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THE IMPACT OF VARIABILITY IN WORKFLOW

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ABSTRACT

Singularity, lack of predictability, turnover, making do, these are only a few factors that compose the process-variability in the construction industry. The knowledge of stability in activities workflow is fundamental to allow a construction company to have accurate planning. This paper evidences the impact of variability into the construction planning by using Monte Carlo simulation. It was developed the Line of Balance (LOB) of a project and generated ten thousand lead times based on the probability distribution measured on gemba for these activities. According to the simulation, the variability has a high impact on projects process time. Moreover, the delays occurred in all ten thousand events of simulation and the average delay was 12 days. In addition, the average idle time observed was 10 days and it occurred because of process-time and flow variability. According to the study, the model proves the negative impact of variability in workflow and a model to calculate LOB buffers should be developed with the intend of presenting less chance of breaks in the flow and projects delay. So, researches concerning about how to dimension theses buffers should be conducted.

KEYWORDS

Lean construction, variability, Line of Balance, buffers, Takt Time Planning (TTP).

INTRODUCTION

The scenario of the construction industry in Brazil has changed in the last decade. Until 2011, the industry has lived a very strong growth. With the increase of the demand for properties, enhanced by the fact that spending power also increase and government politics, the industry has become more representative in the Gross Domestic Product (GDP). To builders it means that incomes increased and to developers meant more launchers.

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However, with the increase of inflation and investors' low confidence, the industry had a decrease in its activity in the last year of 2.6% (CBIC, 2015). With the reduction of the industry activities, there is an even greater need to rise productivity and reduce costs, regarding the stagnation in sales and reduction on properties prices. In addition, the representation of workforce also increase and it is 57% of total project direct cost (SINDUSCON-SC, 2015).

In order to obtain a better performance, several companies have reorganized their processes based on concepts and techniques of Toyota Motor Company®. Toyota is an inspiration for many companies due to their production system based on the so-called lean thinking.

The lean thinking was originated in the auto industry, and it has proved to be effective when applied in other industries such as service industries, government agencies, hospitals, and construction (Liker, 2008).

In the construction industry, process variability is inherent and also a big issue when the final costumer is waiting to receive his property on the accorded time. For this reason the Production Planning and Control won ground in the last decade, where construction companies began to use tools and philosophies to enhance productivity and reduce wastes.

In buildings with repetitive units (similar apartments or repetitive floors), creating flow is important and a challenge. To absorb variability, buffering of time between activities is a common option, but also considered a waste.

The purpose of this paper is investigating the influence of process variability in the civil construction industry planning by using Monte Carlo simulation. This study was made with the partnership with a construction company (RDO Empreendimentos) that uses lean construction principles for almost two years.

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FLOW, VARIABILITY AND BUFFERING

Workflow is divided in dimensions: operational and process, and it is defined as all types of work conducted within available working hours – except obstructions such as downtime, rework and other forms of waste subtracted (Kalsaas, 2013). Ballard (1999) stands that Plan Percent Complete (PPC) is a measure of workflow and also the shielding that should increase it.

Koskela entitle Process Variability Reduction as a Lean Construction principle and stated that reduction of variability within process flow must be considered as an intrinsic goal for this to happen, which means finding root causes of variability (Koskela 1992; 2000).

There are two types of variability in production flows: process-time variability and flow variability. The first is the time required to process a task at a workstation, the second one means the variability of the arrival of jobs to a single work station (Koskela, 2000).

So, these concepts applies in this paper in a way that process-time and flow variability causes lack of workflow and leads to wastes causing delays and makes the activities unbalanced.

To absorb the process variability, buffers are necessary (Koskela, 2000; Yang and Ioannou, 2001; Sakamoto, Horman and Thomas 2002; Kemmer, 2006; Bølviken, Rooke and Koskela, 2014). Although they are expensive, hard to size and hardly an optimal solution (Ballard and Howell 1994). Yet to preserve the independence of one activity considering the interdependence of it with others, buffer has an essential purpose. Besides that Lean stands that buffer is Work in Progress (WIP) and is a waste that hide other wastes, and has to be minimized to expose these others wastes. Buffering is necessary in any production process and is considered a necessary mean. Somehow has to be estimated. Sakamoto, Horman and Thomas (2002) studied the relationship between activities in 3 multi-story commercial projects and developed a method to size smaller buffers between activities to enhance performance in the process as a whole.

Bølviken, Rooke and Koskela (2014) affirms that buffers are another paradox: "it is a waste to guarantee a flow level, a project without buffers, is a risky project." Of course that a company with good expertise and accomplished a good predictability, can reduce these buffers to minimum.

LINE OF BALANCE (LOB) AND WASTES IN FLOW

Bølviken, Rooke and Koskela (2014) said that wastes in flow are divided in two groups: product flow, which would be how the product, the building, would flow in the process as a whole; and workflow, meaning the flow in the operations.

Considering a medium or a long-term plan using a Line of Balance, the wastes that could be avoided in the planning phase, proposed by Bølviken, Rooke and Koskela (2014) would be in the product flow group:

1. Space not being working in;
2. Material not being processed.

Moreover, as consequence, it will reduce unnecessary movement (of people) in the workflow group. It exists a paradox when it comes to making do (Bølviken, Rooke and Koskela, 2014). Already well known, making do is a waste presented by Koskela (2004), which is basically starting a task without having all the constrains removed. Making do in fact is a waste and needs to be removed, but in reality, it is common sense that production in gemba cannot stop, the cost is very high. Therefore, what would be worse, stop the production or start that task knowing that not all constrains are removed? Sure, that in reality, in some cases, it is easy to manage labors to a not planned task, but the consequences in scheduled must be sized.

An example is lack of material, if the project manager commands to start a task knowing that there is not enough material to finish that batch, either he should never start that batch or do what is possible and hope for the best. The same thinking works with project mistakes, security, equipment, and others.

It is common sense that the perfect scenario is everything to be in the right place, in the right time but the empirical experience of project managers and construction companies CEO`s suggests that production should not stop and everything should be done not to cause other wastes, as waiting or materials not being processed.

Kemmer (2006), Seppanen and Aalto (2005) and Bernardes (2001) held that the Line of Balance is the right technique to high buildings with repetitive floors. The tool allows better visualization of the flow in the activities and variables as batch size and cycle time should be consider.

Seppänen and Aalto (2005) stands that the Line of Balance is a graphic technique which is used to manage workflow, reduce risks, and increase productivity. One deficiency of the technique is given by the fact that it has explicit workflow but not the material flow (Bernardes, 2001).

Kemmer (2006) understood that the Line of Balance could also be used to define attack plans, by modifying the variables and analyzing the consequences in medium and long term.

The line of balance can be demonstrated in the Figure 1, where in vertical axis are described the repetitive units, and in horizontal axis is described the time in weeks or days. In the graph are described the tasks that should be done at that moment in that space. The lines inclination is called takt-time, and could be different for each activity based in the project requirements and companies' availability. By changing takt-time in each activity, the planner is forced to insert inefficiencies in the process, such as: materials (inventory), work in progress, subassemblies and stock, represented here as buffers.

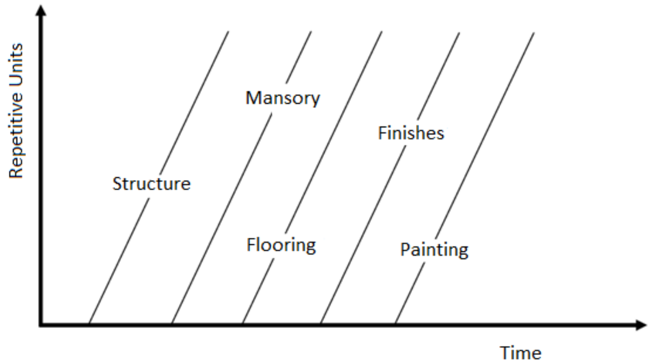

Figure 1: Line of Balance (adapted by Figure 4 of Kemmer, 2006)

RESEARCH PROBLEM

The analysis of the activities variability has been developed in a construction company called RDO Empreendimentos in the state of Santa Catarina in southern Brazil. The company has the expertise to build residential and commercial with average of 12 floors, having already built 46 buildings, 2,000 apartments, and over 330,000 square meters. Currently, the company is growing and owned six on-going projects totaling more 70.510,71m² to be built.

RDO invests in production planning and control for almost two years now, using Line of Balance (LOB) and an adaptation of The Last Planner System (LPS). The Construction Manager gives the tactical support to all projects, managing trades and equipment. The planner is required in all projects, in all planning horizons and each engineer is responsible for executing an average of two simultaneous projects and for managing all the contractors and supply requests, with assistance of an intern.

To manage its projects, the company has been improving its production planning and control system through the use of LOB. Weekly it has a meeting on gemba with all trades plus the engineer and the planner, and monthly meetings in the company's office with engineer, construction manager, design department and supply department for planning the eight week look ahead and remove constrains.

However, by analysing the company in question, it appears that – despite the implemented planning and control system and good level of learning around the use of the method – recurring problems persist. It is perceived that the cause of such problems precedes the control stage of LOB and is grounded on the planning stage, i.e. in the conception of LOB.

This problematic was identified by the company’s technical team and confirmed by this study. It is related to the difficulty of executing the plan and synchronizes the activities planned at the right time. What happened at first is that the planner began planning with a big time buffer at the end of the calendar, in other words, the project’s end was different of the project dead line, and the buffer was consumed little by little. Because of variability, it was causing wastes, such as: (i) stock of material – based in the delay of the beginning of each activity; (ii) waiting – generated by the complexity of manage supply to all trades; (iii) loss of productivity – caused by flow brake and making do.

Secondly, the planner started to input little buffers between activities – sized empirically, and this reduced wastes, because these little buffers absorb the variability, inherent in construction. However, the main problem still was variability, the planner observed that if more buffers were planned, few problems happen, but in the other hand, a lot of “space not being worked on” began to appear. In some cases, the takt-time at the end of the project had to be changed to guarantee that the project dead line would be respected.

Also was observed that some activities has more variability than others, caused by the complexity of constrains removal, gaps between workers’ productivity, lack of quality manpower, lack of contractor commitment, climatology and costumer project changes.

It was verified the need to develop a reliable method for determining the buffers between activities in the LOB design. For this, one opted the statistical analysis of data collected from company's projects in order to find the variability of activities and thus set the buffers in the LOB.

WORK METHOD

To investigate the impact of variability in the construction planning, the present paper used the Monte Carlo simulation applied to a project planned with the LOB, and discussed about the comparison between the deadline planned and the results observed in the simulations, which contains the variability.

The methodological procedures of this paper were divided into five steps: (1) Data collection. (2) Calculation of production rates. (3) Elaboration of project plan. (4) Monte Carlo simulation. (5) Results and Analysis. Each of these steps is detailed in the following sections.

(1) DATA COLLECTION

The data used for the simulation refers to the productivity rate of six activities performed by the teams of RDO Empreendimentos Company. To generate these rates we had to discover the probability distribution of the rates based on real data collected in the field. The longitudinal section observed the period from 2013 to 2014 and used as sample five residential projects with similar characteristics and complexities, in the same region and with an average of twelve floors each. It was chosen seven preceding activities to the data analysis and calculation of productivity indexes. The chosen activities have the following description:

a) Structure - which is included the placement of forms, reinforcement structure, concrete and forms removal.
b) External block masonry – Included marking, elevation, lintels and stakes of external masonry
c) Ceiling mortar coating - which contains the application of coarse mortar and plaster.
d) Internal block Masonry - Included marking, elevation, lintels and stakes of internal masonry.
e) Sanitary system - including the installation of pipe networks to collect rainwater and sewage.
f) Cold and hot water systems - pipe networks for cold and hot water circulation.
g) Internal mortar coating - Which refers to coarse mortar and plaster application on the internal wall masonry.

Data were collected by using checklists applied on weekly basis which were stored in the ERP (Enterprise Resource Planning) system of the company. For this study, one obtained the data from the company's planning system (PPS report), where they were stored. The extracted information are related to cycle time of each repeating unit, how much was produced in this time and the number of trades required for executing each of the activities described before.

The output of this collection was a number of twenty samples per activity. In the field, it was notice that process-time variability and flow variability were detected and had influence of some pattern events. Such as: (i) learning curve; (ii) lack of commitment of last planners; (iii) making do; (iv) unexpected atmosphere conditions; (v) unexpected errors (vi) overproduction and (vii) waiting. In addition, as time passed and the company get used to the new philosophy, wastes tended to reduce.

(2) PRODUCTIVITY CALCULATION

To calculate the productivity per team indicator for each activity, were used the Factor Model approach (Souza, 2000), where the production unit rate (RUP) is adopted to measure the activities' productivity. RUP is the division of Man-Hour by the Quantity of Work: RUP=m.h/QW. In this paper, most activities' unit was measured by square feet (ft^2): RUP=m.h/ft^2.

(3) ELABORATION OF A PROJECT PLAN

After obtained the productivity rates, it was created a fictitious project, and it was given to the company's planner to plan it with his experience in the field. The planner used the LOB to establish the rhythm of activities, time buffers, and deadlines. The Table 1 presents all activities and its data (work quantitative, number of traders and duration).

The LOB was planned with a buffer with one week between activities, it was respected the concrete curing time, it was chosen a takt time of 10 working days and the planned lead-time was 160 working days. The Figure 2 illustrates the planned LOB.

(4) MONTE CARLO SIMULATION

The first stage of the Monte Carlo Simulation was to find the probability distribution of productivity rate per team of each activity and its algebraic expression.

For this, it was used the tool “Input Analyser” by the software Arena®. This software read the real productivity rates collected for each activities, and fit them into a proper probability distribution and its algebraic expression. Table 2 presents the statistical expression and distribution found for each activity.

Table 1: Characteristics of the Fictitious Project and Takt Calculation (Authors)

Activities	Qtve per floor (ft²)	Productivity (m.h/ft²)	Number of trades	Duration (hours)	Duration (days)
Structure	5.242	58,45	30	88,14	10,02
External Block Masonry	4.477	2,28	1	88,08	10,01
Ceiling mortar coating	5.166	3,92	2	87,49	9,94
Internal Block Masonry	13.454	2,28	3	88,22	10,02
Sanitary System	Bath		1	88,63	10,07
Cold and Hot water system	Bath		2	89,81	10,21
Internal Mortar Coating	22.604	1,83	4	89,36	10,15

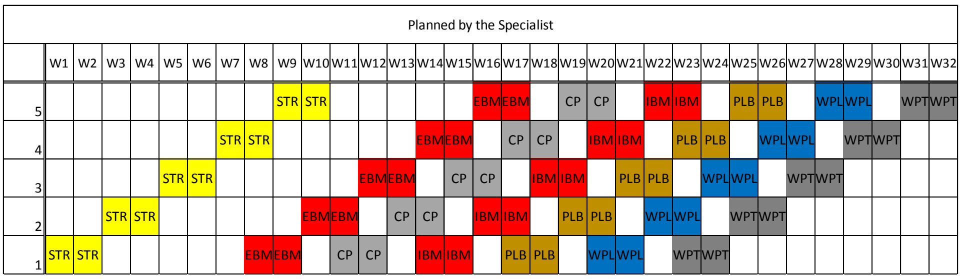

Figure 2: LOB Planner by company's Planner (Authors)

Table 2: Probability distribution and expression for each activity (Autors)

Activity	Distribution	Expression
Structure	Beta	4.37 + 1.99 * BETA(0.61, 0.703)
Internal Block Masonry	Beta	0.16 + 0.13 * BETA(0.991, 0.738)
External Block Masonry	Weibull	0.12 + WEIB(0.0732, 2.59)
Cold and hot water System	Logonormal	6 + LOGN(11.1, 11)
Ceiling mortar coating	Beta	0.19 + 0.45 * BETA(1.88, 2.97)
Internal Mortar Coating	Beta	0.12 + 0.13 * BETA(3.69, 5.7)
Sanitary System	Triangular	TRIA(3, 10, 13)

Proceeding to the second stage, was generated 10,000 random data for each productivity rate per team per activity. Considering that, the project has five floors, were generated five series of 10,000 data for each productivity per team per activity, considering their respective expression of probability distribution.

The next step was to simulate the empirical LOB with the obtained data in the previous stages. To find the difference between the real time and planned for the execution of the activities, first were found the rates of time spent by activity, i.e. dividing the productivity index by the quantitative rates provided by the empirical LOB and multiplied by the number of teams planned for the project. This has been made for all 10,000 data of each series for each activity, thereby acquiring data for direct comparison with the empirical LOB.

RESULTS AND DISCUSSION

The Monte Carlo Simulation permitted to establish 10,000 project realizations through the combination between the beginning and conclusion of the activities respecting the durations of execution randomly generated. The figure 3 illustrates one of the miles obtained combinations.

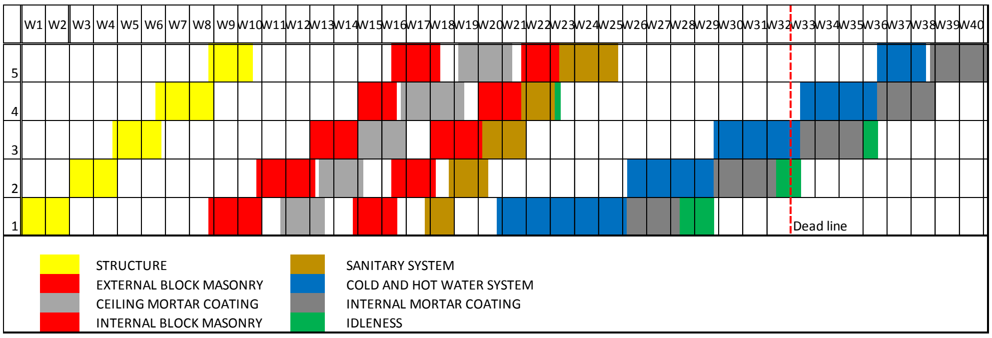

Figure 3: Example of obtained simulation (Authors)

As it can be seen at the Figure 3, the realization of the project has crossed the deadline target for the enterprise. The planned final date for the project were 32 weeks, but the variability of the activities during the execution took the project to finish at the fortieth week, which means eight days or 25% of delay.

Combining all simulations generated in Monte Carlo approach it is possible to verify the impact of the stochastic rates of productivity in the activities for the entire project performance in concern of deadline fulfillment and also idleness within the execution of the projects.

About the deadline planned target it can be seen at Figure 4 the Graph of Frequency Curve of Delay and the Graph of Cumulative Probability of Delays. As one can state, all the 10,000 simulations have exceeded the deadline planned to the project, and the maximum delay observed was 48 days, or almost 10 weeks.

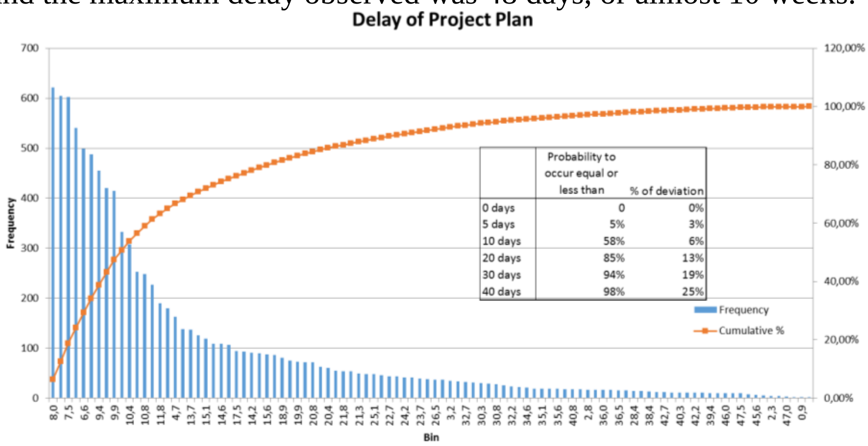

Figure 4: Graphs concerning simulated delays in project (Authors)

Concerning about idleness within the execution of the enterprise the Figure 5 brings the Graph of Frequency Curve of Idleness and also the Cumulative Probability of Idleness. As can be seen, just 6% of the total simulations did not presented idleness times during the execution of the project. The average number of projects has idleness time of about ten days, and the maximum observed idleness time was 74 days.

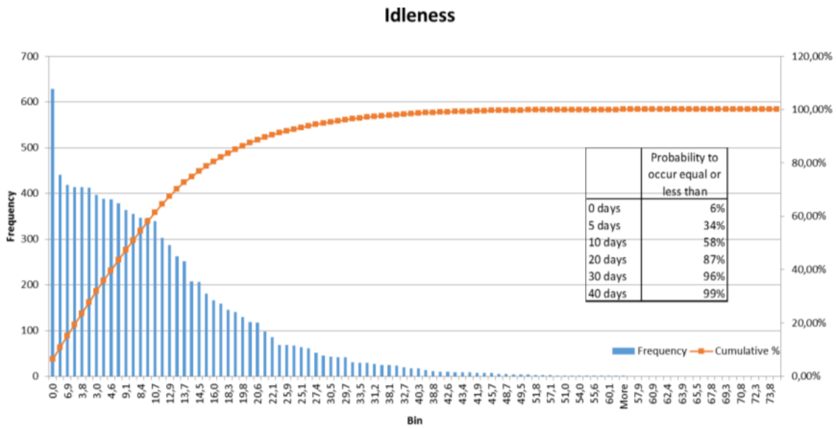

Figure 5: Graphs Concerning Simulated idleness in project (Authors)

The analyses of the Monte Carlo Simulation using the real probability distributions of activities permit to affirm that the process-time variability hardly affects the performance of the construction projects. In the presented simulation all cases have delays in the deadline, and 94% have Idleness times during the execution. These results lead to conclude that despite planners plan time buffers between activities in order to absorb variation in the process, concerning the combination of activities variability it is difficult to administrate trades in the strategic horizon. In this aspect the Look Ahead Planning and the Last Planner tools, gain importance for the integration planning, in order to try to coordinate all the teams and activities and its variability to reduce delays and idleness.

CONCLUSION

The line of balance is becoming an increasingly common planning tool on Brazilian construction companies, and shows efficiency on its purpose.

Nevertheless, when variability is not considered in the planning phase, or if it is a unknown variable and planners end up supersizing buffers, the project tends to be more wasteful.

Another point about buffering is workforce management. When the company is executing in many projects at the same time. The idea is synchronize the exit of a trade in a project and the start of another one, and buffer is input on purpose.

Also it is important to highlight that it cannot think blindly in production performance and forget the financial part of a project. Considering a scenario that the market is not responding as predicted and sales are low, on this case, buffering can be used to delay disbursements and not lose the deadline.

The study was made for a small project and few activities. In more complex projects the impact of variability should be much worse and probability of delay should increase.

Also, it was not considered any action to increase workflow and stabilize the production in this simulation. Last Planner would fit in this case by acting in the problems root causes to reduce variability.

For future studies, a model for sizing buffers between activities considering the variability flow should be investigated and tested on gemba. The aim of this model is to decrease the probability of project delay.

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