# GUIDELINES FOR DEVELOPING A LINE OF BALANCE FOR NON-REPETITIVE AREAS (COMMON AREAS) AT A VERTICAL RESIDENTIAL BUILDING

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## ABSTRACT

The line of balance (LOB) is widely used for projects with repetitive batches. Nevertheless, some authors in academic literature recommend the LOB for non-repetitive areas. In the case of residential projects which have a high repetition of the same batch the LOB is a very useful tool to plan the construction. In the other hand, developing a LOB for common areas (pavements without repetitive areas and services, e.g. underground floors, leisure areas, guardhouse and mezzanine) where there is not repetitive batches is more difficulty, and this is the reason for its scarce use for common areas. Thus, major problems in the project are verified by the lack of planning and production control in common areas.

This article aims to formulate guidelines for developing a LOB for common areas through a case study at a Brazilian construction company. The methodology for developing this paper includes literature review on LOB in non-repetitive areas, characterization of the company and construction sites, development of a common areas plan using LOB and other auxiliary tools, analysis of results and formulation of guidelines for the development of a LOB for common areas.

The results of this study indicated that the LOB in common areas provided plan transparency to employees and engineers, improved the control of project's total term and decreased the allocation of workers teams.



## KEYWORDS

Line of balance, non-repetitive areas, common areas, guidelines.



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## INTRODUCTION

LOB is a variation of linear scheduling methods concerned with the movement of resources through locations (Henrich *et al.* 2005). It's been used in manufacturing industry for a long time to plan and control repetitive one-off projects (Henrich *et al.* 2005).

The construction company of this article is used to the line of balance technique for years to plan the long-term of high-rise residential buildings focusing only in the repetitive pavements. Thus, the pavements without repetitive areas and services (e.g. underground floors, leisure areas, guardhouse and mezzanine) had the long-term plan neglected, causing turbulence in project final delivery. These areas were planned only in medium and short term plans, which proved to be not enough to plan the workflows and the crews.

Facing these difficulties, the engineering team started to implement the line of balance to plan the long-term of multi-stored residential building common areas. In this article, the case presented is often trivial and is close to common sense, but the main objective of it is to formulate guidelines for developing a LOB in common areas suggesting the necessary tools to plan and control the production, through a case study at a Brazilian construction company.

## LINE OF BALANCE

The Line of Balance (LOB) technique was developed in the manufacturing industry in 1940s by the Goodyear Company and expanded by the US Navy in the 1950s (Arditi *et al.* 2001).

LOB is a graph "time x units" (Henrich *et al.* 2005). The main concept on the line of balance is the uninterrupted flow of the crews over the construction units in a determined time unit (Mendes and Heineck 1998, Henrich *et al.* 2005). The major benefit of the LOB technique is to provide production rate, duration of activities, crew's flow, location, date and rhythm information in the form of an easily interpreted graphics format.

The line of balance tries to surpass the Critical Path Method (CPM) difficulties to production schedule and control of multi-story building (Mendes and Heineck 1998). According to Mendes and Heineck (1998), Kenley (2004, 2005) and Kenley and Seppänen (2009) this technique is very suitable for repetitive projects, however it may be adapted for non-repetitive projects as well due to emphasis on the location-based approach.

Many studies with the LOB have been taken for the academics in previous IGLC. Heinrich *et al.* (2005) recommended the use of LOB on linear and continuous project; multiunit repetitive projects; and high-rise buildings. On the other hand, according to the literature review, Heinrich *et al.* (2005) considered the technique to one-of-a-kind project (e.g. complex projects) a simplistic approach which "limits the level of managerial and production control considered necessary for these types of project".

Mendes and Heineck (1998) implemented the line of balance to develop the long-term plan of multi-story building projects. Kemmer *et al.* (2008) applied the technique to simulate different scenarios, varying batch sizes, cycle times, lead times, sequencing, work packaging, team reutilization, repetition, learning effect, continuity, capacity, and crews' interferences as means to evaluate the operational implications of decisions made at the long-term planning level.

Seppänen and Aalto (2005) described a case study of line of balance implementation in an office building project with repetitive units. Kenley and Seppänen (2009) described a location-based schedule methodology and the establishment of a hierarchical location breakdown structure (LBS) to organize in a more complex way than units, the work on site.

Schramm *et al.* (2006) applied the line of balance to study the workflow in the production system design of a large hospital complex and an industrial building. Even with the complexity in these projects, there were repetitive batches and services to plan.

Although several authors described case studies and methodologies for implementing line of balance, few authors had actually written about the line of balance in non-repetitive projects and the main difficulties to implement it.

## CASE STUDY DESCRIPTION

### THE CONSTRUCTION COMPANY

Founded in 1975 at Fortaleza, Brazil, the construction company of this case study focuses specifically to Classes A and B. It has more than 530.000m² of constructed area and 172.000m² under construction, distributed into more than 12 buildings and 500 private units.

The lean journey in this company started in 2004. Over these ten years, the company has been using many lean tools and practices: *kanbans*, *andon*, *poka-yokes*, supermarket concepts in the warehouses, transparency, production in small batches, new solutions formatted in the A3 tool and many others.

### THE PROJECT

The project of study is a residential tower of 23 floors on a site area of 2,630.00m$^2$ at a wealthy neighbourhood of Fortaleza. There are two units per floor and each one has a private area of 206.30m$^2$. The project's gross area is 15,408.00m$^2$ and its common areas include two underground parking floors, swimming pools, a sports court, fitness facilities, kids' room and so on. Figure  represents façade and leisure areas.

The construction site has started its works on May 2011 and is scheduled for finishing on May 2014.


Figure 1: project's façade and leisure areas

## DEVELOPED ACTIVITIES

This case study occurred into five stages:

1. Training in concepts and tools of lean construction: at first, engineers of the construction company were trained in lean construction concepts by professors of NORIE[1] from UFRGS[2] during four months in 2012. Along the classes, one of the professors questioned the company's engineers about workflows at the construction site and production planning and control for common areas. It was suggested for them to initiate a line of balance for common areas, in order to start understanding its flow and reducing its delays.
2. Elaboration of production planning for common areas (using Ms Excel and Ms Power Point, mainly): it was necessary the definition of batches sizes and their attack sequence, further the development of the sequence of activities in the batches, followed by the dimensioning of capacity production resources and the study of workflow using the line of balance technique.
3. Elaboration of production control tools for common areas (using Ms Excel, mainly): after the production planning tools, the company decided to work with well-known visual control tools (already used for the apartments) like the "thermometer" and the "X-Ray" (which will be properly explained later).
4. Evaluation of the line of balance for common areas: after the line of balance was developed for the three pavements of common areas (two underground parking floors and the leisure area at the ground floor), the engineers evaluated the effectiveness of the tool through analysing the indicators and the proper site. They also indicated the improvements made and difficulties perceived.

[1] NORIE – Building Innovation Research Unit
[2] UFRGS – Federal University of Rio Grande do Sul

5. Development of the guidelines for common areas LOB: in order to resume the lessons learned at this case study, the final activity involved the proper development of the guidelines for common areas LOB to be applied in any project as part of a standardize tool at the company.

## CASE STUDY DEVELOPMENT

### PRODUCTION PLANNING

#### Definitions of the Batches Sizes and Attack Plan

The production planning started with the definition of the batches sizes for common areas. The garage floor - level 2 was divided into several batches. The batch size was defined by the longest activity on the floor. In this case, the longest activity was the service of sanding and finishing the ribbed slab. Considering the total duration of this activity for the entire floor area, the engineering team divided the batches area to correspond to five days of production; this is the maximum duration in the short term weekly plan. This area was then the average batch size (which corresponds approximately to 85,00m²). It is interesting that the batches do not need to have exactly the same area, but to have similar complexities. The Figure 2 illustrates the division into 19 batches of the garage floor - level 2 at project.


Figure 2: division of garage floor into similar complexities batches

It is then necessary to establish the best workflow for the batches, in order to facilitate production flow, materials transport, the location of racks, and so on. The previous figure also exemplifies the plan attack by numbering the batches in ascending order.

#### Defining the Sequence of Activities

The process begins by listing all the conversion activities involved in the production of each batch and in the sequence between them. In the figure below, the activities execution sequence was determined by the engineers' team to prepare the long-term planning at garage floor - level 2.

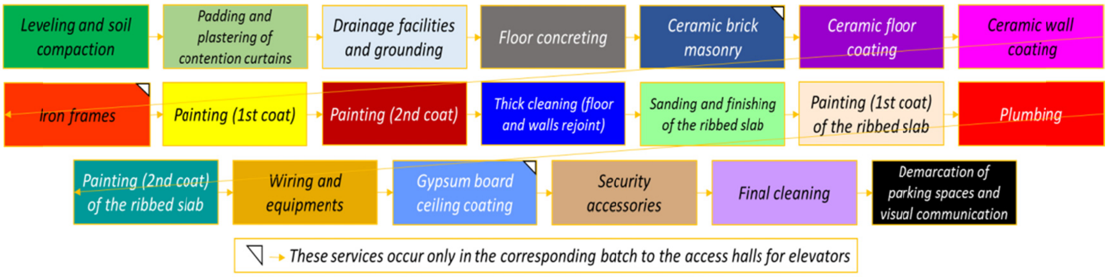


Figure 3: network of activities execution sequence in the case study project

## Dimensioning the Capacity of Production Resources

The third step of the process involves the dimensioning of the production resources capacity. For the line of balance to be drawn, it is important to define the desired flow pace for activities, the amount and the composition of crews, the length based on the historical productivity rate and the deadline for delivery the complete pavement.

To obtain the length of each activity package, it was necessary to quantify the total amount of production needed and then divide this amount by the number of batches that contain this package. In this pavement, there is one special circumstance: some batches do not have all activities set in the network. For example, the package of ceramic wall coating can only be executed on the peripheries of the floor, as there are no walls in-between the parking spaces.

It is also important to highlight that engineers team tried to define batches that would have similar areas or similar complexities, in a way it could be possible for the activities packages to have the same length.

Figure 4 is a worksheet elaborated by the engineers in which they filled in the detailed information about the professional composition of necessary crews in each activity and the activities' length in days.

| Production Resources Capacity's Worksheet | | | | | | |
|---|---|---|---|---|---|---|
| Item: | Garage Floor - Level 2 | Production Team | | | Cycle Time per batch (approximately) | Batches included |
| | | Professional | 1/2 Professional | Helper | | |
| | **Floor Execution** | | | | | |
| 1 | *Leveling and soil compaction* | 1 | | 3 | 1,00 | 1 to 19 |
| 2 | *Padding and plastering of contention curtains* | 2 | | 1 | 2,00 | 1,2,3,4,5,6,10,11,13,14,16,18 |
| 3 | *Drainage facilities and grounding* | 1 | 1 | | 0,25 | 1 to 19 |
| 4 | *Floor concreting* | 3 | | 6 | 0,25 | 1 to 19 |
| 5 | **Ceramic brick masonry** | 2 | | 1 | 5,00 | 19 |
| 6 | **Ceramic floor coating** | 4 | | 2 | 4,00 | 1 to 19 |
| 7 | **Ceramic wall coating** | 2 | | 1 | 2,50 | 1,2,3,4,5,6,10,11,13,14,16,18,19 |
| 8 | **Iron frames** | 1 | | | 2,00 | 19 |
| 9 | **Painting (1st coat)** | 2 | 1 | 1 | 2,00 | 1 to 19 |
| 10 | **Painting (2nd coat)** | 2 | 1 | 1 | 2,00 | 1 to 19 |
| 11 | **Thick cleaning (floor and walls rejoint)** | | | 2 | 4,00 | 1 to 19 |
| | **Ribbed Slab Finishing** | | | | | |
| 12 | *Sanding and finishing of the ribbed slab* | | | 3 | 2,50 | 1 to 18 |
| 13 | *Painting (1st coat) of the ribbed slab* | 2 | 1 | | 1,00 | 1 to 18 |
| 15 | *Painting (2nd coat) of the ribbed slab* | 2 | 1 | | 1,00 | 1 to 18 |
| | **Facilities** | | | | | |
| 14 | *Plumbing* | 2 | | 1 | 1,00 | 1 to 19 |
| 16 | *Wiring and Equipments* | 2 | | 1 | 1,00 | 1 to 19 |
| 17 | **Gypsum board ceiling coating** | 1 | | 1 | 6,00 | 19 |
| 18 | **Security accessories** | 1 | 1 | | 0,50 | 1 to 19 |
| 19 | **Final cleaning** | | | 6 | 0,50 | 1 to 19 |
| 20 | **Demarcation of parking spaces and visual communication** | 1 | | 1 | 1,00 | 1,2,3,6,7,8,10,11,12,13,17,18 |

Figure 4: the production resources capacity's worksheet

## The Line of Balance

Finally, the line of balance of the floor was properly drawn with this information about batches size, attack plan, execution activities sequence and crews. It was simulated many times until the engineering team obtained the desired workflow, buffers and pace of each crew. A pertinent observation is related to the identification of the holidays and possible strikes on schedule. Figure 5 represents the line of balance for garage floor - level 2 at case study project. The holidays are shown with the red mark in the columns.

In order to view the complete line of balance and better comprehend its features, see the related link[1].

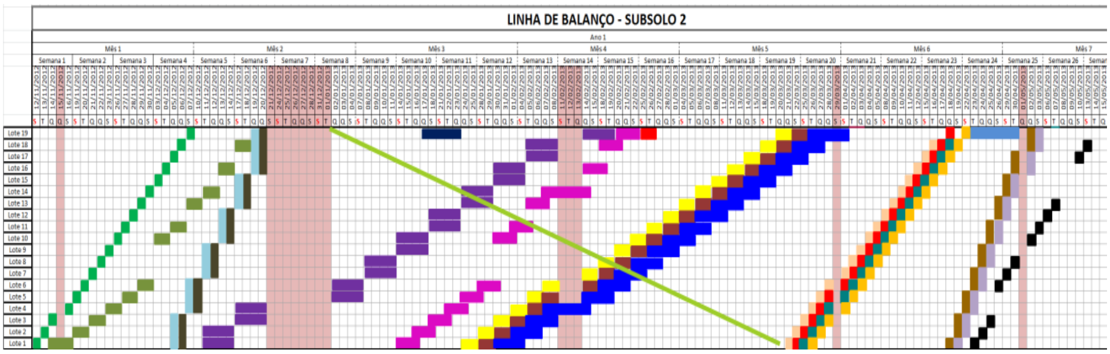


Figure 5: line of balance of garage floor – level 2

## PRODUCTION CONTROL

The thermometer and the X-ray are two simple tools created by the company, whose purpose is to monitor the execution of services at a long-term level. These two tools complement each other, as the thermometer provides a numerical index and the X-ray provides a visual indicator. The intention is to control lead times of production batches and deviations of pace between the actually executed and the planned for the line of balance.

The company already uses these two tools since 2004 for monitoring the lines of balance of apartment towers. Because they are already well established in the planning of construction sites, it was decided to adapt these tools to the line of balance for common areas. The person responsible for drawing up and proper monitoring these controls is the project manager, who updates the indicators fortnightly. These indicators must be exposed in the administrative room in the site to ensure greater information transparency.

As soon as the activity package is completed in a batch, the engineer fills in this information in the system, so that service in that particular batch at the "X Ray" becomes green (Figure 7). The information is also recorded in "Thermometer" tool (Figure 7), which generates a main numeric indicator: the deviation of completed production packages in relation to planned in percentage and total number.

[1] www.crolim.com.br/pdf/garage2lob.pdf

**X-Ray: Garage Floor - Level 2**

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| BATCH 19 | '11 | XXX | XXX | '14 | XXX | 16 | 17 | 18 | 19 | XXX |
| | '01 | XXX | '03 | '04 | '05 | '06 | 07 | '08 | 09 | '10 |
| BATCH 18 | '11 | '12 | '13 | '14 | '15 | 16 | XXX | 18 | 19 | 20 |
| | '01 | '02 | '03 | '04 | XXX | '06 | '07 | '08 | XXX | '10 |
| BATCH 17 | '11 | '12 | '13 | '14 | '15 | '16 | XXX | 18 | 19 | 20 |
| | '01 | XXX | '03 | '04 | XXX | '06 | XXX | '08 | XXX | '10 |
| BATCH 16 | '11 | '12 | '13 | '14 | '15 | '16 | XXX | 18 | 19 | XXX |
| | '01 | '02 | '03 | '04 | XXX | '06 | '07 | 08 | XXX | 10 |

Activities packages by batch

Figure 6: "x-ray" visual control tool at September 13th, 2013

**Thermomether: Garage Floor - Level 2**

| ITEM | SERVICES | PLANNED | EXECUTED | % CONCLUDED | % DELAYED | DIFFERENCE |
|---|---|---|---|---|---|---|
| 01 | *Leveling and soil compaction* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 02 | *Padding and plastering of contention curtains* | 12,00 | 12,00 | 100% | 0% | 0,00 |
| 03 | *Drainage facilities and grounding* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 04 | *Floor concreting* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 05 | *Ceramic brick masonry* | 1,00 | 1,00 | 100% | 0% | 0,00 |
| 06 | *Ceramic floor coating* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 07 | *Ceramic wall coating* | 13,00 | 12,00 | 92% | -8% | -1,00 |
| 08 | *Painting (1st coat)* | 19,00 | 18,00 | 95% | -5% | -1,00 |
| 09 | *Iron frames* | 1,00 | - | 0% | -100% | -1,00 |
| 10 | *Painting (2nd coat)* | 19,00 | 18,00 | 95% | -5% | -1,00 |
| 11 | *Thick cleaning (floor and walls rejoint)* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 12 | *Sanding and finishing of the ribbed slab* | 18,00 | 18,00 | 100% | 0% | 0,00 |
| 13 | *Painting (1st coat) of the ribbed slab* | 18,00 | 18,00 | 100% | 0% | 0,00 |
| 14 | *Plumbing* | 19,00 | 19,00 | 100% | 0% | 0,00 |
| 15 | *Painting (2nd coat) of the ribbed slab* | 18,00 | 18,00 | 100% | 0% | 0,00 |
| 16 | *Wiring and equipments* | 19,00 | 17,00 | 89% | -11% | -2,00 |
| 17 | *Gypsum board ceiling coating* | 1,00 | - | 0% | -100% | -1,00 |
| 18 | *Security accessories* | 19,00 | - | 0% | -100% | -19,00 |
| 19 | *Final cleaning* | 19,00 | - | 0% | -100% | -19,00 |
| 20 | *Demarcation of parking spaces and visual communication* | 12,00 | - | 0% | -100% | -12,00 |

Nº of batches by activity package

| SCHEDULE FOLLOW UP | |
|---|---|
| TOTAL AMOUNT OF PACKAGES | 303 |
| AMOUNT OF PLANNED PACKAGES | 303 |
| EXECUTED PACKAGES | 246 |
| DIFFERENCE BETWEEN PLANNED AND EXECUTED PACKAGES | -57 |
| % PLANNED PACKAGES | 100% |
| % EXECUTED PACKAGES | 81% |

Figure 7: "thermometer" control tool at September 13th, 2013

## RESULTS

### IMPROVEMENTS PERCEIVED

The improvements realized with the implementation of the line of balance for common areas are related to the greater transparency of processes and services, and the possibility of managers to track deadlines on these areas. Additionally, planning the long-term level in advance facilitated the medium-term planning, because restrictions were more easily perceived in terms of physical spaces (batches) and services.

The project managers indicated that the division of common areas in batches helped to attack the sequence of services, contributing for delimiting storage areas in according to modifications in the layout site plan.

They also commented that the sequence of services in LOB naturally promote greater involvement to other third party services (installation, industrial flooring, etc.), because planning becomes more transparent and tangible to them. It facilitates the perception of interferences between construction company services and partners', which obviously improve and reinforce the list of restrictions for the medium term, and assists their commitment to the short-term tasks.

Finally, it was also perceived the benefit of starting the activities of common areas in advance (1½ years before the completion of construction) in order to keep crews workflow uninterrupted in several common floors.

Before the line of balance implementation, the crews from the towers, as soon as they finished their planned works, were allocated into the common areas without planning. This way, the services of the common areas would become completely dependent on the completion of the apartments. Once the line of balance for common areas was drawn and the project managers understood the size and total term of services contained therein, it became clear to them that teams for common areas should be allocated regardless the tower planning, definitely segmenting the two scopes of planning.

In terms of quantitative results, it is possible to compare the estimated allocation of crews into floors of common areas without previous planning – using the default amount of the company for every project - and the line of balance planning for garage floor – level 2 (Table 1).

Table 1: differences between production with and without the line of balance for common areas

| | Allocation of teams | |
|---|---|---|
| | **No planned common areas** | **Planned common areas** |
| **Services** | Not planned | 20 activities packages |
| **Workers** | 15 | Average of 3 workers for each service (2 professionals and 1 helper) |
| **Peak of Workers** | 15 | Peak of 9 people (average of 6 workers) |
| **Remuneration** | R$21,810.00 per month | Variable between R$2,538.00 and R$9,000.00 per month |
| **Total labor cost** | Estimated in R$ 283,000.00 (13 months of segmented work) | Estimated in R$38,000.00 (7 months) |

## DIFFICULTIES

Besides the line of balance for the garage floor – level 2, other lines of balance were drawn for the garage floor – level 1 and the ground floor. However, two main difficulties were identified in relation to the implementation of these lines of balance in particular.

At the garage floor - level 1, it was necessary to allocate all temporary facilities. This situation disrupted the crews flow from the garage floor - level 2 and made the compliance to planning extremely difficult. Also, near the end of construction, the employees' cafeteria had to be transferred to this floor requesting more area. Due to all these difficulties, the project's management team failed to implement planning with the line of balance in this floor.

On the ground floor, as Figure 1 shown above, there are several different leisure areas: lan house, kids room, bar and ballroom, pool, game room, sports court, fitness center, lounge etc. These rooms have very different areas among themselves and with distinct complexities (precautions inherent in the execution of the pool, for example, are different from the services necessary to execute the kids' room) and hindered the division of batches with the same cycle time of activities.

Thus, it was very difficult for the engineers to draw and monitor a line of balance for this floor. Because of the great complexities of the batches, the cycle times of each activity vary greatly, and the engineers were used to a LOB with same pace (as for the apartments tower and garage floors). Therefore, they decided to create, for this particular floor, a sync team graphic. Consequently, the management team of the project opted to prioritize the reuse of teams between batches instead of guaranteeing an even pace between them.

## GUIDELINES

As a main result of all the experience lived by the engineering team at this case study project, a set of guidelines was developed to facilitate the use of the line of balance technique for others construction companies. All phases once described in the research method compose the guidelines below (Figure 8).

The first step is to define all the batch sizes of a non-repetitive area, trying to scale batches which contain similar areas to services execution. Further, it is necessary to study the plan attack and visualize the physical flows among the batches. For that, it is important to plan also the construction site layout. A simple tool to execute the step 1 of the guidelines is to use a floor plan of the non-repetitive area.

The second action is to elaborate the network of activities execution, respecting all physical and techniques restrictions between the activities packages. It's necessary to check which package will be executed in each batch. The third step is dimensioning the production resources capacity and organizing it in a worksheet that contains a description of packages, crews and its professional composition, duration, production rate, and so on. Due to complexity and area of production among the batches, the duration of activities may vary.

The forth step includes the study of workflow using the line of balance which needs to be drawn based on previous information. This step requires a lot of line of balance simulations to decide the best pace of crews flow and distribute the buffers. The production control must be done in the fifth step by the use of some tools: "x-ray" and "thermometer". Both tools inform the actual production deviation in relation to the planned in the line of balance.

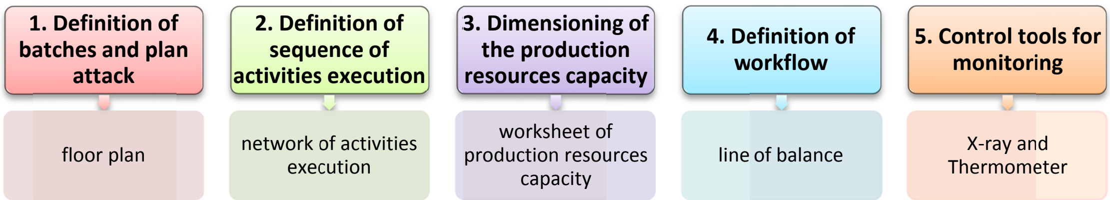


Figure 8: step by step for develop a line of balance for non-repetitive areas

## CONCLUSIONS

Differently of common sense about line of balance, the use of this technique for non-repetitive areas is possible when batches sizes are well defined and their complexity is indeed considered. This technique improved the transparency of long-term plan for the case study project and allowed the engineering team to control all the activities packages on site using simple tools already applied by the company.

It is concluded that the goals set at the beginning of the case study were achieved. First, the main result of the paper is the set of guidelines for developing a LOB in common areas. The development of these guidelines was extremely beneficial to the company because it was possible to take advantage of them to other construction sites of the same company. Improvement opportunities perceived in this case study were considered in the following projects, which currently already have a new tool for controlling and monitoring: the graph of pace deviation.

Anyway, the team has perceived some difficulties in developing this type of planning that shall be considered in future researches. Obstruction of pavements in common areas with temporary facilities (workers' cafeteria, bathrooms, etc.) prevents the execution of services as desired pace and flow. Moreover, the need to use a sync team graphic instead of the traditional line of balance may be prioritized in cases of very different batches.

About the limitations of the research, it is important to note that the project has not been finished yet, which is why it could not be possible to draw more definitive conclusions on the total labor cost and total term of executed services.

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## REFERENCES

Arditi, D., Tokdemir, O. B. and Suh, K. (2001). "Effect of learning on line-of-balance scheduling." *International Journal of Project Management* 19: 265-277.

Heinrich, G., Tilley, P. and Koskela, L. (2005). "Context of production control in construction", *Proceedings of the 13th Annual Conference of the Int. Group for Lean Construction*, Sydney, July 19-21, pp. 189-98

Kemmer, S. L. *et al.* (2008). "Medium-term planning: contributions based on field application." *Proceedings for the 16th Annual Conference of the International Group for Lean Construction* (IGLC 18),299-308, Manchester, UK.

Kenley, R. (2004). "Project micromanagement: Practical site planning and management of work flow". *Proceedings of the 12th International conference of Lean Construction*, Helsingør, Denmark, 194–205

Kenley, R. (2005). "Dispelling the complexity myth: founding lean construction on location-based planning." *Proc. 13th Annual Conf. of the Intl. Group on Lean Construction* (IGLC 13), Sydney, Australia, July 19-21

Kenley, R. and O. Seppänen, (2009). Location-based management for construction: Planning, scheduling and control. Spon Press, London and New York.

Mendes Jr, R. And Heineck, L.F.M. (1998). "Preplanning Method for Multi-Story Building Construction using Line of Balance." *Proc. 6th Annual Conference of the International Group for Lean Construction* (IGLC-6), Guarujá, Brazil.

Schramm, F. K., Rodrigues, A. A. and Formoso C. T. (2006). "The role of production system design in the management of complex projects". *Proceedings for the 14th Annual Conference of the International Group for Lean Construction* (IGLC-14), Santiago, Chile, July 227-239.

Seppänen, O. & Aalto, E. (2005). "A case study of Line-of-Balance based schedule planning and control system". 13th Conference of the International Group for Lean Construction. Sydney, Australia.