. By merging these two activities, a single multi-skilled crew will be required to perform the job in a continuous way in order to maximize the value-adding time.

Work Standardization: Required tasks completion, technical procedures, tools and equipment and responsibilities should be well defined along with quality standards and completion schedules for every activity. It is strongly recommended to establish these guidelines in written documents. Work must be performed in a continuous way to achieve nearly 100% of work commitments.

Total Quality Control: All the subcontractors should be responsible for controlling quality immediately after work completion, making necessary repairs in order to achieve quality standards and completion schedules. 100% first-time-through should be accomplished. Note that the white bursts next to the activities in Figure 3 indicate actions for production improvement. In this case, they establish the goal of implementing Work Standardization and Total Quality Control in every activity.

FIFO Lane: A production system based on a FIFO lane is recommended. This means, for example, that when a wall section (typically under 150 m2) enters into a process, this should be the first out. This applies to the whole production cycle. Finally, the work plans should also meet the FIFO approach.

Ordering and Reception of Supplies: The routes for the supplies have been established in Figure 3. It is very important that suppliers meet this schedule and increase their reliability. Also, a Kanban card system has been established for the reception of rebars. The supplier delivers all the labeled rebars bearing in mind where they need to be installed. Whenever a rebar is delivered, this should be recorded and stored into the nearest storage point (to the installation place). Following the rebar installation, the label should be deposited in a Kanban post, so the production control can withdraw these labels and keep a precise track of the supplies.

Value Stream Sync: A suitable takt time for production was calculated and the future state value streams were adapted in order to fit this rhythm with the resources and capacity available. Note the change in the cycle time and the value-adding percentage in Figure 3. This shows the reduction of unnecessary inventory times . Quality could be improved if Total Quality Control is implemented. Safety should be addressed by allocating efforts for building better and safer protective installations and educating workers on the proper use of the protective gear and equipment.

Long-term Relationship with Subcontractors: If the subcontractors accept the goals of the future state production and if they adapt their productivity accordingly, then it is very important for the GC to maintain a good relationship with the subcontractors. Thus, the subcontractors are able to keep their work commitments.

Waste Management: the GC could manage its own construction waste, which is neither complex nor expensive and it is highly recommended for this project. Given the project's large site area, more waste containers can be easily placed to classify the construction debris/residues before disposal.

Metals, organics, paper and cardboards waste can be easily recycled, so the recommendation is to store these three materials in separate containers and negotiate with different recycling companies to periodically take out the containers when filled, with a goal of 100% recycling as shown in Figure 3. On the other hand, it is difficult to find someone willing or able to properly manage concrete residues, excavation rubble, bricks or wood waste. The recommendation is to re-use the first three on-site. They can be used in the landscaping project or as drainage and fill material.

Site Sustainability: To avoid air pollution due to suspended dust, the recommendation is to cover the piled debris and excavation surroundings with biodegradable geotextiles. In order to improve water usage on-site, it is also recommended to establish cleaning stations for the equipment, outfitted with water tanks or barrels. Contaminated water runoff (from equipment cleaning or precipitations) flowing out of the site should be managed and diverted/contained to avoid contamination of natural water bodies, both superficial and subterranean.

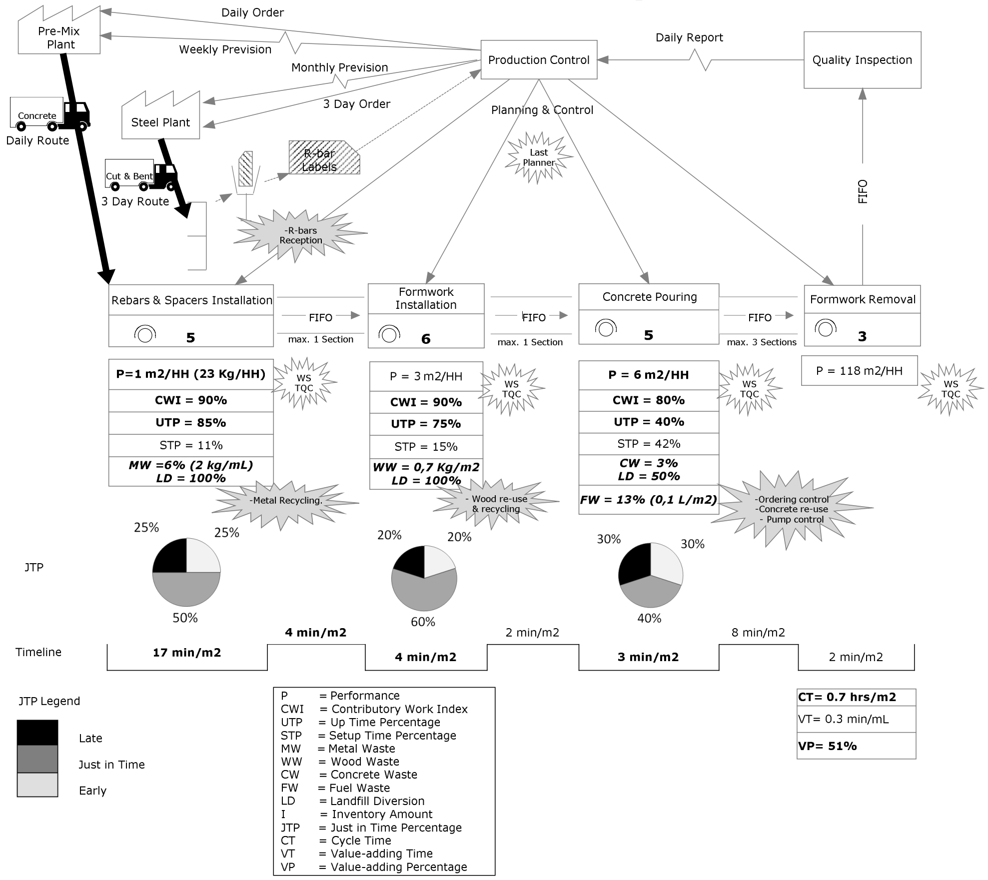

Figure 3: The Future State for Walls Value Stream.

CONCLUSIONS

This research showed that a detailed diagnosis of the main construction elements of the current production state of a project can be elaborated using a very untraditional perspective to construction work in which production is analyzed using an adapted VSM methodology. This enabled to analyze the productive and environmental waste that systematically occurred and it revealed improvement opportunities that typically remain hidden to the production control personnel. Future or improved states of the value stream were also produced and recommendations for the improvements were provided. These future states are aimed at considerably reducing waste by synchronizing production to the costumer's needs.

It is important to note that performance in construction can also be improved by refining the buildability of the project. This issue was not considered in the present analysis -though it has a direct effect on the construction stage of the project-, because of buildability is a part of the design stage, which is excluded from the scope of this research. Thus, improvements involving changes in the design were avoided. Nevertheless, some changes were recommended (not in the structural design, but in the landscaping and drainage design) in order to allow the re-use of construction waste within the site.

VSM is able to distinguish between value-adding and non-value adding activities, while traditional tools are not. On the other hand, a large number of units were produced simultaneously at different work fronts so traditional tools can work from a more fragmented standpoint. VSM analyzes the flow of one unit of production throughout the value stream.

The main contribution of this research is to provide a sustainability analysis focused on the execution stage of a project, including the environmental as well as the productive dimensions. It also constitutes a pioneer experience of the VSM implementation including these two dimensions in fundamental construction activities, showing the integration of Lean Construction and Green Building concepts (green-lean approach) and its use in practice. The conceptual adaptation of the VSM technique to achieve an adequate implementation in the construction site and the formal aspects of the elaborated maps should also be mentioned as a contribution. These were designed to display information in a clear and practical way and to convey a clear picture of the current production state and the proposed future one.

The VSM methodology that includes the environmental and the productive dimensions will allow construction managers to efficiently identify and measure waste sources. Using a green-lean approach of thinking will enable managers to more effectively see improvement opportunities and propose realistic implementation plans. Thus, they will be able to reduce costs, materials and energy usage; improve the human resource management; comply with the schedules and with quality standards; decrease the process variability; and minimize the environmental impacts generated by their projects.

Note that a full VSM implementation was not developed in this research, so the indicator pallet can be extended and improved. It is also possible to quantify other environmental sources of waste such as the estimate of emissions released to the atmosphere (carbon footprint) or the water footprint of the construction site, if additional resources are devoted to such tasks. Further research can be conducted to include other VSM aspects in construction. For instance, the implementation of VSM in case studies with projects of different types, such as buildings, highways or others; the cross-comparison between the current state of the value stream in projects of the same type; and the monitoring of the implementation process of the value stream future state seem as natural extensions of this research.

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