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APPLYING LEAN TECHNIQUES TO IMPROVE PERFORMANCE IN THE FINISHING PHASE OF A RESIDENTIAL BUILDING

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ABSTRACT

In Peru, the Last Planner System (LPS) is widely implemented by contractors during structural work. However, during the finishing phase, its efficacy is reduced, as teams deal with high levels of variability, uncertainty within supply chains, and unpredictable production capacities among subcontractors. The work structuring is frequently based on a one-week takt on successive floors, and pull planning during the structural work becomes push planning during the finishing phase, as teams impel subcontractors to meet deadlines. All this implies that improved work structuring is needed to enhance the flow of operations during the finishing phase.

To meet this need, we designed a case study in two stages. First, we used direct field observation of a Peruvian building project to describe the current state of the work structuring in the finishing phase. Value Stream Mapping (VSM) was used to identify the productive stream, focusing on the identification of wastes. Second, we applied some Lean techniques during the finishing phase in a large community-housing complex. Our conclusion is that assigning the tasks in sufficient detail and modeling the production units according to the project's complexity can improve the flow of the finishing stage. The use of flowlines is also recommended.

KEYWORDS

Last Planner System, Pull Planning, Work Structuring, Value Stream Mapping, Flowline.

INTRODUCTION

The Last Planner System (LPS) has been applied successfully during the construction phase of numerous building projects (Ballard and Howell 1994). In Peru, too, LPS has been implemented by major contractors, with several positive results: higher profits (Ballard and Howell, 2004) and on-time completion of design milestones (Arbulu and Soto 2006). Some Peruvian construction companies also implement LPS during the structural phase (Calampa 2014), while in the Lean community, the system has also

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been applied during the finishing phases of building construction (e.g. Brodetskaia et al. 2011; Brodetskaia et al. 2013; Priven and Sacks 2015; Priven and Sacks 2016).

In Peru, it is a major challenge to sustain LPS implementation during the interior construction phase. Production teams deal with high levels of variability, and cultural issues regarding subcontractor commitments in the construction process make it difficult to sustain LPS from start to finish. Weekly meetings only have to do with construction assignments, omitting analysis of constraints and the make-ready process (Brodetskaia et al. 2013).

This paper hypothesizes that if a construction project were to apply Lean techniques under LPS during the finishing phase of residential buildings, the overall performance of the system would improve. A case study helps to illustrate current practice. First, we use direct field observation and document analysis to determine the way LPS is currently implemented in the finishing phase of a residential building. We employ Value Stream Mapping (VSM) to identify wastes and the productive stream, and to propose a smoother workflow. Afterwards, we recommend new work structuring for the finishing phase, with the use of flowlines to help last planners visualize activities and organize pull planning sessions. A second case study allows us to determine the feasibility of these recommendations and measure percentage of plan complete (PPC) as a performance indicator.

We emphasize, however, that our conclusions are tentative, requiring further confirmation before being applied to the Peruvian housing industry. The results also might be complicated by regional variations in planners' and engineers' behavior.

BACKGROUND

WORK STRUCTURING

Work structuring is the breakdown of both product and process into chunks, separate sequences, and assignments in order to allow the workflow to run more smoothly and with less variability. This in turn reduces wastes and increases value (Ballard 2000). The goal of work structuring is to make the workflow more reliable while delivering value to the customer. In particular, work structuring views a project as consisting of production units (PUs) and work chunks (Ballard 2000).

VALUE STREAM MAPPING (VSM)

According to Rother and Shook (2003), a value stream consists of all the actions (both value-added and non-value-added) required to bring a product through the production flow from the raw material to the hands of the customer. As such, Arbulu et al. (2003) have introduced VSM as the basis for analyzing the current-state map of construction supply chains. VSM is considered one of the gateways for Lean production precisely because it permits a systemic view of the value flow in the production process, identification of real problems and wastes, and recommendations for improvement (Pasqualini and Zawislak 2005).

LOCATION-BASED SCHEDULING

Location-based scheduling methods explicitly consider location as a dimension in the production process. A project can be modeled as a series of locations in which activities flow through different units in turn. Thus, in each location, activities are linked through a logical relationship network. This allows for easier planning of continuous resource use, which in turn enables cost savings and fewer scheduling risks, since subcontractor crews can be kept on site (Soini et al. 2004). Line of Balance (LoB) is one such method, dividing a project into repetitive and equal units. Similarly, the flowline method is focused on a series of locations, which may vary in size or in the tasks to be performed there (Kenley and Seppänen 2010).

LITERATURE REVIEW

Interior finishing work is typically characterized by uncertainty, instability, and waste. There are no technical constraints requiring that such work be performed floor by floor, and usually multiple subcontractors carry it out. Quantities often vary between locations, and jobs usually have long lead times. Also, subcontractor production capacity is unpredictable, causing turbulent workflow (Brodetskaia et al. 2011). Re-entrant flow patterns, in which crews return to a location multiple times, make it more difficult to plan and control tasks (Brodetskaia et al. 2013).

In order to understand dynamic flow during the finishing phase, Brodetskaia et al. (2011) devised a workflow model for systems and interior finishing work, taking into account features such as non-linear tasks, instability, and re-entrant flow. The model enabled evaluation of the impact of management policies on production flow, in different levels of detail. More recent research yields new insights into how LPS works. Even when implemented partially, LPS still improves workflow, as it engenders a social network among subcontractor trade crews (Priven and Sacks 2015). As such, LPS has a social impact, building relationships across projects, and can contribute to improved coordination. To strengthen these social networks, Priven and Sacks (2016) devised an artefact called Social Subcontract (SSub), which aims to improve communication, mutual respect, and collaborative behaviour among subcontractor trade crews. Studies have concluded that SSub together with LPS at once leverages the make-ready process, improves coordination, and facilitates workflow more than LPS alone.

The question driving our research is how to strengthen the implementation of LPS in the finishing phase of building construction in Peru, where small subcontractors abound. Using the perspectives previously discussed, we seek to develop basic workflow and scheduling models by means of case studies.

CASE STUDY 1

PROJECT BACKGROUND

The first case study focuses on the finishing phase during the construction of a residential building. Said building consists of seven stories covering 5,800 square meters, and its 30 apartments display high-quality finishing in an exclusive area in Lima. The project was studied over two months to better grasp the subtasks and their interactions, identify wastes, understand current work structuring, and interact with last planners and production engineers. The tasks monitored were (1) painting, (2) tiling, (3) door installation, (4) closet installation, and (5) kitchen-cabinet installation. Each main task in this phase has a special subcontractor.

WORK STRUCTURING

The production unit of many tasks is one full story per week. The chunks of work are oversized, and little control can be exercised in such circumstances. Likewise, tasks are not planned at the operational level. There are sub-tasks that divide work into other activities, which are not considered. The assignment of resources is only based on subcontractor's experience. This myopia makes it difficult to identify constraints on time.

VALUE STREAM MAPPING

Based on the observations, it was possible to produce a VSM for each task analyzed. For example, Figure 1 shows the painting task for a production unit of one full apartment. It is noteworthy that the added-value activities constitute 40% of the lead time of the activity. Sub-processes in general tend to be planned; however, in this case, only three out of ten were laid out beforehand. There is a huge gap of 40 days during which any sub-process is performed in the production unit. If we analyze the Value Stream Map below, we see there is much room for improvement.

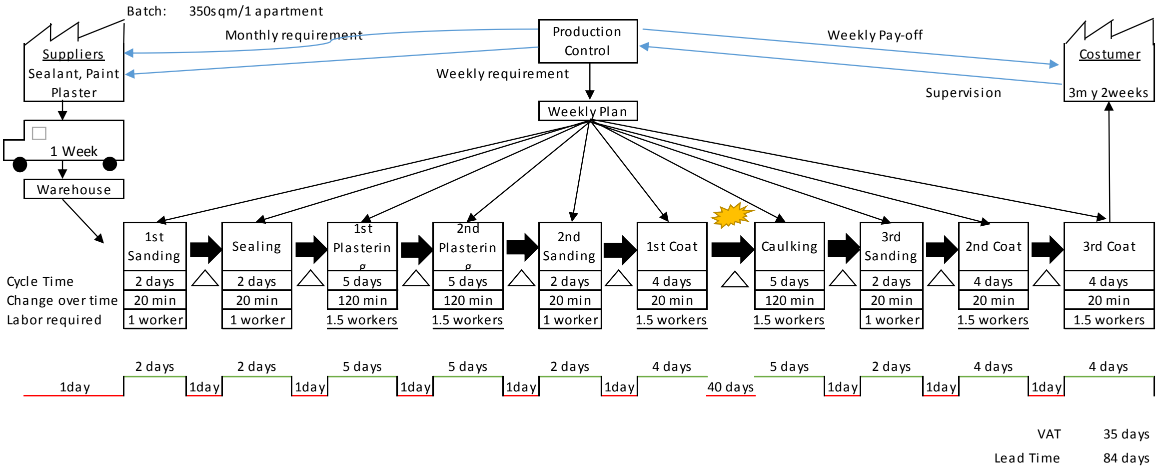

Figure 1: Value Stream Map of Painting

WASTES

In compliance with the transformation-flow-value theory of production, Bølviken et al. (2014) developed a taxonomy to categorize the different wastes that occur during construction. Three main categories of waste were established: material wastes, time loss, and value loss (Bølviken et al. 2014). Applying this taxonomy, the principal wastes during the finishing phase of this building project are: (1) Material loss: Plastic and cardboard are used to protect finishing at all times, due to continuous presence of crews for re-entrant flow (Brodetskaia et al. 2013). Also, the level of prefabrication is too low, since a large amount of raw material reaches the construction site; (2) Time loss: The amount of time between sub-processes is too high. Some 40% of painting lead time or 5% of kitchen-cabinet-installation lead time involves value-added activities. The rest of the time, there are no crews working. There are many unprocessed materials, and a high rate of inventory loss; (3) Value loss: Some tasks have a high incidence of non-conformities due to the artisanal processes, low tolerance, and strict quality control. Moreover, if a design does not meet customer requirements once installed, it is changed. Safety and health issues also affect workers.

CONTRACT RELATIONS

The contract with the subcontractor is only based on take-off, unit price, and the start and end dates of tasks contracted. However, most contractors focus principally on the unit price. Very few elements are controlled, collaboration and pull planning are confined to the first weeks of tasks, and reassignment of crews is generally left to the subcontractor. The contractor only pushes the subcontractor to meet the completion deadline.

LPS IMPLEMENTATION SHORTFALLS

Some conclusions can be drawn from this first case study: (1) The phase schedule only considers main tasks. The production unit is either one full story (e.g. painting) or one full apartment (e.g. tiling, doors); (2) At the beginning of the phase, pull planning is used with very few subcontractors; (3) During the look-ahead planning, phase-schedule tasks are not properly broken down into operations. This is because there is little knowledge of subtasks; (4) Weekly meetings only serve to track achieved progress and plan again, based only on the foreman’s word, with little analysis of constraints; (5) Make-ready activities are not indicated transparently. Weekly work plans often have to be restructured; thus the flow becomes difficult to manage; (6) In the end, pull planning is neglected, and planners push subcontractors to finish their tasks by the contract’s completion date; and (7) There are many invisible losses. On average, during 90% of the lead time of major activities, no subtask is performed. This results in extended schedules.

LEAN TECHNIQUES FOR IMPROVEMENT

PRODUCTION UNITS

In the first case study, work structuring in the finishing phase focuses on one full story. For example, the tiling crew must finish their activities (nine bathrooms and four kitchens in Figure 3) for one floor in a single week, and then move on to the next story. It is necessary to reduce the batch and to plan activities with no interference, considering the position of five production units. These production units are (1) bathrooms, (2) kitchens, (3) closets, (4) doors, and (5) painting. The first three PUs are in different locations in each story, so crews could be allocated at the same time without interfering with each other. By contrast, the last two PUs should be scheduled independently, because they require most of the space within the story.

The next step is to identify the correct subtasks for the project and visualize these activities at the right level (Dave et al. 2015). In the first case study, the subtasks and work sequence were identified as shown in Table 1. For example, the floor tiling crew moves from bathroom 1 to bathroom 9 and hands over the work to the wall tiling crew. In turn, the wall tiling crew yields to the grouting crew, and so on.

Table 1: Subtasks within production units

Subtask	PU1 Bathrooms	PU2 Kitchens	PU3 Closets	PU2 Doors	PU2 Painting
A	Floor tiling	Wall cabinet	Structure	Frames	Sealing
B	Wall tiling	Base cabinet	Doors	Doors	1st Screeding
C	Grouting	Granite board	Shelves	Frame painting	Sanding
D	Marble board	Wall Tiling	Drawers	Door painting	1st Coat
E	Sanitary	Sink	Knobs	Knobs	Screeding&Sanding
F	Cabinet	Faucet	Sealing	Doorpost	2nd Coat

FLOWLINE

According to Dave et al. (2015), the steps necessary to implement an integrated planning and scheduling system are: (1) create the location breakdown structure, (2) identify activities at the proper level of detail and how they relate to one another, (3) apportion activities based on take-off, consumption, resources and the know-how of the specific trade contractor. On the basis of steps 1 and 2, Figure 2 shows the flowline of the aforementioned painting production unit 5. This level of detail would help last planners visualize the work, detect process clashes, identify constraints, and have better-informed pull planning sessions.

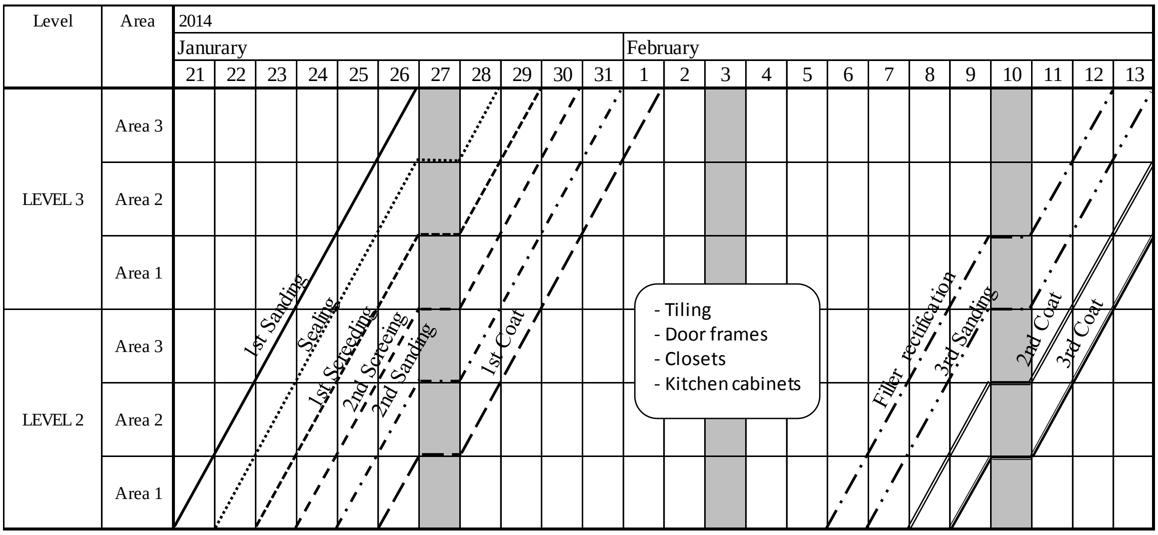

Figure 2: Painting flowlines

CASE STUDY 2

PROJECT BACKGROUND AND CONTRACT RELATIONS

The second case study focuses on a large community-housing project. The project consists of 28 five-story buildings occupying 99,330 square meters. Each building includes 100 flats with basic finishing and highly repetitive processes. The phase studied lasted three months, and the tasks monitored were (1) painting, (2) doors, (3) windows, (4) tiling, and (5) flooring.

The contractor had previous experience in community housing. In the finishing phase of the previous project, the team faced some constraints in terms of the design and the development of the work structuring. One of the problems was the contracts, as the documents only specified the start and end dates, tolerances, and cost. The flow process was not part of the formal agreement with the subcontractors. Therefore, they were reluctant to attend meetings to track their progress, engage in collaborative planning, and analyze underperformance. Based on this experience, the second case study requires the subcontractors to attend the weekly meetings.

WORK STRUCTURING

The production units were designed on the understanding that community housing has less finishing work than other residential buildings. For instance, the project does not include kitchen cabinets, closets, or wall tiling. Because of this, the work chunks were divided into two production units: (1) Bathrooms, kitchen, and laundry room; (2) Living room, dining room, and bedrooms. Assigning different crews for each production unit allows for reduction of conflicts in the field, and each subcontractor can estimate his workload independently.

Bedroom with floor, window, door and painting

Kitchen with basic finishing: floor, cabinet, and sink

Figure 3: General plan divided into two production units

PULL PLANNING SESSIONS

Contracts with subcontractors were key drivers for participation and attendance in pull-planning sessions. In these collaborative meetings, planners and subcontractors discussed the possibility of work completion in the field, taking into account the pull plan, the daily workload, the available resources, and the time of day that activities were to be completed.

To generate a flowline, it is possible to define each location and timeframe in self-contained boxes. In other words, all work related to that activity and location should be completed within the time-location box (Dave et al. 2015). The use of these boxes is useful for visualization purposes in highly repetitive projects with short schedules. For example, Figure 4 shows the flowlines for the first production unit.

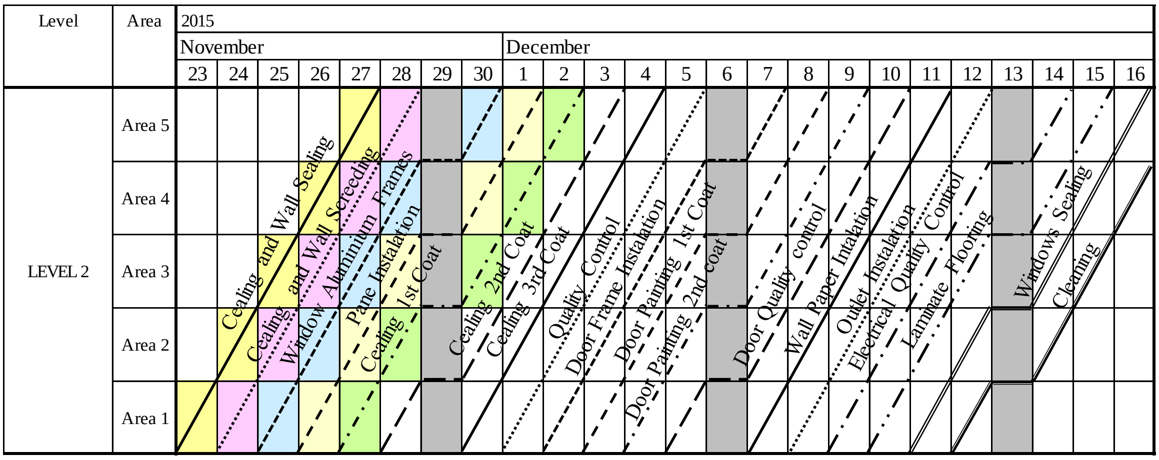

Figure 4: Flowlines with boxes in the second production unit (Adapted from Dave et al. 2015)

Additionally, local trade contractors agree that repairs due to non-conformities hinder their workflow. Going back to do these repairs is time-consuming and causes production delays. To protect the weekly work planning, the contractor included an additional crew to repair non-conformities, so as to guarantee flow within the subcontractor's crew. The subcontractor assumed the cost of this crew, subtracting it from their monthly payments. In this way, the boxes are finished on time, and clashes are avoided.

Even though the contractor understood the use of the flowlines and their application, in practice, for simplicity, and in the context of highly repetitive activities, tasks were controlled through Excel schedules. The contractor made the flowlines for purposes of visualization. Hopefully, planning and control with flowlines will be used in the future with more complex projects.

PPC AND WEEKLY WORK PLANNING COMPLIANCE

During the early weeks of the phase, PPC was 60%. It was at this point that the contractor and the subcontractors agreed on the inclusion of the additional crew that would deal with non-conformities and facilitate the flow of the subcontractor's crews. As a result, PPC increased to 75%. The phase was later delayed two weeks, but this was the result of the client's having purchased products that arrived late on site.

CONCLUSION

The case study suggests that LPS implementation during the finishing phase in residential buildings improves the performance of the production system. It is necessary to redesign the production units, grouping activities according to location and similarity of tasks rather than in terms of a full apartment or story. In addition, each production unit must be defined with work chunks at the right level. Otherwise, it will be difficult to observe the workflow during the planning process, and conflicts will arise in the field. The pull planning process also requires better visualization: here flowlines can be used to good effect, and hopefully the method will be used in the company's future projects. Full deployment of these strategies, however, requires training and leadership among the managers of both contractors and subcontractors. An additional crew to repair damages or finish incomplete work was a local strategy tacitly agreed upon with subcontractors. Contracting relationships are vital to sustain LPS implementation within the world of small subcontractors. The general contractor needs drivers to steer production control. Attendance at weekly meetings and resource allocation have a direct effect on improved workflow and cooperative behavior (Sacks and Harel 2006).

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