LINE OF BALANCE – IS IT A SYNTHESIS OF LEAN PRODUCTION PRINCIPLES AS APPLIED TO SITE PROGRAMMING OF WORKS?

Rafael de Sousa Leal Martins Moura[1], José Márcio Feitosa Monteiro[2] and Luiz Fernando Mählmann Heineck[3]

ABSTRACT

Evidence on the use of Line of Balance as a scheduling technique already exists in the Brazilian construction industry since the 80'. More recently it has been associated with Lean Construction applications, especially as tool for tactical planning of works. This conceptual paper discusses how line of balance can be taken not just as a straightforward graphical device to depict site programming in long, medium and short terms but also as an appropriate graphical tool to represent, induce and make self-evident the application of several Lean Production ideas like takt time, buffers transparency, integrated planning of long, medium and short term, minimization of production and transfer batches, PDCA, production levelling, inventory minimizing, pull production and parallel operations, among others. Each of these concepts is illustrated using line of balance displays. The work concludes that Line of Balance is akin to Lean Production and Lean Production is very well represented by Line of Balance diagrams, aiming at further discussions on this conceptual synthesis (lean is line and line is lean).

KEYWORDS

Line of balance, building schedules, lean construction, lean conceptual synthesis, graphical communication of lean principles.

INTRODUCTION

Customers have gradually become more stringent on their requirements. In addition to quality products, they also demand more affordable products and stricted delivery dates. Realizing the need to adapt to this new market and observing the context of the adoption of management techniques and production of the auto industry, that combine quality and low cost by optimizing processes, the construction industry has been gradually trying to adjust its management tools to these new market requirements.

Starting from the Toyota Production System, a new production philosophy was devised for the building sector called Lean Construction. The basic principles of Lean Thinking can be summarized as follows: (a) value specification, (b) alignment in the best sequence of actions that create value, (c) carrying out these activities without interruption, (d) the rhythm of demand commands the rhythm of production and (e)

[1] Master Student, Federal University of Ceará, Fortaleza, CE, Brazil, rafaelleall@hotmail.com
[2] Civil Engineer, Fortaleza, CE, marcioccap@gmail.com
[3] Professor, State University of Ceará - UECE, Fortaleza, CE, Brazil, freitas8@terra.com.br

continuous improvement (Womack and Jones, 1996). More precisely these principles are called value, value stream, flow, pull and perfection, respectively.

Lean Construction assumes a process model consisting of material and information flows, from raw inputs to finished products, encompassing activities like transportation, waiting, processing and inspection. Waiting, inspection and transportation are activities that do not add value to the final product (Formoso, 2001). Effectively, processing activities that add value are those that meet the needs of internal and external customers.

For the successful application of Lean Philosophy to construction sites, it is necessary to adopt a new system of work planning to systematically organize all departments within a construction company that contribute to production. Moreover planning, according to Mendes Júnior (1999), is a tool that helps operatives to address their work and therefore should be understood and used by them.

Losso and Araújo (1995) maintain that there are several methods of planning and control for civil construction, among which stand out simple techniques, such as the Bar Charts or Gantt Charts up to PERT/CPM Networks that might be appropriate for complex jobs. However, when project is repetitive in nature, the technique most appropriate for planning and control is Line of Balance, by taking advantage of continuity of work (Mendes Júnior, 1999).

In simple terms, Line of Balance graphically represents the activities of a process sequenced over time, considering the repetitive nature of the activities of a building. Through this tool site managers can better visualize the execution sequence of activities, which may result in improvement of productivity and quality of construction.

Recognizing the influence of the philosophy of Lean Construction in building industry, this paper aims to analyze their major principles and discuss if they can be taken into consideration by the graphical outcomes of a Line of Balance schedule of works.

NEW PHILOSOPHY OF PRODUCTION AND LINE OF BALANCE

PRINCIPLES OF LEAN CONSTRUCTION

The concept of Lean Construction emerged in 1992 as a counterpoint to conventional production philosophies. One of its early milestones was the publication of a technical report containing the bases of this new philosophy adapted to construction produced by Lauri Koskela (1992).

After this report, other authors started to enhance the philosophy as Ballard and Howell (1996) who stated that Lean Construction has at least two focuses of distinction from conventional construction management: waste reduction and better management, highlighting information system processes, along with production processes.

Heineck et al. (2009) summarized Koskela' principles reducing then to 3 major focus of attention as management outcomes goes: cycle, flow and coordination. The first reflects the reduction of lot size by transforming activities in repetitive cycles. The second states that Lean practices should reflect on operations that do not stop while being carried out and that have a more continuous sequence. The third principle states that coordination activities should be enhanced in order to overcome the

potential chaotic building environment. In practice, coordination will benefit from site planning and programming at the strategic, tactical and operational levels.

Consensus among many authors indicates that Lean Construction philosophy has as its main focus creation of value for clients, improving operations in small steps and continually aiming to reduce, waste, whether of time, equipment or money.

LINE-OF-BALANCE

Pacheco and Heineck (2008) point out that there are three different views on the initial development of line of balance scheduling ideas. One version dates creation in 1942 by the United States Navy followed suit by applications made by the National Housing Agency in the United Kingdom towards programming repetitive house buildings in the 50' (Suhail and Neale 1994) [1]. Another version by Turban (1968 *apud* Lutz and Hijazi, 1993) [2], attributes the creation of Line of Balance to a direct outcome of previously developed Goodyear Assembly Line at the beginning of the 40'. A third version is proposed by O'Brien (1969) [3]. He said, citing another author (Kane), that line of balance emerged in 1951 as the creation of the Naval Special Projects Office, taking its final shape in 1962 (Navy Office of Naval Material, 1962) [4]. In Brazil the line-of-balance technique has been used since 1981 (Macedo, 1981), became common in construction sites by 1990s as reported in research works like (Heineck and Peixe, 1990; Losso and Araujo, 1995; Heineck, 1996; Coelho, Vargas and Heineck, 1996).

Junqueira (2006) argues that this tool can indicate the sequence of activities through various repeating units of work (floors, apartments, single family homes, miles of road and miles of pipelines, for example). Through the adoption of this concept it follows that activities durations will define production rates. Greater production rates can be obtained by reducing cycle time or employing multiple crews to perform de same job in different construction units.

Line of Balance suggests that all activities are to be performed with one single rate, making it a completely parallel programming, where there is no wasted time between the end of one activity and the beginning of another (Mendes Júnior and Heineck, 1998).

The essence of balancing allows to define how many units (rooms, apartments and floors) will be completed in a given time what brings the following benefits: the reuse of building gangs in different operations, the best team's schedule, uninterrupted work for a team (what improves productivity), minimization of inventories of work in process, better definition of tasks and visual management (Junqueira, 2006).

The idea of work packages displayed on Line Balance allows to identify some details of the progress of work, such as the activity to be performed (what); the team that perform such work (who), the place of execution of the activity e.g. (apartment or floor (where) and the moment in time the activity is performed (when). Finally, it is

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1 Suhail, Saad A.; Neale, Richard H. (1994). CPM/LOB: New Methodology to Integrate CPM and Line of Balance. Journal of Construction Engineering and Management, v. 120, n.3, p. 667-684, September 1994.

2 Lutz, James D.; Hijazi, A. (1993). Planning repetitive construction: Current practice. Construction Management and Economics, n. 11, p. 99-110

3 O'Brien, J.J. (1969). Scheduling handbook. New York: McGraw-Hill Inc, p. 246-255.

4 Navy Office of Naval Material, Line-of-balance technology, NAVEXOS, p.1853.

noteworthy that, according to Mendes Júnior (1999), an imbalance between activities can negatively affect project performance causing stoppages in tasks, inefficient use of both teams and equipment, and excessive costs. The schedule of activities for repetitive projects aims to balance production rates and thus induce better use of resources. A complete and current review on research papers on LOB was performed by Lucko et al. (2013) which aims at filling a gap in the body of literature in connection to the evaluation of advantages accruing from the use of site planning tools, based on reports on actual performance improvements.

METHODOLOGY

This research work was developed by a literature review of intrinsic concepts both on Lean Philosophy and line of balance programming technique. The quest was to find what they have in common or can easily be translated from one to the other. It proceeded by drawing lines of balance to accommodate such common features, providing exemplification and explanation on the authors reasonings on the similarities of those concepts.

LEAN CONSTRUCTION IN LINE OF BALANCE PROGRAMMING

Some characteristics of Lean Thinking can be applied to initial sketches of a line of balance, such as the definition of a production rate (takt time), synchrony and parallelism between operations. Another example is the rational distribution of employees throughout a site and strategies to allow flexible work, as it is the case with cellular production. On the other hand, adherence to a strict sequence of work provides continuous improvement through the learning effect (Pacheco and Heineck, 2008). In order to better discuss such ideas, reasonings were organized as follows. Characteristics such as integrated planning of long, medium and short term, minimization of production and transfer batches, PDCA, production leveling, pull production, takt time, synchrony, parallel operations, inventory minimization, interference avoidance and reduction of cycle time are shown in different charts (Figures 1 to 11) hereof. Reduction of lead, correct sizing of buffers, increased transparency, and strict definition of trajectories and sequences of activities are illustrated in a single chart in Figure 12.

INTEGRATED PLANNING OF LONG, MEDIUM AND SHORT TERM

The line of balance technique is a tool used for long-term planning, but it is possible to integrate a medium-term and short-term view of the activities to be performed as shown Figure 1.

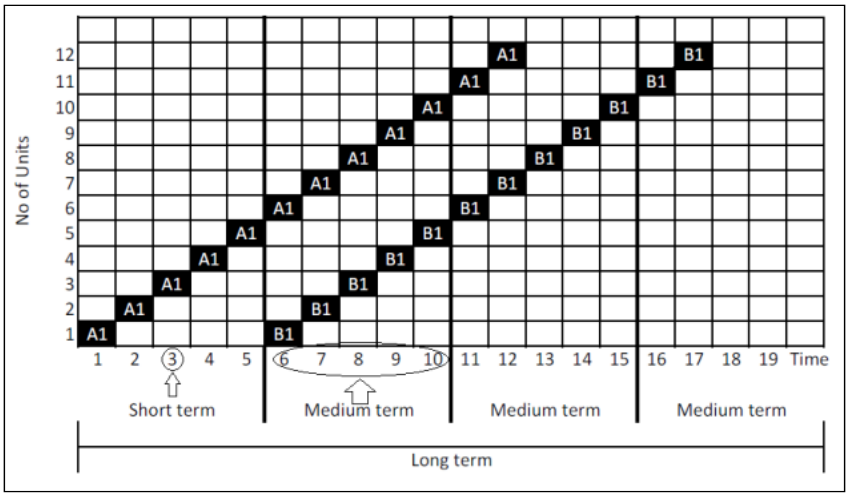

Figure 1: Illustration of the scope of long, medium and short term.

MINIMIZATION OF PRODUCTION AND TRANSFER BATCHES

According to Pacheco and Heineck (2008), repeating units of work might cause learning effects, what leads to the reduction in activities duration. The smaller the repeating unit, the greater the learning effect, what reduces also global lead time. Figure 2 shows how this can be done by splitting typical building activities.

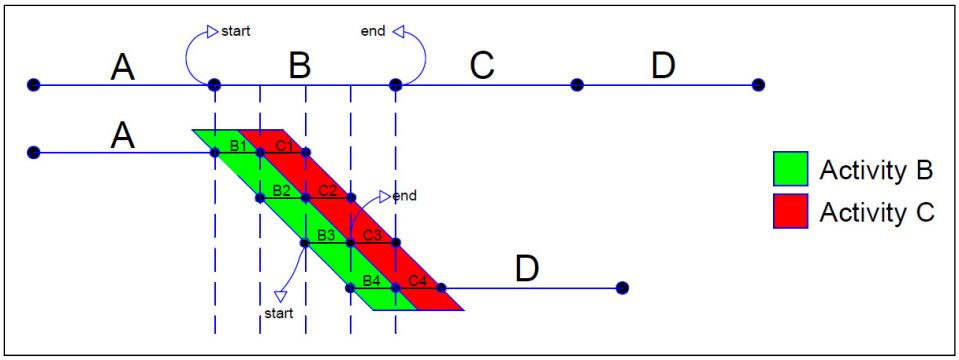

Figure 2: Minimization of production and transfer batches (Pinheiro, 2009).

PDCA

In drawing LOB, repeatability of cycles is a parameter that comes naturally. This repetition occurs according to the PDCA cycle traversing its four phases: planning, doing, checking and acting. Checking might tell that goals are not being met; acting (reacting) will provide the managerial mechanisms to allow continuous improvement in the next cycles (Pinheiro, 2009).

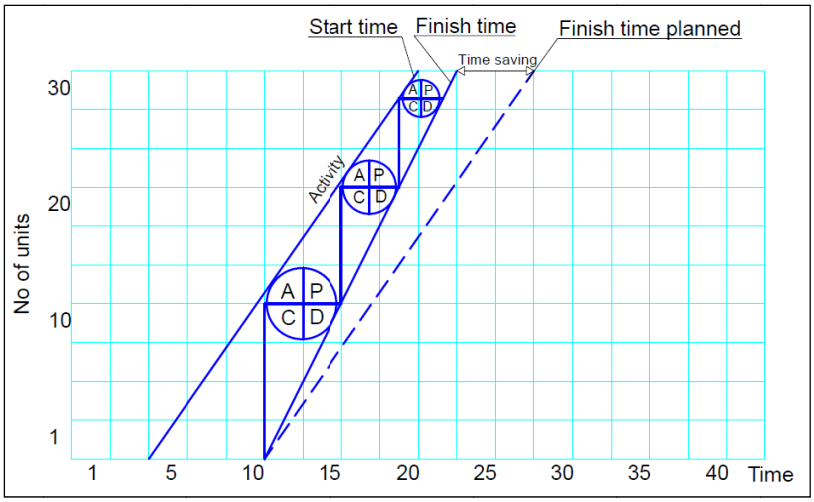

Figure 3: PDCA cycles to improve repetitive work

PRODUCTION LEVELING

Production leveling is obtained by reducing cycle time, what brings smaller activities duration at each repeating unit. This is what is shown in Figure 4. It has all the activities going on throughout most of the project duration, which causes a greater stabilization in the consumption of resources, as it is the case with parallel programming with low production rates (all activities under the same low takt time) (Pinheiro, 2009).

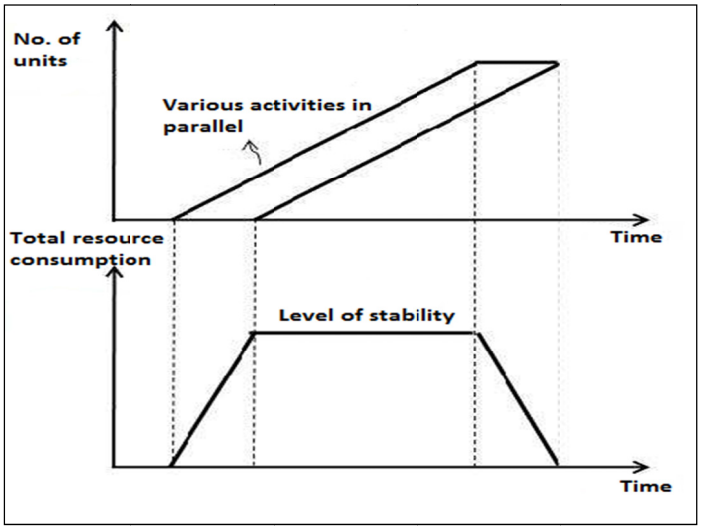

Figure 4: Resource leveling due to the parallelism of activities (Pinheiro, 2009).

PULL PRODUCTION

Visualizing activities to be performed in a given space and time makes it is possible to indicate which activities shall be pulled by their successor ones. The use of kanban is the answer of Lean Construction to pull production: line of balance allows to understand how kanban works on a building site. Figure 5 shows one predecessor

activity being pulled by its successor. Pull production allows the minimization of inventory, once the process is viewed as a whole, knowing the exact moment that resources will be used.

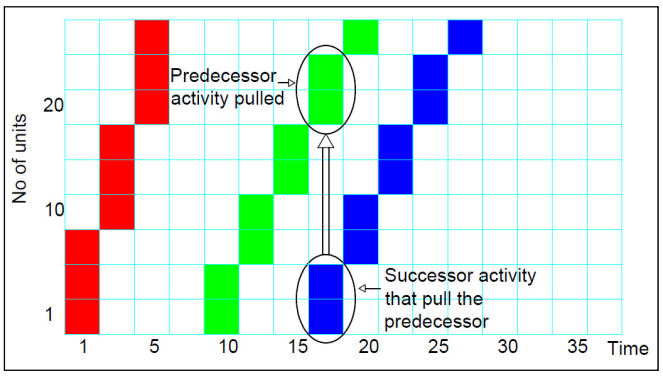

Figure 5: Pull production.

PRODUCTION RATE (TAKT TIME)

According to Arditi, Tokdemir and Suh (2002), LOB is a variation of linear scheduling methods that allows the balancing of operations such that each activity in continuously performed. Its major benefit is that it provides production rates and duration information in the form of an easy to interpret graphic format like the one shown in Figure 6.

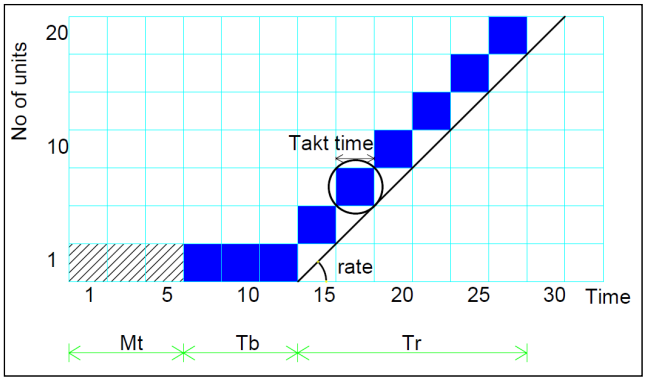

Figure 6: Production rate indicated by the line of balance slope (Pinheiro, 2009).

SYNCHRONY

The sequence of activities in a line-of-balance enables the choice of how best to avoid overlapping of activities. Knowing the rate and sequence of activities for each operator, is possible to establish synchrony and identify any delaying activity (bottleneck). Figure 7 shows the combination of three production rates for interdependent activities: the best way of combining them is through a common rate of progress, avoiding their occurrence at the same time in every repetitive production unit.

Ohno (1988) says that synchronization in production is obtained by establishing a single production rate. This production rate should be extended to the external supply

of materials. Although the author refers to the automobile industry, this concept might be used in the construction industry.

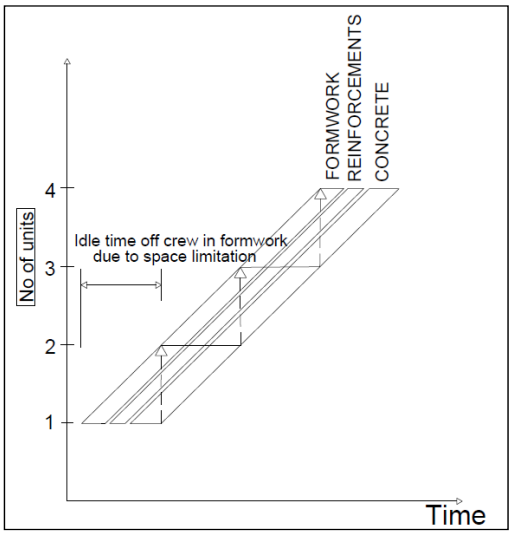

Figure 7: Combined rate of production for space-dependent activities (Arditi, Tokdemir and Suh, 2002).

PARALLEL OPERATIONS

Construction industry has a different production problem as compared to the remaining manufacturing enterprises in the sense that there is a flow of workers and not of products through an assembly line. Thus, through the line of balance it is possible to identify different production-like cells working in parallel and in small batches, obeying the same rate and sequence of activities. By production-like cell is meant the fact that each activity looks like being carried out by specialists, but there is no hindrance to make workers tackle different activities in close-by repeating units, as it is indicated by the vertical loop in figure 8. Advantages of parallel production and cell are the elimination of peaks and valleys of consumption of resources, teamwork, focused layout (more control) and decreased transport distances.

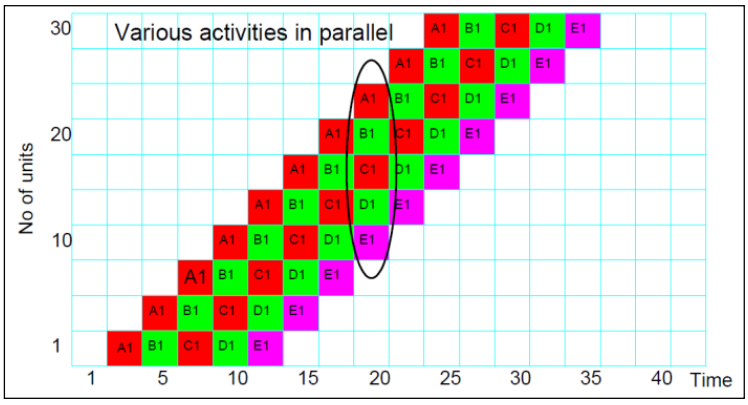

Figure 8: Activities in parallel (or cell-like production).

INVENTORY MINIMIZATION

Line of balance can view inventory by an arrow that indicates when materials should be supplied to each repetitive unit of work. This makes it possible to quantify the partial consumption of inputs. It also provides a clear evaluation for the total amount of material stocks that might be needed, what can illustrate the just in time advantages. Just in time can be made clear by diminishing arrows indicating when materials should be provided for each unit of work.

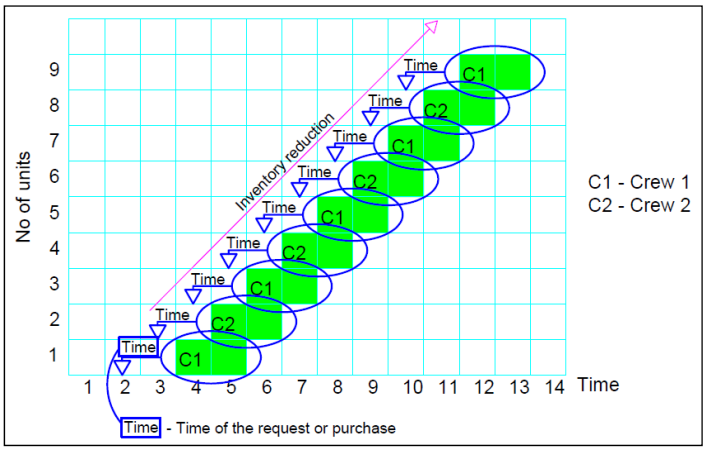

Figure 9: Inventory minimization.

INTERFERENCE

When two or more activities occupy the same space and are performed at the same time it is claimed that interference of tasks can be harmful to production. Line of Balance helps to visualize the occurrence of interference activities and thus preventing them from occurring, anticipating problems that are commonly detected only during work execution. Another approach is to arrange different activities in production cells: possible work interference between such grouped activities might now be solved by workers themselves,

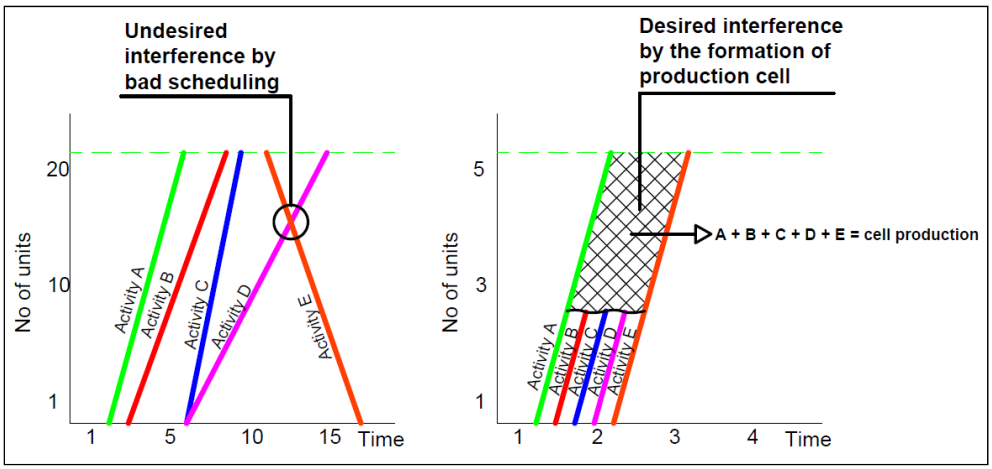

Figure 10: Undesired and desired interference.

CYCLE TIME

For Alvarez and Antunes (2001) the duration of a cycle is obtained by the time period between the repetitions of the same activity in two different production units. The cycle time is easily detected in a line of balance. Once it is detected, increased rhythms of work can be obtained by reduced cycle times.

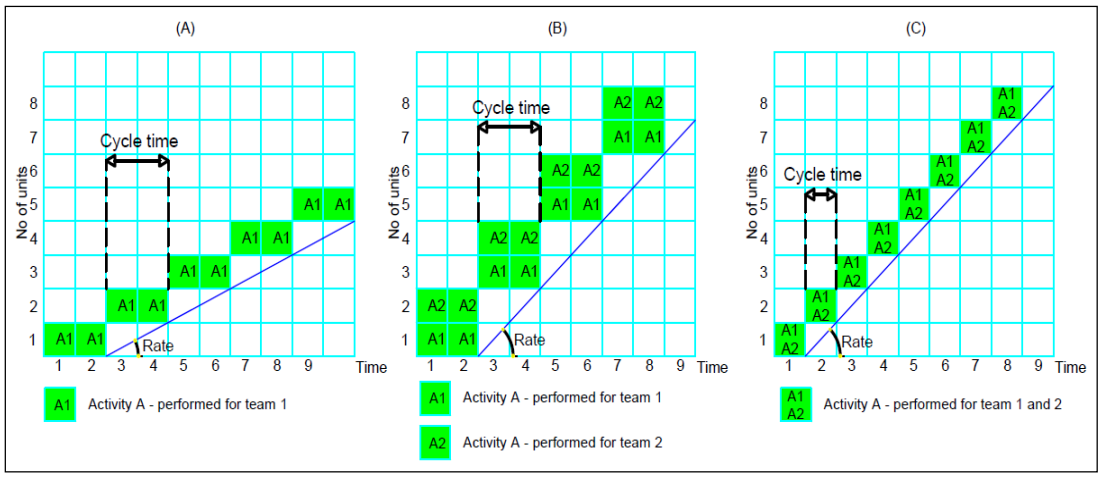

Figure 11: Cycle time and different production rate different.

LEAD TIME

According Sellitto and Walter (2008) the term lead-time means at least two things: (i) supply times related to the replacement of materials, and (ii) the measure of time that a production system spends to turn raw materials into finished products available for clients. Figure 12 illustrated lead time for activity A.

BUFFERS TRANSPARENCY

Time between the completions of two activities can be easily identified in a line of balance. This is the Lean concept of buffering. Buffers can be established in terms of possible delay of time between succeeding activities (horizontal buffer) and production units waiting to be tackled by the same activity in different construction units. Figure 12 visualizes buffers (horizontal and vertical) for activities B and C. Buffers should be set at reasonable target values and ideally converge to zero.

TRAJECTORY AND SEQUENCE OF ACTIVITIES

The trajectory in LOB can be seen by the sequencing of squares in the orthogonal plane that displays the technical interrelationship of tasks to carry out a building. It is characteristic of line of balance to display the sequence of tasks and consequently the basic outline of technical precedence. In this sense, it first needs a PERT/CPM type of logical network of activities. Then such network of activities is arranged in sequences from building unit to building unit. Figure 12 shows a typical Line of Balance for several activities. One sequence of work is related to the technical arrangement of work such that a unique building unit can be completed. Another sequence of work is given by work crew trajectories. Dashed arrows in this chart, accompanied by the

words "upward trend" and "downward trend", graphically exposes these Lean Production concepts that are used in Line of Balance.

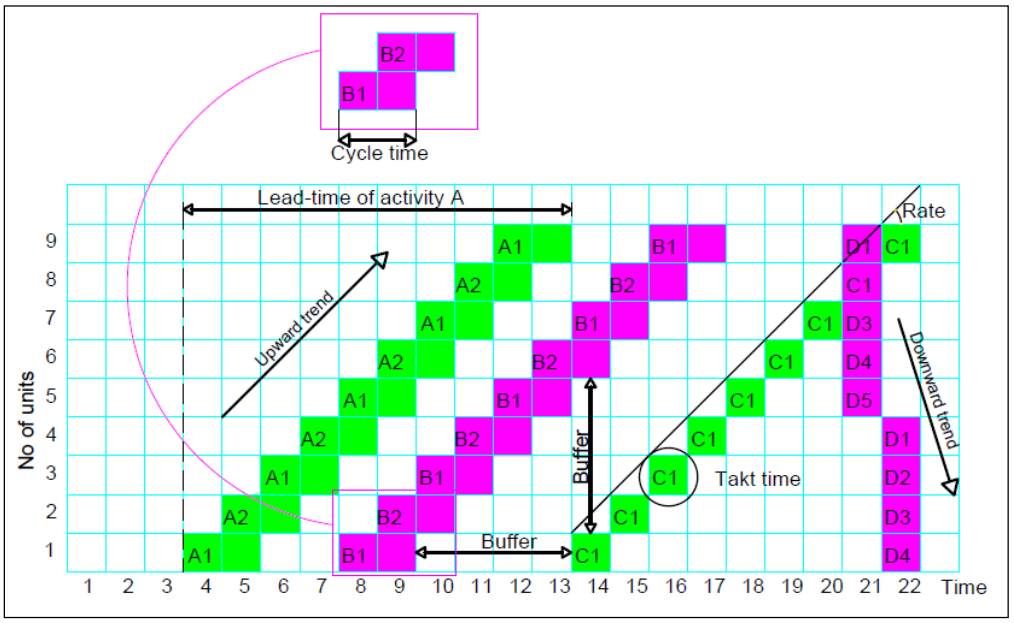

Figure 12: Some features of sequencing lean line-of-balance.

CONCLUSIONS

The paper reviews several concepts of the Lean Philosophy, identifying activities that create value. In order to attain the value producing goal, management should improve the flow of information and assure the timely delivery of finished units of construction. Line of Balance is studied in order to identify its potential relationship as a planning technique to the principles of Lean Construction. This research work recognizes Line of Balance tool as a planning device that gives support to the Lean philosophy: it takes the latter theoretical concepts into practical graphical easy to understand applications.

Thus, this research effort concludes that Line of Balance is akin to Lean Production and Lean Production is very well represented by Line of Balance diagrams, aiming at further discussions on this conceptual synthesis (lean is line and line is lean).

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