COMBINING VALUE STREAM AND PROCESS LEVELS ANALYSIS FOR CONTINUOUS FLOW IMPLEMENTATION IN CONSTRUCTION

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ABSTRACT

This research focuses on the use of concepts and tools of Lean Thinking seeking the implementation of continuous flow in construction. An exploratory case research approach was used in the work. Such study was carried out in a construction site of a resort in the northeast region of Brazil. Taking as a basis literature and successful implementation path used in other industries, a combined analysis was used, first in value stream level and second in processes level. As result of this research, Value Stream Maps (VSM) of the execution of the standard apartment was drawn for a sample of services, including dry wall and ceramic tiling. The maps made possible an organized discussion about the applicability of important lean concepts, such as: takt time, cell production, etc. Line of Balance, Operator Balance Charts and Standardized Work Combination Table were analysed to improve flow. As conclusion, the path of implementation suggested in lean literature and used in several other industries presented interesting potential considering this case study and encourages future studies using and detailing this approach.

KEY WORDS

Continuous flow, Value stream maps, Operator balance chart, Standardized work combination table

INTRODUCTION

Most works aiming improvement of construction adapt conceptual and theoretical models developed in other industries (e.g. Hopp and Spearman 1996; Womack et al. 1991), while others have searched new theories for management in the construction industry (for example, Koskela 2000; O'Brien et al. 2002).

Currently several studies related to construction production management have focused on the paradigm of Lean Thinking (Womack and Jones, 1996), which is based on the Toyota Production System (TPS). This paradigm has as one of its main contributions the concept of continuous flow, understood as "producing and moving one item at a time, or a small and consistent bath of items, through a series of processing steps as continuously as possible, with each step making just what is requested by next step" (LEI, 2003, p.9).

The differences between construction and manufacturing are well known, and the translation of concepts and tools requires generalization and adaptation (Lillrank, 1995). Translating continuous flow concept to construction environment is a quite difficult challenge. On one hand lack of flow is clear: construction production systems are characterized by many interruptions, generating all kinds of wastes and sub-use of resources (labour, equipment and materials) (Koskela 1992).

Several studies have focused on the subject of creating flow in construction (Santos 1999;

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Santos *et al*. 2002; Ballard and Tommelein 1999), and on tools to support flow, such as production control (Ballard 2000), mechanisms to pull production (Ballard and Howell, 1998; Tommelein and Li, 1999), visual devices to increase transparency (Formoso and Santos 2002), reduction of the cycle time (Ballard 2001; Elfving *et al.* 2002), *poka-yoke* (mistake-proof) devices (Santos and Powell 1999), batch size reduction (Santos and Powell 2001).

In spite of all these efforts, the application of continuous flow in construction is still understood in a fragmented way (Picchi and Granja 2004), resulting in implementation difficulties. In other industries, approaches for integrating continuous flow achieving with other lean concepts, such as value stream improvement, have helped companies to obtain better results (Rother and Shook 2000).

The main objective of this research is to analyse if the approach for lean combination and implementation used in manufacturing has the same potential of usefulness in construction, for achieving continuous flow.

A case study approach was adopted in this exploratory research, carried out in a project site in the city of Natal, Brazil. The project is a Resort with 396 rooms, owned by an international group. The first research phase consisted of data collection and the second one of results analysis and discussion. Data was collected by interactions with job site managers and took as a framework the path proposed by Rother and Shook (2000). The suggestions were partially implemented, due to project phase restrictions, but important insights could be obtained. Based on that, a preliminary analysis model for achieving continuous flow in construction is proposed.

A COMBINED ANALYSIS OF VALUE STREAM LEVEL AND PROCESS LEVEL

Womack and Jones (1996) have proposed five principles for Lean Thinking: value, value stream, flow, pull, perfection. In fact, these principles are presented by the authors as steps of implementation: understanding customer requirements, analysing waste through all steps, implementing flow and pull and improving continuously. This approach is detailed by Rother and Shook (2000), who describe value stream mapping as a primary tool for planning lean transformation. Rother and Harris (2002) complement this approach presenting tools for work cell design, enabling continuous flow.

Rother and Shook (2000) point out the importance of starting in the value stream level (a whole factory or a whole construction site), and just after that going into details in processes level (each task level), avoiding isolated improvements without a system view. Most implementations, in construction or even in other industries, start directly analyzing the process level, with limited results (Picchi and Granja 2004; Rother 1997).

This approach has been used successfully by several companies in different industries[4], and could be summarized by the following steps:

- Value Stream Mapping and designing a future-state value stream map proposing necessary improvements to reduce waste, represented by non value-adding activities; after that, action plan establishment to guide implementation;
- Implementation of continuous flow, balancing workers' activities, implementing work cells, etc., and establishing pulled production were necessary;
- Use of standardized work for the definition of rhythm and sequence;
- Continuous improvement of standardized work by successive *kaizens*.

This approach is supported by some analysis tools, described below.

VALUE-STREAM MAPPING (VSM)

The VSM shows graphically every step involved in the material and information flows from orders reception to delivery. Generally, two maps are conceived: one current-state VSM, representing present value stream and its wastes, and a future-state VSM, representing the design of improvements in the value stream, towards lean implementation. Rother and Shook (2000) list eight key questions that drive the current state analysis towards a lean future state.

Following concepts, among others, are useful to understand VSM data (Lei 2003; Rother and Shook 2000; Rother and Harris 2002): Cycle Time (C/T): measures how often a part or production actually is completed by a process, and *Takt* Time (TT): related to the rhythm of consumption, or customer demand.

OPERATOR BALANCE CHART (OBC)

The operator balance chart is "a graphic tool that assists the creation of continuous flow in a multi-step, multi-operator process by distributing opera-

4 Several cases are described in literature, for example in www.lean.org; some of the authors of this paper have experienced this approach in different industries.

tor work elements in relation to *takt* time" (Lei 2003, p.53).

An OBC uses vertical bars to represent the total amount of work each operator must do compared to *takt* time. Creating an OBC helps the critical task of redistributing work elements among operators. This is essential for minimizing the number of operators needed by making the amount of work for each operator nearly equal to, but slightly less than *takt* time (Lei 2003). Rother and Harris (2002) give examples of practical use of this tool to improve work design.

STANDARDIZED WORK COMBINATION TABLE (SWCT)

This form shows the combination of manual work time, walk time and machine processing time for each operator in a production sequence. It provides more details and is a more precise process design tool than the OBC. This table is a support to Standardized Work, a key concept in lean thinking, based on three elements: 1°) *takt* time; 2°) the precise work sequence in which an operator performs tasks within *takt* time; 3°) the standard inventory (Lei 2003).

OTHER TOOLS

Several other tools can be used to support the analyses, most of them described by Lei (2003), Rother and Harris (2002) and other authors.

Although generally not used in manufacturing, the Line of Balance (LOB) is regarded as an useful tool in the value stream level, helping the analysis of construction tasks rhythm and interferences, and aiming at continuous flow (Seppänen and Junnone 2004; Kenley 2004; Seppänen and Kankainen 2004).

CASE STUDY RESULTS

The case study data collection was developed in a three weeks interaction of researchers with the job site managers. During this time, the main related lean concepts and tools, presented previously, were introduced to the team, and tools were applied, starting with a value stream analysis. The structure and external masonry were almost finished at that time and the work focused on the future tasks from that stage to the end of construction.

The starting point of analysis was the existing computer based long term plan, elaborated by the company's planning department. Several problems could be identified, such as tasks interference and restrictions due to design and materials delivery. The environment was requiring several stabilization actions, taken by the managers and not focused on by this research. The proposal was to analyze lean tools implementation, aiming continuous flow creation, as part of the overall improvement effort..

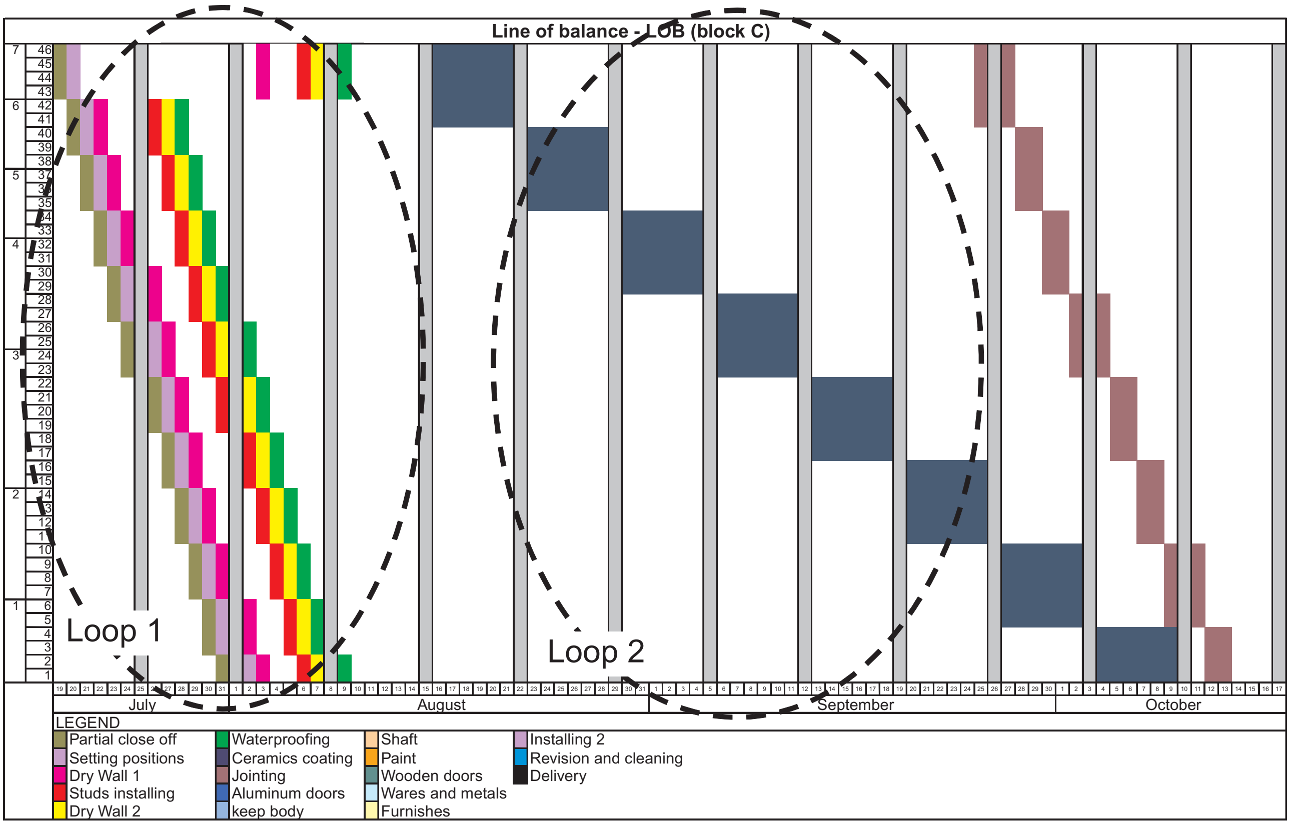

Figure 1: Extract of Line of Balance—LOB (Block C)

The pathway described previously was tested, directing the analysis from value stream level to process level, using in a logical sequence the following tools: LOB, VSM, OBC, SWCT. The VSM was drawn in two levels: whole project and group of tasks.

LINE OF BALANCE (LOB)

LOB of one building (Block C) of the project is presented in Figure 1. It was elaborated through many meetings between the researcher and the project planning engineer. This plan represents an improved version of the initial project schedule, based on a preliminary study of the work flows, synchronization between the processes and restrictions of resources. Although improved, several restrictions in design and material deliveries resulted in buffers and unbalanced rhythms.

After the elaboration of the LOB, some points were identified where continuous flow could be implemented. In Figure 1 these points are shown by loops 1 and 2, respectively dry-wall and ceramic tiling, each of them including its sub-activities.

LOB application was useful for: a) identification of interferences among trades, enabling easy visual analysis; b) definition of work pace for each task; c) identification of groups of tasks that occur in a same project phase and that could be clustered for flow implementation.

VALUE-STREAM MAP (VSM)—PROJECT

Current-state map of the standard apartment execution is presented in Figure 2. In this map the main processes involved in the construction of an apartment are shown. Differently to the application of the map in other contexts, in which a single part is mapped, in this case a whole apartment was followed as a product unit. The rhythms and inventories between processes were extracted from the LOB presented in Figure 1.

The suppliers are represented in a simplified way by a single box (left hand side of the map), grouping companies responsible for the supplies for each process. On the other side of the map the information related to the customer is registered. The customer is a company who paid `ready processes' by weekly measurements. The definition of the volume of production is established by the physical schedule of the project, settled between the constructor and the customer before the begin-

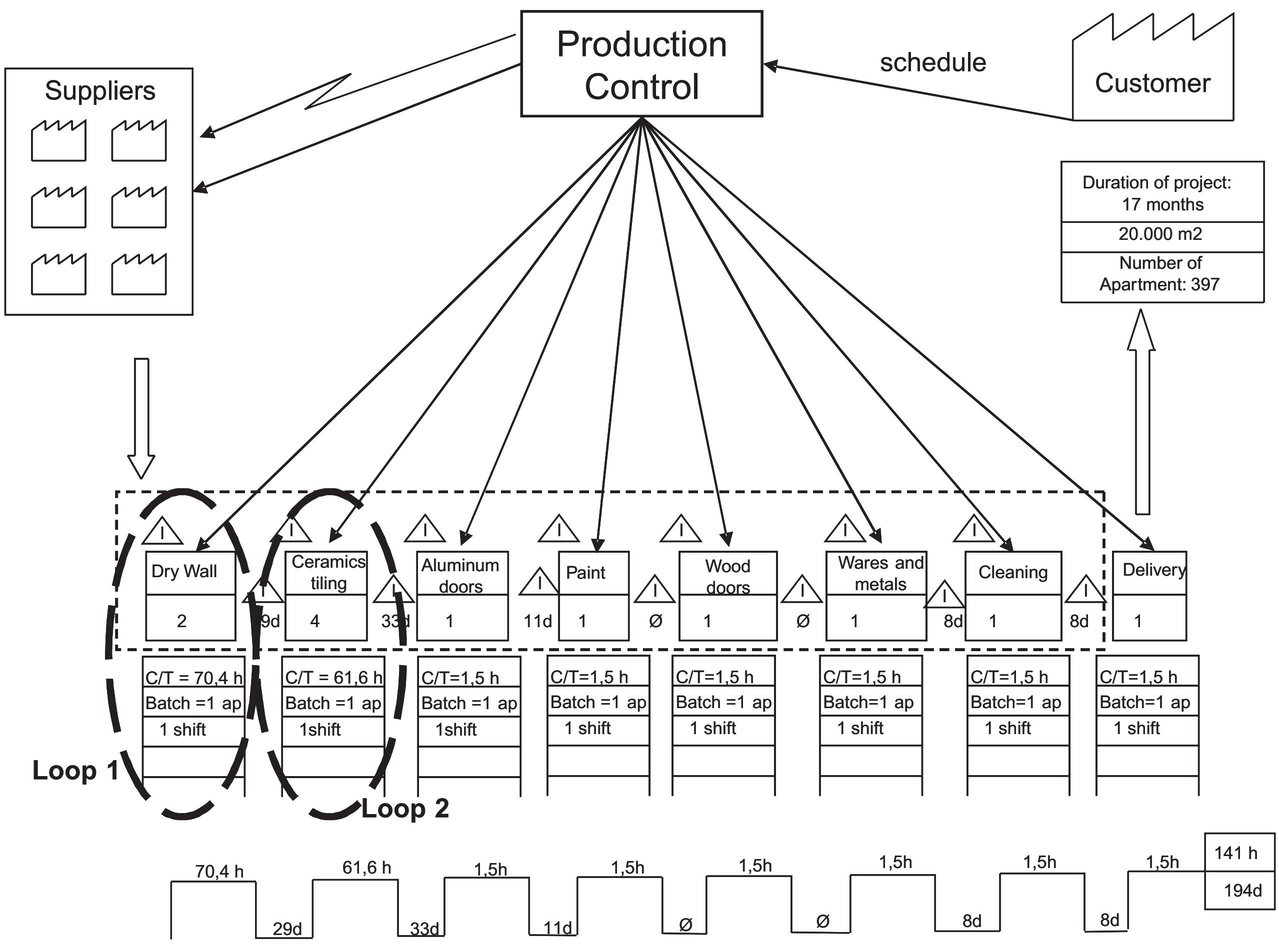

Figure 2: Current-state map of a Standard Apartment

Table 1: Analysis of key questions proposed by Rother and Shook (2000)

Questions	Discussions
1. What is the takt time?	From Figure 1 one can observe a total available time of 18 days (8,8h each—brazilian's day work) or 158,4 h, to produce 46 apartments. Takt time is 3,44 h for each apartment.
2. Will finished goods be built to replenish a supermarket from which customers pull, or will them be built and directly shipped to clients?	One option would be keeping an established number of apartments with dry-wall finished, and another one would be prepared just if next process demands (supermarket); the option adopted was to build and deliver to next process execution immediately.
3. Where to use continuous flows process?	To achieve continuous flow two work cells were proposed, for the execution of tasks Positioning + Dry wall 1, and studs installation + Dry Wall 2.
4. Where pulled systems should be used?	A supermarket was planned between processes and suppliers, regulating materials delivery on demand.
5. At what single point will production be scheduled?	Just the first cell (positioning + dry wall 1) should be planned; cell 2 (studs+dry wall 2) would work in a FIFO (first in first out) with a maximum of two apartments between cells.
6. How to level the production mix at the pacemaker process?	This question is related to different products mix. In construction a parallel would be different size apartments mixing, planned by production control.
7. What increment of work will be consistently released?	One apartment. This is also the work transferred to another team.

ning of the project. The total duration of the project was seventeen months.

The discussion of a whole project future state was not an objective of this research, but should be the following step after the current state drawing. According to job sites priorities, the future state was drawn just for loops 1 and 2, identified in Figure 1 and 2.

This representation shows us: a) the sense of wastes in the form of waiting, inventories, etc., for a typical apartment; b) cycle times for each activity, making clear eventual unbalanced work; c) Total lead time versus total processing time; d) The relationship between information flow and materials flow, showing opportunities for the elimination of several programming points, which generally generate conflict and flow interruptions.

VALUE-STREAM MAP (VSM)—GROUP OF TASKS

Line of Balance (Figure 1) shows us groups of tasks that happen in sequence and that are concen-

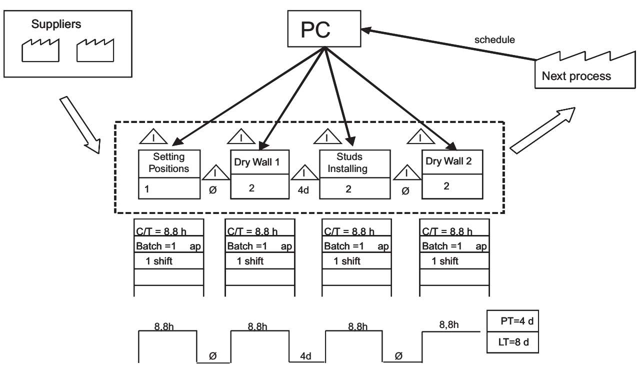

Figure 3: Current State Map—process level - Dry Wall

trated in a period of time, considering each apartment execution (Figure 2). In fact these task grouping is one improvement obtained in the analysis of LOB and VSM in the project level, seeking continuous flow. Most projects planned in a traditional way do not show clearly these groups, presenting tasks with different rhythms and interferences (Seppänen. and Junnone 2004; Kenley 2004; Seppänen and Kankainen 2004).

Group of tasks level VSMs were drawn for both loops 1 and 2. As an example, the analysis for loop 1 (dry-wall) is presented in Figure 3. The dry wall installation was divided into following sub-processes: positioning, dry-wall 1 (structure, floor perforations for services, first side closing), studs installation, dry-wall 2 (second side closing and finishing). Current State map shows us four sequential processes, each one with a day of work (8,8h) duration, and a waiting of 4 days between Dry-wall 1 and Studs installing. The total process time (PT) is 4 days and total lead time (LT) 8 days.

For the elaboration of the future VSM the eight key questions proposed by Rother and Shook (2000) have been used. The discussion referring to these questions is presented in Table 1.

As result of this discussion, we obtained the map presented in Figure 4. The creation of two cells combining some tasks without waiting inside cell between combined activities resulted in a reduction of production time (PT) in 2 days. One can observe that a controlled inventory of product in process has been created between the cells of dry wall 1 and 2, set as a maximum of 2 apartments. This level of inventory reflects uncertainties evaluated by job site managers, such as

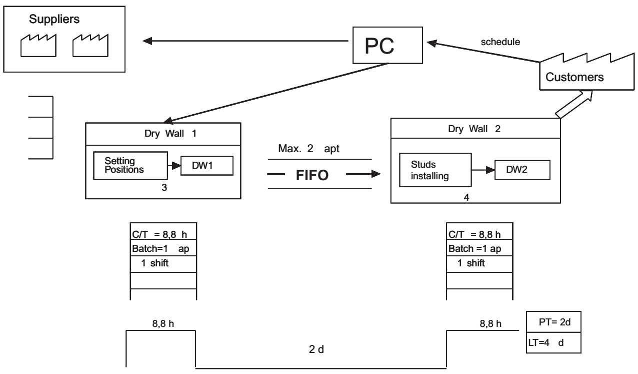

Figure 4: Future-state map of the Dry Wall.

positioning changes, and could be reduced in the future, improving reliability of design and previous works. The use of just in time, represented by a supermarket between site and suppliers, could reduce the inventory of raw materials, not quantified in current state map. The final lead time (LT) would be 4 days, against 8 days in current state (Figure 3).

Similarly as the application in project level, VSM in the level of group of tasks has brought interesting insights regarding flow creation, in a more detailed scale. The systematic application of the questions directs the use of lean tools, such as cell work, pulled system, FIFO, in an integrated vision.

OPERATOR BALANCE CHART (OBC)

After VSM analysis identified opportunities to create flow among tasks, a detailed analysis in the process level must be done, in order to balance and optimize operator's time. This analysis is supported by the OBC (Rother and Harris 2002). To exemplify this application, ceramic tiling (loop 2) is discussed; previously, a value stream map in group of tasks was drawn, not presented in this paper.

Before OBC analysis in a traditional way, the job site managers had planned to use 6 teams of 3 workers each working in parallel, to accomplish the 46 apartments of Block C in 48 days as required in the LOB (Figure 1). Data was gathered interviewing the foreman, collecting times for ceramic tiling sub-tasks, occurred during the execution of a pilot apartment. The total work content was 69 hs (Figure 5a), representing the total sum of work elements as if one apartment were done by just one worker. In this Figure the sub-tasks included in the ceramic tiling can be seen, as bathroom floor, bathroom wall, etc. Figure 5b shows the division of work among 3 workers, as planned originally by the foreman.

OBC is useful to compare workers time to each other and to compare Cycle Time (C/T) against *Takt* Time (TT). *Takt* time can be calculated as: total available time (48 days x 8.8hs = 422.4 hs) divided by the number of apartments (46), resulting in a TT of 9.18 hs, meaning the average time to deliver one apartment's ceramic tiling.

Figure 5b shows us some wastes: a) the division of work among workers is unbalanced, so some of them wait for others; b) The cycle time (34hs) is much lower than 6x*takt* time (55.08hs), so the crews' definition was overestimated (in Figure 5b C/T of one team was compared to 6xTT, since 6

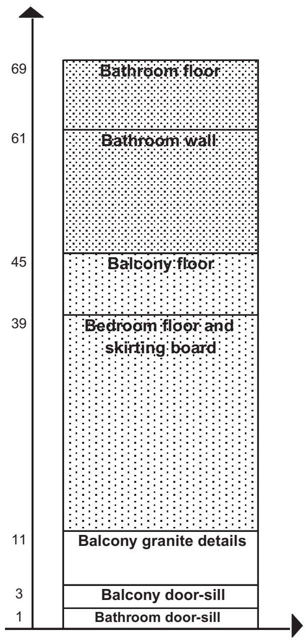

Figure 5a: Work content

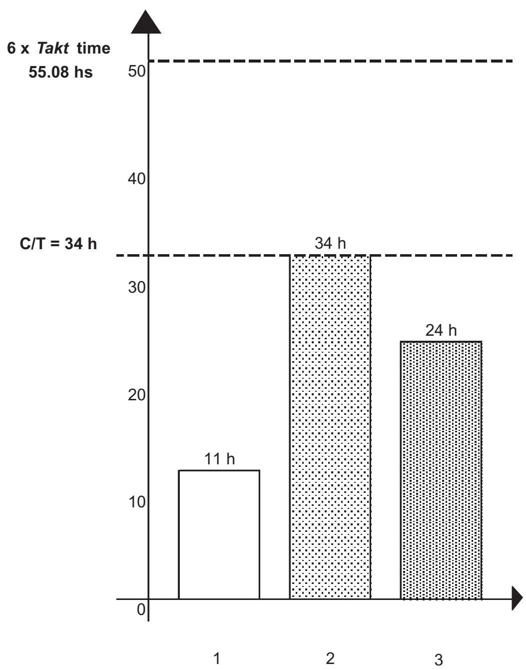

Figure 5b: Operator Balance Chart

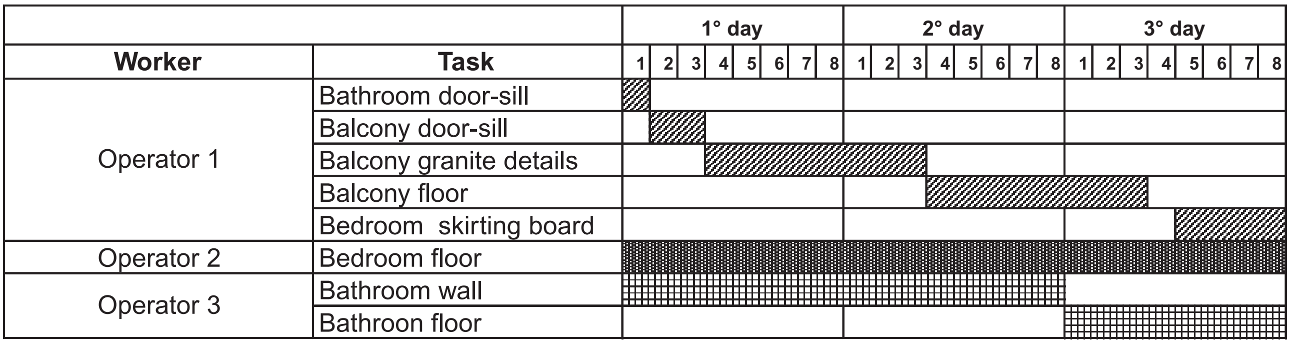

Figure 7: Standardized Work Combination Table—Ceramic Tiling

teams are working in parallel) (Rother and Harris 2002).

The original job site managers' plan was to use 18 workers (6 teams of 3 workers), but the ideal number of workers can be calculated by dividing the total work content (69hs) by *takt* time (9.18), resulting 7.5 operators (Rother and Harris, 2002).

The job site managers decided to keep the three workers team, and an analysis of optimization of OBC was done, resulting in Figure 6. In this Figure work was balanced among 3 workers in a team, resulting in a C/T of 24hs, instead of 34hs, and 3 teams would be enough, facing 3xTT = 27.5 hs, totalizing 9 workers, instead of the original number of 18. This observation motivated the job site managers to think about different possibilities, for example redefining LOB, reducing duration of ceramic tiling execution (representing a *Takt* Time reduction), which would result in a higher number of ceramic teams and working with a higher *Takt* Time (longer duration) in other tasks (job site managers have evaluated that more than 6 ceramic tiling qualified teams would be difficult to hire for that job site, what had determined the long original duration for this task).

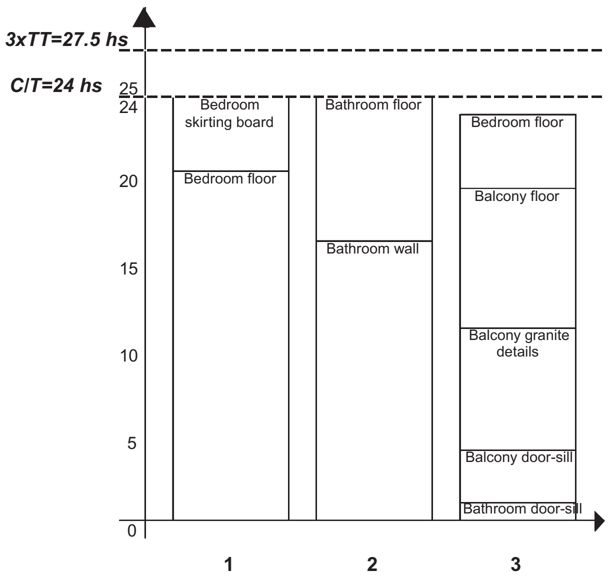

Figure 6: Optimized proposal for OBC

The OBC brings the analysis to the operator efficiency level, showing unleveled labor allocation among workers, for example some of them overwhelmed and some of them inactive part of time. The concept of takt time brought the exact sense of needs regarding labor allocation for producing just the necessary to accomplish task duration, defined by the LOB time deployment from client's requirement of total project duration.

STANDARDIZED WORK COMBINATION TABLE (SWCT)

A sketch of a SWCT was elaborated (Figure 7), analyzing interferences and establishing what each worker should be doing at each hour of the 3 days Cycle Time (for this table it was considered 8 hs net of work per day, leaving 0.8 hs for auxiliary work, such as cleaning up, etc).

This Table is a powerful tool to communicate expected rhythm to workers and to control the task evolution, providing a short term problems exposure and solution. Benefits of standardized work use in construction are discussed by Nakagawa and Shimizu (2004).

PRELIMINARY PROPOSAL FOR CONTINUOUS FLOW IMPLEMENTATION IN CONSTRUCTION SITES

This work took as a basis the implementation path proposed by Womack and Jones (1996), Rother and Shook (2000) and Rother and Harris (2002) and tested it in an exploratory case study in a job site. The application showed encouraging results and demonstrated opportunities for some minor adaptations, such as combining VSM with LOB analysis and using VSM both for project and groups of tasks. These insights can be summarized in a preliminary proposal, presented in Figure 8.

This proposal recommends the same starting point as proposed by the authors referred previously: value stream level followed by process level analysis. Since in construction the total dura-

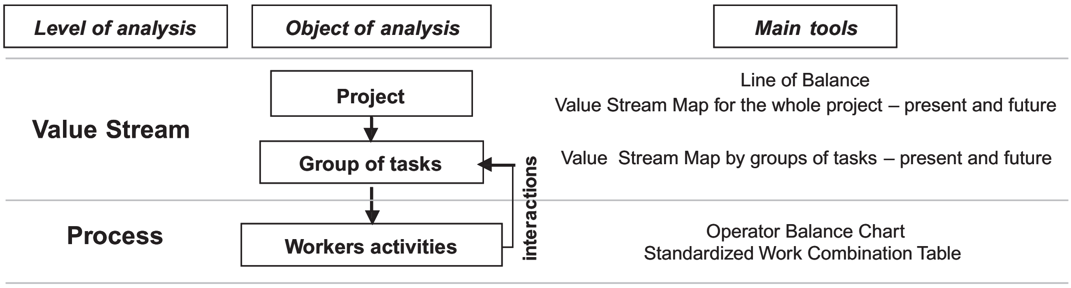

Figure 8: Preliminary proposal—sequence of analysis for continuous flow implementation in construction

tion of project is established, but the rhythm of groups of tasks can be redistributed (affecting the equivalent *Takt* Time of each group), an interaction between processes and group of tasks analysis is expected, during planning activities. This path can help to draw a future state and to plan process level improvements, and should be followed by an action plan and implementation.

CONCLUSION

Continuous flow is a core concept in lean thinking, and one of the most difficult ones to implement. Isolated applications in process level have been done, showing the possibility of application of this concept in construction. In literature and other industries implementations the recommended starting point is value stream, than followed by the application of tools such as Value Stream Map, Operator Balance Chart, and Standardized Work Combination Table.

This research took this path as a basis and applied it in an exploratory case study. Results showed that the approach used in manufacturing is useful also for construction, despite requiring appropriate abstractions and adaptations. Examples of adaptations identified in this work that could enhance the application in construction are: combining VSM with LOB, analysing VSM in project and groups of tasks level, and considering process level and value stream level interactions in the definition of *takt* time for groups of tasks. The usefulness of each tools for flow improvement were demonstrated and discussed in this case study, showing the potential of this approach for construction.

The results are encouraging, showing that also in construction this sequence of analysis and these tools are valuable to identify wastes and to plan continuous flow implementations.

Future studies are suggested, primarily: a) applying the approach in different projects since the very beginning, and b) completing the implementation cycle up to standardized work and *kaizen*.

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