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Methodology to Improve Labor Productivity in Construction: A Housing Project of Highly Repetitive Processes Case Study

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Abstract

The purpose of this article is to present a methodology to identify and reduce waste considering Lean construction tools, time and motions study techniques. This investigation was carried out during the construction of 1,392 housing units located in Lima, Perú. The present case study focused on the analysis of highly repetitive processes during the structuring and finishing phases. The methodology presented has different stages. First, we used direct field observation to describe the current state of the work structuring. Second, we applied Value Stream Mapping (VSM) and Flow Process Chart in order to identify the productive stream, focusing in the identification of value adding activities and waste: no value adding necessary activities and no value adding unnecessary activities. Then we prepared and analyzed the information. Finally, with the lessons learned, we ideated and tested improvements in the organization of the work and design of the flows of labor, materials and equipment, among others. The success of this methodology is reflected on the reduction of waste and the improvement of labor productivity obtained in the final measurements and in the improvement opportunities identified.

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Keywords: work structuring, productivity, time and motions study, Value stream mapping, flow process chart

1. Introduction

The construction industry is one of the largest industries with a high impact on the economy. However, its productivity is considerably low when compared to other industries [1]. Improving the effectiveness of production control has attracted the interest of researchers and lean construction practitioners over the years. In Lean construction, production activities improved continuously with respect to waste and value [2].

Lean construction, has been implemented to enhance construction systems, with the main goal of improving competitiveness and performance [3]. Also, Lean construction seeks to increase productivity and reduce waste in the construction industry [4]. However, the greatest obstacle to waste removal is the lack of attention of site management to determining waste [5]. One reason that waste is not properly recognized, is the absence of appropriate tools for measuring waste or value. Traditional process models in construction are not sufficient to distinguish between value adding and non-value adding activities [6].

In particular, waste is generally associated with waste of materials in the construction processes while non value adding activities such as inspection, delays, transportation of materials and others are not recognized as waste [7]. Most of these waste activities are intangible [8] and hidden [9]. Process analysis is a simple

and effective tool that can be used to identify waste. This alternative investigates the overall flow of steps in a process and provides a method to improve the flow by making continuous improvements [10].

The purpose of this article is to present a methodology to identify and reduce waste considering Lean construction tools and time and motions study techniques. The present case study focused on the analysis of highly repetitive processes during the structuring and finishing phases.

2. Background

This section will review the main concepts and tools used during the case study.

2.1 Gemba Walk

Gemba is the Japanese word for actual place, and lean practitioners use it to refer to the place where value is created in production [11, 12]. This concept was developed in the Lean manufacturing paradigm into the practice of Gemba walks. Ohno described as a practice of Toyota Production System, the routine of going and seeing how the work happens at the shop floor [12,13].

It is essential to understand the importance of going and seeing for the construction process [14, 15]. Kerem brought an important insight considering that the managers discovered that none of the wastes they observed had ever been reported to management, and they would have remained unidentified if not for the Gemba session [13]. After the application of Gemba walk, several managers said that even though they had heard and learned about lean in the past, they had never been able to link it to their daily work [12, 13].

2.2 Work structuring

The purpose of work structuring is the breakdown of both product and process into chunks, separate sequences and assignments in order to make work flow more reliable and quicker while delivering value to the customer [16].

2.3 Value-adding activities and wastes

The definition of value-adding was made by Koskela. Value adding activity is an activity that transforms material or information towards that is required by the costumer and non-value adding activity is an activity that takes time, resources or space but does not add value [2]. Taiichi Ohno identified seven wastes: overproduction, time on hand, transportation, processing itself, stock on hand, motions an making defective products [12]. Subsequently, researchers suggested more waste types like making do [17], not using people´s full abilities [18] and behavioral waste [19].

A first interpretation of flow in construction is part of the TFV theory of production [20] which views production as a flow composed of value adding activities (transformation) and non-value adding activities (waiting, inspection and moving) [21]. The flow concept views production as a flow, which means, that in addition to transformation there is no value adding activities. It is main objective is to eliminate or minimize the share of non-value adding activities. As a result, it is expected some improvement such as lead time reduction, variability reduction, flexibility and transparency [20]. Lean construction represents a way to design production systems to discourage, minimize and eventually eliminate wastes of material, time and effort and emphasizes reduction of non-value adding activities as a means of value improvement [20, 21, 22]

2.4 *Value Stream Mapping*

Value stream mapping consists of all actions (both value-added and non-value-added) needed to bring a product through the production flow from the raw material to the client delivery [23, 24]. VSM permits a systemic view of the value flow in the production process, identification of problems and wastes, lessons learned and continuous improvement [25]. Value stream mapping is a powerful lean tool to improve the productivity of manufacturing industries [26, 27].

2.5 Flow process chart

The flow process chart is a modeling and simulation tool that aims to list all phases of a productive process, allowing quick visualization and understanding, facilitating its analysis. [28]. This tool shows several types of symbols utilized in process flowcharts, each one with a different characteristic that changes the way to analyze an activity, it´s up to the professional to define which one fits best the studied process [28]. The flow process chart makes it possible to create a common understanding, clarify the steps in a process, identify hidden productive costs such as distance traveled, delays and inventory. Once these are identified, the analysts can take steps to minimize them and then reduce their costs [28, 29]. Construction process analysis implements process charts and top-view flow diagrams common among process analysis techniques [30, 31]. The process chart records each step of a construction operation and also records flow within a unit, a section, a department or between departments. Flow may include the sequence of the flow of a product or an equipment or a worker [32].

2.6 Time study

A time study consists of to determinate the time required to complete a process, activity, task or step [33]. Frederick Taylor began the time study associated with work activities and developed the task concept. Around the same time, Frank and Lilian Gilberth, conducted the motions studies [34]. There are two basic procedures to make a time measure: (1) Reading continuous; (2) Return to zero or repetitive reading [29]. In the first procedure, we activate the chronometer, without stopping it, until the end point of the study. In the second one, we activate the chronometer and disactivate it for each element, task or step and then returned it to zero. This is done constantly until the end point of the study [29]. The time study, with a chronometer, is an old technique of work measurement that measures the time it takes an average worker to complete a task [35, 36, 37]. The objective of work measurement is to determinate the standard time and to increase the efficiency of work [38]. In addition to the use of a chronometer, other tools are used for the time, for example, video camera, computers, barcodes, specialized software, among others [39, 40]. Time and motion study can be employed to construction sector with promising results [41].

3. Methodology

This investigation was conducted during the construction of 1,392 housing units located in Lima, Perú. The present case study focused on the analysis of a housing project of highly repetitive processes during the structuring and finishing phases. The methodology is described in the following stages.

3.1 Stage 1: Direct Field observation and work structuring

A first step is to conduct a Gemba walk in order to get a sense of material and process flow. We need to observe how the process is conducted, what kind of materials and tools are used for each process, and what activities could add value or not. Then, we used work structuring in order to divide the process into chunks and make work flow more reliable. For the present work we divided the tasks in processes, then in subprocesses and finally in microprocesses.

3.2 Stage 2: Recordings and registrations

The data collection was conducted by the researchers of the present investigation. For the time study we used the video camera, with this tool we recorded all the processes of this case study. The procedure used in this time study was the continuous reading, it means that we recorded all the processes since the beginning until the end of each one. In order to register all the time and motions, we were located in a strategic place of the project. Finally, we proceeded to watch all the recordings and we registered, second by second of the film, in an excel spreadsheet.

3.3 Stage 3: Value Stream Mapping

Based on the observations and data collected, it was possible to produce a Value Stream Mapping for a task. First, we defined a task to be analyzed. Second, we identified the processes, the relations between processes, suppliers, customers. Third, we registered the time for each process, time for preparation,

number of workers, the time of inventory and finally we calculated the lead time and the added value. After that we analyzed the results obtained according with the transformation-flow-value theory of production.

3.4 Stage 4: Flow process Chart

Based on the observations, the recordings of time, motions and the structure of the work, it was possible to make a process flow chart. In this chart we registered the total time of the process, the productivity of the process, the subprocesses for each process, the total time for each subprocess, the materials, tools and equipment used for each subprocess and the constructive sequence for each subprocess. Likewise, it was possible to show a deeper analysis. With the previous collected data, we produced a flow subprocess chart. In this chart we registered the microprocesses for each subprocess, the total time for each microprocess, the materials, tools and equipment used for each microprocess. Then, with this information, we quantified wastes and the level of value adding activities.

3.5 Stage 5: Identifying opportunities for improvement

In this stage, with the information previously obtained, we focused on identifying opportunities to reduce or eliminate wastes. We used tools such as histograms and pareto diagrams to identify those wastes that consume more time. Also, we used tools such as cause and effect and 5 whys in order to analyze and identified the principal causes.

3.6 Stage 6: Development of improvement strategy and Implementation

In order to ideate an improvement strategy, we organized this stage as following: First, we had meetings with the participation of the construction staff and crew leaders. During these meetings we described all the wastes that we could identified. Also, we watched the recordings and we showed to all the participants the activities adding no value. Second, we asked for different alternatives for solution. In order to ideate them we used tools such as 4W (who, what, where and when), brainstorming and ECRS (eliminate, combine, rearrange and simplify). Third we conducted a brief discussion about the different alternatives and finally we voted for the ones that could work. The alternatives selected were implemented and the results were registered.

4. Results

4.1 Stage 1: Direct Field observation and work structuring

As a result of the observation during the structuring and finishing phases, we could breakdown the work into chunks. Figure 1 (a) shows an example of the slab concrete task. This task is divided in processes of preparation, transportation, slab concrete pouring and curing. Besides that, we can observe that the process of slab concrete pouring is divided in subprocesses of concrete pouring, vibration and finishing and finally we can notice that each subprocess is divided in what we called microprocesses. This work structure facilitated the identification of wastes.

4.2 Stage 2: Recordings and registrations

For this study we used a video camera in order to record the processes second by second. After these was filmed, the investigators of this study registered the information in excel spreadsheets. Figure 1 (b) shows an example of the data registration of the slab rebar installation. The spreadsheet registers the subprocesses, microprocesses, the time for each microprocess, number of workers, production and productivity of the process.

a

Task	Process	Subprocess	Microprocess
Slab concrete	Preparation		
	Transport		
	Slab concrete pouring	Concrete pouring	Waiting time Motion Transport Pouring Spreding Resting time
		Vibration	Motion Checking Transport Additive pouring Waiting time Vibration
		Finishing	Waiting time Additive pouring Coordinations Motion Spreading Checking
	Curing		

b

Process :	Slab rebar installation
Time (hrs)	3.13
Production (kg)	382.98
#Workers	2
Productivity (kg/Labour hours)	61.27

Subprocesss	sec acum	sec	min	Microprocess
Bar straightening	12.00	12.00	0.20	Transport
Bar straightening	15.00	3.00	0.05	Bar straightening
Bar straightening	16.00	1.00	0.02	Motion
Bar straightening	23.00	7.00	0.12	Bar straightening
Bar straightening	27.00	4.00	0.07	Motion
Bar straightening	34.00	7.00	0.12	Bar straightening
Bar straightening	39.00	5.00	0.08	Motion
Bar straightening	53.00	14.00	0.23	Bar straightening
Bar straightening	57.00	4.00	0.07	Motion

Fig. 1. (a) Concrete slab: process, subprocess and microprocess; (b) Spreadsheet for data registration

4.3 Stage 3: Value Stream Mapping

Based on the observations, it was possible to produce a VSM for each task analyzed. Figure 2 shows the door installation task for the production of one unit. As we can observe the greatest amount of time is concentrated on activities that do not add value. For example, there is a huge gap of 30 days within the processes of applying the second coat of paint and the second door installation. In compliance with the transformation-flow-value theory of production [42], among the main losses are: (1) Material loss: Rework of painting due to continue presence of crews for re-entrant flow; (2) Time loss: Waiting time due to the interruption of other activities. Also, there are many unprocessed materials, and a high rate of inventory loss; (3) Value loss: Lack of quality in doors and frames due marks of painting and dents produced by other crews. If we observe the Value Stream Map in figure 2, there is still a lot of room for improvement.

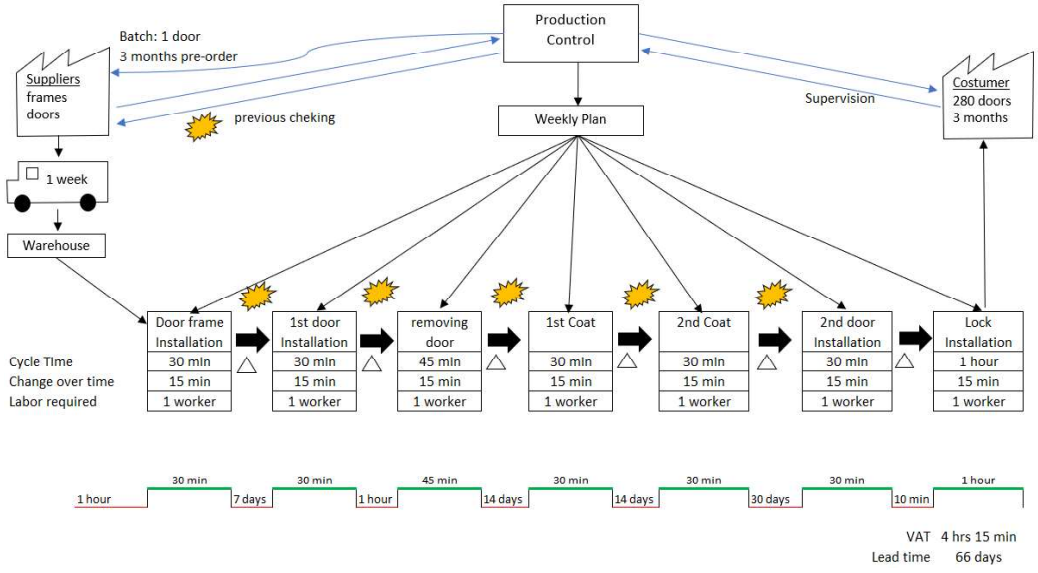

Fig. 2. Value stream mapping of door installation

4.4 Stage 4: Flow process Chart

Based on the observations and data collected, it was possible to produce a flow process chart. During the investigation it was observed that each process was composed of smaller elements that we called subprocesses and these had to be identified and measured. Figure 3(a) shows a flow process chart of the door frame installation process. This chart registers the total time, productivity, number of workers, production and time for each subprocess. This chart identifies, for example, that the subprocesses wood

block placing and wall perforation, represent the majority of time with 25% and 15% of the total process time, respectively.

Also, we registered the microprocesses for each subprocess. For example, the Figure 3(b) shows the flow process chart of the subprocess frame installation. This chart registers the total time, productivity, number of workers, production and time for each microprocess. Also, this chart identifies that only 42% of the time are composed by activities that add value. Besides that, we calculated that the worker had more difficulty in the microprocess stoppers placing which presented the 33% of the total time of the subprocess. Finally, through these charts, it was possible to have a deeper analysis which allowed us to identify wastes, how time is spent and there is still much room for improvement.

a

Process Door frame Intallation
Time 30.42 min
Workers 1
Productivity 2.00 Frames/labor-hours

#	Time (min)	Symbol	Subprocess	Workers	Quantity
1	0.87		1st Cut	1	2 pieces of frame
2	0.87		2nd Cut	1	2 pieces of frame
3	0.85		3rd Cut	1	2 pieces of frame
4	3.15		Sanding	1	1 frame
5	0.82		Tracing	1	3 traces
6	2.47		Frame assembling	1	1 frame
7	0.95		Checking size	1	1 frame
8	4.40		Wall perforation	1	6 times
9	7.73		Wooden blocks placing	1	8 wooden blocks
10	2.73		Wooden blocks cutting	1	8 wooden blocks
11	2.95		Frame Installation	1	1 frame
12	2.63		Screwing	1	9 times

b

Process Door frame Installation
Total time 30.42 min
Workers 1
Productivity 2.00 Frames/labor-hours

Subprocess Frame Installation
time 2.95 min
Workers 1
Productivity 20.34 Frames/labor-hours

#	Time (min)	Symbol	Microprocess	Workers	Quantity
11.1	0.22		Motions	1	----------
11.2	0.32		Transport	1	1 frame
11.3	0.38		Frame installation	1	1 frame
11.4	0.87		Hammering	1	8 times
11.5	0.98		Stoppers placing	1	2 stoopers
11.6	0.18		Checking	1	----------

Fig 3. (a) Flow process chart: Frame Installation; (b) Flow subprocess chart: Frame Installation

4.5 Stage 5: Identifying opportunities for improvement

Based on the information and the previous analysis, it was possible to produce histograms, pareto charts, among others, in order to show the different opportunities for improvement. Figure 4(a) shows an example of the activities distribution adding and no adding value in the structuring phase. In this figure we can observe that the activities that add value (VA) are between 21% and 56% and have an average of 32% of the total time. As we can see the greatest amount of time is distributed in activities that do not add value. In order to know the type of wastes, Figure 4(b) shows the activities that do not add value but are necessary (NVAN) and the activities that do not add value and are not necessary (NVAU) during the wall rebar installation process. In this analysis 45% of time are NVAN and 22% are NVAU. Also, it was found that transport of material represented 27% (more than half time of NVAN) and motions 13% (more than half time of NVAU) of the total time of the process. In this example, we found that the principal cause for these wastes were that the workers had to move continuously to the warehouse which was far from the work placement, also there were not specific routes to return which made the work more difficult.

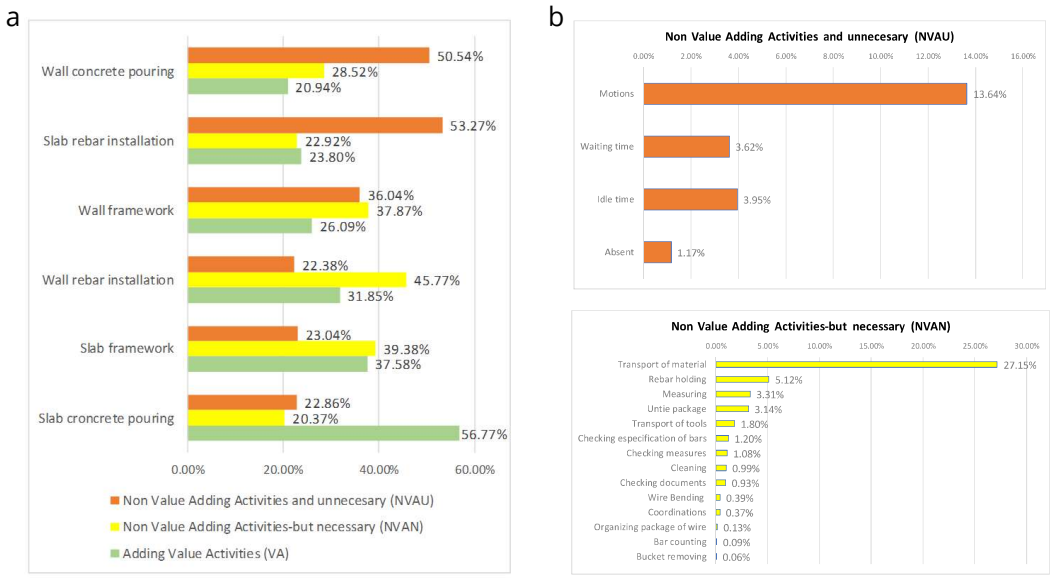

Fig 4. (a) VA and NVA in the phase of structure; (b) NVAU and NVAN in the wall rebar installation

4.6 Stage 6: Development of improvement strategy and Implementation

The different strategies were proposed during meetings by the investigators, the engineers of the project and by construction workers. At the end of the meetings several solutions were proposed by the participants and selected to be implemented in the processes, some examples of these are: (1) Wall and slab installation: The most relevant wastes were motions and transport of material. The suggestions proposed were: i) Arrange another temporary storage areas close to the crews; ii) Create a standard procedure and communicate it to workers iii) Provide panels with indications of the access routes. (2) Wall and slab frame work: In these processes, the most important wastes were transport of equipment and transport of tools. The suggestions were: i) Provide a basket to storage the tools and transport the basket by the tower crane; ii) Create a schedule of the tower crane and communicate it to workers. (3) Wall and slab concrete: the most relevant waste was waiting time. The suggestion was: i) Prepare a smaller volume of mix in the concrete plant to reduce the preparation time. (4) Patching walls: the most relevant wastes were transport of material and tools. The suggestion was: i) Create a simple equipment of transport to take the bucket fill of mix and the tools. (5) Door frame and door installation: the most important wastes were transport of tools and rework. The suggestions were: i) Provide a tool holder to reduce transport times; ii) Implement a control system on the site in order to bring access according to the weekly plan. Also, one important suggestion was to conduct weekly coordination meetings with all crew members in order to create a culture of continuous improvement. These suggestions were implemented in different processes during the execution of the project and then these were measured to evaluate the improvement. Table 1 shows some examples of the results. As we can see, it was possible to reduce waste. We achieved reductions of waste around 6% to 9.5%. Besides, we had an increase in labor productivity around 10.5% to 18.4%.

Table 1. Results of implementation.

Processes	Waste Initial (%)	Waste Final (%)	Productivity Initial	Productivity Final	Productivity Increase (%)
Wall rebar installation	68%	58.5%	65.3 kg/lh	77.3 kg/lh	18.4%
Wall framework installation	74%	68%	7.2 m2/lh	7.9 m2/lh	10.5%
Wall concrete pouring	79%	70.3%	1.1 m3/lh	1.3 m3/lh	13.6%
Patching walls	26%	19.8%	8.4 m2/lh	9.3 m2/lh	11.1%
Door frame installation	66%	58.7%	2.0 und/lh	2.3 und/lh	12.9%

5. Conclusions

This study shows that there is still a lot of room to continue reducing waste. We identified that no value adding activities represent the majority of time in the processes. For example, 62 % in the slab framework process, 66% in the door frame installation, 68% in the wall rebar installation, among others. In addition, by combining time and motion study tools and lean tools were very useful to identify wastes from different perspectives and contributed to the reduction or elimination of no value activities and improve labor productivity. We found that the majority of wastes were transportation, motions and rework. These wastes were due to a lack of management control. For example, transportation and motions wastes occurred because a bad distribution of the material and access routes not well defined. Rework wastes happened due to a lack of communication methods between engineers and crew members. The meetings with the crew members were very productive, each participant suggested alternative solutions that contributed to reduce waste in the processes. We considered that the implementation of meetings to ideate solutions focused in waste reduction should be scheduled weekly. The major advantage of this methodology is the simple steps that do not require extensive training and are useful to reduce wastes and improving processes. The keys for the success of this implementation are the continuous commitment of the participants at all levels of the project and having a culture of continuous improvement.

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