# ACTIONS TO IMPLEMENT CONTINUOUS FLOW IN THE ASSEMBLY OF PRE-FABRICATED CONCRETE STRUCTURE

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## ABSTRACT

Most production systems in the construction industry have a large number of interruptions in the work of gangs, resulting in waste and under-utilization of resources. Such interruptions are typically caused by variability in the production system and lack of synchronization of processes. This paper discusses the implementation of continuous flow in the process of assembling the pre-fabricated concrete structure of an industrial building, located in the State of S Paulo, Brazil. The implementation process was mostly based on Lean Thinking principles, involving tools for creating continuous flow. Action-research was the research strategy adopted for developing this study, which was divided into two main stages: (a) implementation of production control for making the production system minimally stable; (b) implementation of a proposed assembling sequence and rhythm, based on a small batch repetitive cycle. The implementation was successful in terms of reducing the cycle time, improving the productivity in the assembling process, reducing waste in the utilization of cranes, and, specially, increasing stability of the assembly process.

## KEY WORDS

Continuous flow, pre-fabrication, Lean Thinking, small batch, increasing stability.

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## INTRODUCTION

One of the main factors that cause wastes in construction sites is the interruption of work flows, which are usually caused by high variability in the production system, lack of synchronization between processes, and insufficient stability. Several manufacturing industries have been successfully using Lean Thinking concepts, principles and tools for reducing waste and improving their performance.

The use of small batches helps the production system to become more flexible and efficient. Therefore, changes in market demands and product quality standards may be identified more quickly. In this respect, an important contribution of Lean Construction researchers was the introduction of construction production system flow concept (Koskela, 1992, Santos, 1999; Santos et al, 2002; Ballard and Tommelein, 1999).

One of the core Lean Thinking principles proposed by Womack and Jones (1996) is the implementation of continuous flow in production, which means that roducing and moving one item at a time, or a small and consistent batch of items, through a series of processing steps as continuously as possible, each step making just what is requested by next step (LEI, 2003).

In the manufacturing industry the production of unitary items in a production line can be regarded as a reasonable way of production (cars, pens, mobile phones, etc). However, the implementation of continuous flow in manufacturing is not something trivial and also involves the implementation of a series of actions in the plant and, mainly, behavioral changes in people involved, from line workers to company senior management (Liker, 1996).

Transferring the concept of continuous flow to the construction industry is a major challenge. It is necessary to generalize and adapt some concepts related to continuous flow, originated in the automobile industry, in order to be used in construction (Lillrank, 1995). This research work considers that the core Lean Thinking concepts and principles can be used to help answer this challenge (Koskela, 2000; Womack and Jones, 1996; Picchi and Granja, 2004).

This article presents the preliminary results of a research project that involved the accomplishment of an empirical study on the assembling process of pre-fabricated concrete structures. The objective of this study was to implement continuous flow through the introduction of small batches and work standardization and to analyze the benefits this implementation for the company.

## CONTINUOUS FLOW

This study adopted the model of implementation of continuous flow proposed by Rother and Shook (2000) and Rother and Harris (2002) as a starting point. This model can be summarized by the following steps:

(a) Value Stream Mapping (VSM): draw a current state value stream map and design a future-state map, proposing improvements for reducing waste, represented by non value-adding activities;

(b) Implementation of continuous flow: involves balancing workers activities, and implementing work cells, establishing pull production were necessary;

(c) Use standardized work in order to define the rhythm and sequences;

(d) Continuous improvement of standardized work by successive kaizens.

This model was tested in an exploratory study, which is described in a previous IGLC paper (Bulh s et al., 2005). The results of that study suggested that VSM should be used in combination with the Line of Balance (LOB), which is a well known construction planning technique. A preliminary proposal for implementing continuous flow was devised, as represented in Figure 1.

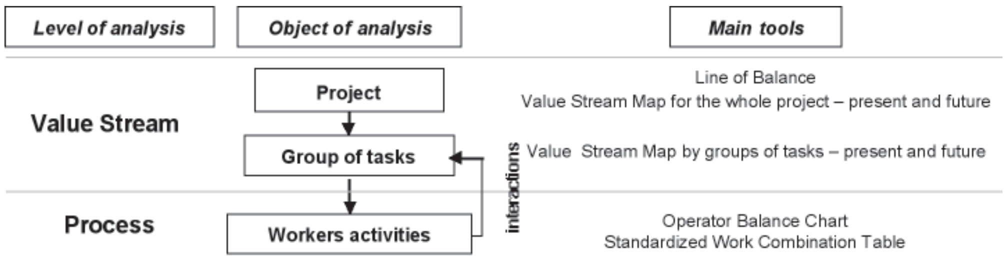



*Figure 1.Preliminary proposal – sequence of analysis for continuous flow implementation in construction (Bulhões et al, 2005)*

This proposal recommends the same starting point suggested by Rother and Shook (2000): value stream level followed by process level analysis. In construction, the total duration of the project is established at the beginning of the project. However, the rhythm of gangs can be defined for groups of tasks (affecting the equivalent Takt Time[1] of each group). As a result, the interactions between processes and groups of tasks must be analysed during production planning. This path can help to draw a future state, including process level improvements. That previous study also suggested the use of the Operator Balance Chart (OBC) and Standardized Work Combination Table (SWCT) for the process analysis level. Those are useful tools to support the creation of continuous flow in processes with multiple stages and operators.

## RESEARCH METHOD

This research study was carried out in two job sites of Munte Constru es Industrializadas Ltda., a construction company specialized in the manufacture and assembly of industrialized concrete structures, located in the State of São Paulo, Brazil.
The study was divided into following phases:

(a) Literature review;

(b) Case study: analysis of the current state assembly process in job site A and identification of its main problems and wastes;

(c) Implementation proposal;

(d) Action research: partial application of the proposal in job site B:

  (d1) implementation of production control in order to achieve a minimum stability in the production system;

[1] Related to the consumption rhythm, or customer demand.

(d2) implementation of a proposed assembling sequence and rhythm, based on a small batch repetitive cycle;

(e) Analysis of data and interviews with employees (on-going).

Due to project duration constrains, the proposal (step c) could not be fully implemented in job site B. Step d was limited to those two actions (d1 and d2), and a third action, presented in the proposal, was not applied.

## DESCRIPTIONS OF JOB SITES

Table 1 presents the main characteristics of the job sites. Both consist of the production and assembly of pre-fabricated concrete structures, involving similar component types, work teams and equipment. However, the size (volume, area, number of parts) of job site B is much bigger than job site A.

| Characterization | Job site A | Job site B |
|---|---|---|
| Description of the Job site | Assembly of a pre-fabricated concrete structure of a warehouse composed by the following components: columns, beams, slabs, roofing tiles and stairs. | Assembly of a pre-fabricated concrete structure of a mall composed by the following components types: columns, beams, slabs, roofing tiles and panels. |
| Area of the job site (m | 3.072,25 | 178.000,00 |
| Volume of concrete (m | 832,03 | 10.130,73 |
| Number of parts | 578 | 8.741 |
| Team | 1 part-time engineer, 1 administrative support, 1 foreman, 5 assemblers and 1 crane operator. | 1 part-time engineer, 1 administrative support, 1 foreman, 5 assemblers and 1 crane operator. |
| Available equipment | 2 cranes (one full-time and one part-time). | 2 cranes (one full-time and one part-time). |
| Duration of structure assembly | 25 days | 250 days |

*Table 1.Characterization of job sites A and B*

It is important to point out that the job sites used components produced in a new pre-cast plant, which had been recently installed. For that reason, this plant still had some additional production management problems, such as high variability in production cycle times, equipment being tested, causing frequent stops, and transportation teams between plant and job sites under implementation.

## JOB SITE A ASSEMBLY PROCESS ANALYSIS

At the beginning of the project a delivery plan was prepared (dates, sequence and quantity of pieces for transportation load), but as the factory had high instability, the plan was abandoned, resulting in an assembly process that was based in informal planning.

In order to help the analysis of the assembly process of job site A, a Value Stream Map (VSM) was designed, indicating a difference of 164,5 h (262 h 94,5 h) between total construction duration and the real processing duration. This difference was mainly because of:

a) Components inventory: this occurred frequently because some of the components could not be assembled since there were interdependencies with other components that had not been assembled yet. Another problem was that some assembled components obstructed the crane movement, as result of wrong assembly sequence.

b) Work in process: some components that had already been assembled (columns and beams) had to wait for the assembly of the slabs and roof tiles. This happened because the assembly sequence definition did not consider interdependencies between components, and also due to the use of large assembly batches of the same type of piece.

c) Factory components delivery delay: this caused a sub-utilization of resources (crane and assembly gangs). The capacity of the assembly equipment in this project was nearly eight deliveries per day, but the actual average was three loads per day. The equipment idleness was nearly 66%: 802 hours of actual use compared to the 370 hours estimated in the budget. In crane production terms, this means 1,04 m h (actual) versus the 2,24 m h (budget).

d) Design changes: the client made unexpected last-time design changes and the company design division did not reacted on time, partly due to ineffective information flows. This also was one of the major causes for factory components delivery delays.

### Implementation proposal

Based on the diagnosis presented above, the following intervention proposal was devised for implementing continuous flow in job site B:

1. Improvement of process stability level through the implementation of a hierarchical and formal planning process.

    a) Long term plan: a computer schedule should be created (as soon as the contract is signed) by the planning and factory control divisions. Based on this schedule the project should be divided in main stages, defining the general sequence of the structure assembly. This stages and sequence definition should be done by the project engineer in agreement with the client.

    b) Middle term plan: based on the stages defined in the long term plan, each big stage should be fractionated into small work batches, preferable repetitive and controllable ones. For this purpose, the use of Lines of Balance was suggested. After the definition of those batches and based on more detailed information of deadlines, restrictions should be discussed among the divisions involved (project engineer, planning, design and supplies).

c) Delivery plan: this plan was already part of the company system, and based on this proposal it should be carried out and discussed by the people involved in the process (job site, Rafard and Itapevi factory production and transportation divisions). Besides that, this plan should provide information of problems, including causes of delivery problems, and corrective actions.

4. Standardized Assembly Cycle: this action aims to create a repetitive standardized assembly cycle, based on small batches and leveling (assembling different pieces and completing a module every day). This standardized assembly cycle pulls the factory pieces delivery. The most important issue in this action is the creation of a reliable factory-transportation-assembly system, in which the problems were identified and solved.

5. Standardized work implementation: at this level a study of operators movements should be done, in order eliminate waste, using tools such as the Operator Balance Chart (OBC) and the Standardized Work Combination Table (SWCT).

Besides this job site plan, other actions should be implemented by the company, focusing on improving the reliability of the design process and of the pre-cast component plant.

### Job site B Proposal Implementation

As discussed previously, the proposal was partially implemented in job site B, due to project duration constrains and deficiencies of process stabilization. The third action – standardized work, presented in the proposal, could not be applied and it has been planned to be implemented in a further case study.

### Production stabilization

As a start point, a long term plan was produced, using Microsoft Project. This plan was prepared during the contract signing stage and contains information related to the main deadlines of the contract, such as design, fabrication and assembly. According this plan, the project had two deadlines for delivering two different areas: the main area was to be delivered by October 2005 and the second area (identified as stage 3 in Figure 2 (a)) by March 2006.

The original plan was to assembly modules in vertical rows. Since the mezzanine designs were under modification by the client, the main area was divided in two stages. Stages 2 (that contained the mezzanine), was to be assembled after Stage 1.

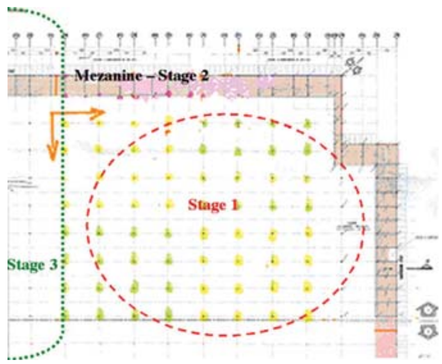
| | |
|---|---|
|  |  |
| Project stages (a) | View of roof tiles assembled (b) |



*Figure 2. Job site B*

The sequence initially proposed was: assembling a large number of columns, after those assembling beams and, at the end, assembling the roof tiles. This sequence generates problems in the factory, since it will be necessary the transportation in a specific day of nearly one hundred and twenty roof tiles (light weight components of fast assembly) and this causes an over-use of transportation equipment. This also causes unleveled production (large amounts of a single type of piece) and high level of components inventory (since production is slower than assembly).

Based on that, the project was divided in small batches, in order to obtain a controlled, balanced and continuous flow, improving the assembly process by reducing the equipment movement (Figure 2 (b)).

Figure 3 shows the tables with the assembly sequence of stage 1. The production batch of stage 1 consists of four columns, four beams and forty roof tiles, and a twelve-column supermarket. This buffer was created to absorb problems during the assembly period, such as inclement weather, and transportation or factory delays. According to the engineer supervisor, the beams assembly had a difference of only one day compared to the columns assembly, and in case of any problem that could cause a delay in the columns assembly. Such a small difference would not allow the assembly of other components, causing a complete stop in the assembly process. For those reasons the column supermarket was created.

| Assembly | | | |
|---|---|---|---|
| **Days** | **C** | **B** | **RT** |
| **22/8** | 6 | | |
| **23/8** | 6 | | |
| **24/8** | 4 | 4 | |
| **25/8** | 4 | 4 | 40 |
| **26/8** | 4 | 4 | 40 |
| **27/8** | | | |
| **28/8** | | | |
| **29/8** | 4 | 4 | 40 |
| **30/8** | 4 | 4 | 40 |
| **31/8** | 4 | 4 | 40 |
| **1/9** | 4 | 4 | 40 |
| **2/9** | 4 | 4 | 40 |
| **3/9** | 12 | | |
| **4/9** | | | |
| **5/9** | 4 | 4 | 40 |
| **6/9** | 4 | 4 | 40 |
| **7/9** | | | |
| **8/9** | | 4 | 44 |
| **9/9** | | 4 | 44 |
| **10/9** | | | |
| **11/9** | | | |
| **12/9** | | 4 | 44 |
| **13/9** | | 4 | 44 |
| **14/9** | | | 69 |
| **15/9** | | | 81 |
| **16/9** | | | |
| **17/9** | | | |
| **Total** | **64** | **56** | **686** |

Columns Inventory

Production batch

*Figure 3.Structure assembly batches – stage 1*
*(C=columns; B = beams; RT = roof tiles)*

After the general definition of the project assembly sequence, the assembly batches definition and assembly dates for each stage, meetings with representatives of the engineering department (engineers, planners, technical board, design coordinator and designer) were carried out in order to discuss the restrictions of that plan. Despite that, problems with design continued to occur, causing the need to make changes in stage 2 assembly sequences.

The delivery schedule, which had already been used by the company (Figure 4), established actual delivery dates and problem reports, was planned for daily coherence with the standardized assembly batch. The new configuration of the spreadsheet was discussed in several meetings with the people involved. In the last meeting it was agreed every Monday the project engineers was going to create an assembly plan that was supposed to be accomplished from the following Wednesday to Tuesday (following week) and this plan was to be handled to the company planning division in order to analyze the fabrication possibilities of the components, and also would be handled to the transport division to check the transportation availability. By Wednesday, those divisions and the project engineer were to define the final plan.

| Trip | Parts to be delivered | Volume (m?) | Planned delivery date | Actual delivery date | Problem |
|---|---|---|---|---|---|
| 1 | P38A, P39A | 8,36 | 28/11/05 | 28/11/05 | |
| 2 | P38A, P9A | 8,29 | 28/11/05 | 28/11/05 | |
| 3 | P42A, P10C, P10C, P10C | 8,76 | 28/11/05 | 28/11/05 | |
| 4 | P41A, P11A | 8,29 | 28/11/05 | 30/11/05<br>01/12/05 | Column P11A was produced on 29/11/05 |
| 5 | P38A, P39A | 8,36 | 28/11/05 | 29/11/05 | |
| 6 | P38A, P10C, P10A, P10A | 8,87 | 29/11/05 | 29/11/05 | |
| 7 | P39B, P9B | 8,29 | 29/11/05 | 30/11/05 | Trucks had to be allocated to another plant |

*Figure 4.Extract of delivery plan*

After the implementation of this new delivery schedule, the production system was evaluated by the following information: Percentage of Deliveries on Time (PDT), comparison between planned and actual deliveries and problems during this period.

## STANDARDIZED ASSEMBLY CYCLE

In parallel with the stabilization of production, a standardized assembly schedule was implemented, by studying of the components flow from factory to the job site. This study intended to synchronize and stabilize the flow, mainly involving the transportation division of the two factories and the transportation staff as well. The Figure 5 shows the table that contains information related to the assembly standard schedule of Stage 1.

| Trucks | Truckers | Origem | Parts | Start time | Conclusion time | Duration | Unloading/ Assembly |
|---|---|---|---|---|---|---|---|
| Truck 1 | José Carlos | I | Column (2) | 07:00 | 07:20 | 00:20 | U |
| | | | Set up | 07:20 | 07:40 | 00:20 | |
| Truck 2 | João | R | Roof tiles (10) | 07:40 | 08:20 | 00:40 | A |
| Dolly 1 | Walderez | R | Roof tiles (10) | 08:20 | 09:00 | 00:40 | A |
| Dolly 2 | Donizete | I | Roof tiles (10) | 09:00 | 09:40 | 00:40 | A |
| | | | Set up | 09:40 | 10:00 | 00:20 | |
| Truck 3 | Subcontracted | I | Beams (2) | 10:00 | 10:20 | 00:20 | U |
| | | | Set up | 10:20 | 10:40 | 00:20 | |
| Truck 1 | José Carlos | I | Column (2) | 10:40 | 12:00 | 01:20 | A |
| | | | Lunch | 12:00 | 13:00 | 01:00 | |
| | | | Set up | 13:00 | 13:20 | 00:20 | |
| Dolly 2 | Donizete | I | Roof tiles (10) | 13:20 | 14:00 | 00:40 | A |
| | | | Set up | 14:00 | 14:20 | 00:20 | |
| Truck 3 | Subcontracted | I | Beams (2) | 14:20 | 15:40 | 01:20 | A |
| | | | Beams (2) | 15:40 | 16:40 | 01:00 | A |
| | | | Set up | 16:40 | 17:00 | 00:20 | |
| | | | Column (2) | 17:00 | 18:00 | 01:00 | A |

*Figure 5.Standardized assembly schedule – Stage 1*

As shown in Figure 5, eight daily component trips were planed, and for that purpose five trucks were assigned for the transportation of the components (some of those trucks would make two trips a day). Besides that, it was defined the truck drivers that were to be involved in the transportation process to this job site. The idea was to create a team environment and increase the commitment level of the truck drivers to their tasks.

Figure 5 also presents other important aspects that were introduced during the study: were: definition of component origin, which could be either from the Rafard (R) or Itapevi (I) plants; sequence and timing of components trips; and whether the piece was to be directly assembled (A) or just unloaded (U) from the truck, for later assembly. For the definition of the schedule table, meetings were carried out involving one of the researchers and representatives of the planning and design divisions.

Figure 6 shows an example of the transportation schedule table, containing batches that were pulled by the standardized assembly cycle (Figure 5). This table was use as a model in the meetings with the transportation division and truck drivers.

| Truck | Parts | Plant departure time | Trip duration | Site arrival time | Unloading & assembly time | Trip duration | Plant arrival time | Loading time | Conclusion |
|---|---|---|---|---|---|---|---|---|---|
| Truck 1 | Column (2) | 6:00 | 1:00 | 07:00 | 07:20 | 1:00 | 08:20 | 1:00 | 09:20 |
| Truck 2 | Roof tiles (10) | 5:40 | 2:00 | 07:40 | 08:20 | 2:00 | 10:20 | 1:00 | 11:20 |
| Dolly 1 | Roof tiles (10) | 8:20 | | 08:20 | 09:00 | 2:00 | 11:00 | 1:00 | 12:00 |
| Dolly 2 | Roof tiles (10) | 8:00 | 1:00 | 09:00 | 09:40 | 1:00 | 10:40 | 1:00 | 11:40 |
| Truck 3 | Beams (2) | 9:00 | 1:00 | 10:00 | 10:20 | 1:00 | 11:20 | 1:00 | 12:20 |
| Truck 1 | Column (2) | 9:40 | 1:00 | 10:40 | 12:00 | 1:00 | 13:00 | 1:00 | 14:00 |
| Dolly 2 | Roof tiles (10) | 12:20 | 1:00 | 13:20 | 14:00 | 1:00 | 15:00 | 1:00 | 16:00 |
| Truck 3 | Beams (2) | 13:20 | 1:00 | 14:20 | 15:40 | 1:00 | 16:40 | 1:00 | 17:40 |

*Figure 6.Transportation schedule example – Stage 1*

## Evaluation of results

The implementation was considered to be successful in terms of reducing the cycle time, improving the productivity in the assembling process, reducing the waste in the utilization of cranes and, specially, increasing the stability of the assembly process. This improvement was achieved, despite the fact that the proposed implementation was only partial. Also, the degree of success varied among stages 1 to 3. The main barriers for the implementation of continuous flow was the lack of stabilization upstream (design factory transportation), pointed out by the delivery schedule data analysis, and the lack of understanding of the new production philosophy by the people involved.

Standardized assembly cycle was accomplished only partially in stage 1, because of the deficiencies in the stabilization process that still persisted in the company production system. For example, the design batches were not delivered on time, and, for that reason, at the end of the second stage, a meeting with the company design manager was carried out. In that opportunity the Whys technique was used, in order to identify the main causes of design problems. At the end of the questioning cycle, an apparently simple organizational reason for this problem emerged: the externally hired designer was not involved in the decision making process.

Despite the partial implementation, the following results were observed, comparing job sites A and B:

a) **Reduction of components inventory:** while job site A had large amounts of uncontrolled inventory, Job site B presented a small and controlled supermarket (12 columns in stage 1), to protect the job site flow from upstream uncertainties.

b) **Reduction of component work in process:** this problem did not occur in job site A, since small assembly batches were defined in order to reduce them. This problem was observed in job site B in short periods due to upstream unreliability.

c) **Higher protection against variability:** one problem was that the factory still presented lack of stabilization, and also caused the delays in the delivery of some components to job site B. However, those delays did not have a major impact in the assembly process, since the production batches were small.

d) **Productivity increase:** the small batch strategy and the standardization and control of assembly and transportation cycles contributed for a significant increase in productivity, as result of several factors, such as: 1) earlier problems identification and solution; 2) crane movement rationalization; 3) less gang waiting for pieces shortage, due to a supermarket of pieces; 4) learning curve due to high repetition of the cycle. Job site B used the same crane available in the previous project. The same productivity rate considered in job site A (2,26 m h) was used in the cost estimate. This resulted in an estimate of 2,915 crane hours. In fact, only 1,420 crane hours were necessary, resulting in an average productivity of 4,64 m h, which represents a 105% increase over budget. Contrastingly, job site A had achieved a productivity rate of 1,04 m h, much lower than the estimated productivity rate of 2,24 m h (54% decrease over budget). Therefore, crane productivity in job site B (4,64 m h) was 346% higher than in job site A (1,04 m h), as depicted in Figure 7. Job site B was originally planned to work with two cranes, but only one was necessary for accomplishing the deadlines on time. Since the gang production is directly related to crane effectiveness, a similar gain in labor productivity can be inferred, although it was not directly measured.

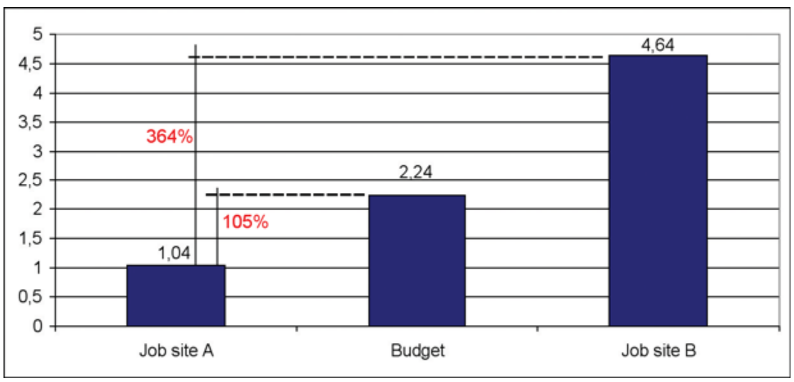



*Figure 5.Crane productivity comparison*

## PRELIMINARY CONCLUSIONS

Although the proposed implementation was not fully carried out, some substantial benefits were observed. Small batches assembly strategy, standardizing and controlling the assembly cycle, and process stabilization led to a 105% productivity increase, in relation to the budget, and a 364% increase, comparing job sites B and A. This research work has also highlighted the role of production stabilization in order to create an adequate environment for the implementation of continuous flow. An important issue also brought to discussion by this study is the need to get peoples' involvement and commitment. One of the main barriers for obtaining continuous flow was their resistance to changes and the lack of prioritization in individual actions.

Regarding the preliminary proposal for continuous flow implementation, presented in Figure 1, there is a need to refine, adjust the use of the tools. VSM was used only for mapping the current state (analysis of job site A), while a future state map and its implementation is necessary. The line of balance was used to define the assembly rhythms based on the deadlines settled with the client. That tool was not used at the process level, since there was not a minimum stability that would allow a detailed study of the processes to be carried out. This was not included in the proposal. The OBC and SWCT were not used, since it was not possible to implement standardized work.

The results encourage further studies on the application of stabilization and continuous flow approaches, and the development of implementation methods.

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