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## COMPARING PRODUCTION DESIGN ACTIVITIES AND LOCATION-BASED PLANNING TOOLS

Clarissa Biotto<sup>1</sup>, Mike Kagioglou<sup>2</sup>, Lauri Koskela<sup>3</sup> and Patricia Tzortzopoulos<sup>4</sup>

**Abstract:** What are the differences between production system design and work structuring? And between phase scheduling and work structuring? Which lean planning tool is better suited for each one of these design processes: line of balance, takt-time planning or flowline? This paper aims to answer these questions through a comparison and deeper understanding of production design processes, as well as the potential uses of location-based tools for production planning and control in each design effort.

The method used is the literature review analyses on main lean terms and tools applied for production system design. With a better comprehension of the terms and tools, it is expected that academics and lean practitioners will be able to apply lean construction in a more aware and sensible manner. The results will also support researcher's decision about the most suitable lean tool to apply in the case studies in different production design processes.

**Keywords:** Production design, phase scheduling, work structuring, line of balance, flowline, takt-time planning.

### 1 INTRODUCTION

The production system management is divided in three major activities: design, operation and improvement (Koskela & Ballard 2003). In lean construction literature, the Production System Design (PSD) also refers to Work Structuring (WS) (Ballard et al. 2001). Although it occurs before the construction act, it is known that, during the production system operation, some production system design activities also take place, e.g. the Phase Scheduling (PS). It occurs because information becomes available and accurate for decision-making just after the beginning of construction. Whether PSD, WS or PS, these design processes have different features, uses and scopes, which are not very clearly described in the literature.

In the lean literature, there are some tools for production design that express the work structure in a visual fashion, such as line of balance (LOB), flowline (FL) and takt-time planning (TTP). These tools use the locations in a building/facility as the unit basis for production planning and control, structuring the work in different ways. For that reason, it is also important to clarify these differences among them, and the potential use of these tools.

The aim of this paper is to present brief descriptions and comparisons about production

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design, such as PSD, WS and PS, as well the tools used to devise them, namely, LOB, FL and TTP. This literature review is part of an ongoing doctoral research, in which papers were used to track how the lean tools and processes are being applied in academia and industry.

Through the clarification of production design processes and planning tools, it will be possible for construction managers to choose the most suitable tool for each design process in development, based on the accuracy of information, the stakeholders' commitment and level of uncertainty in the construction project.

## 2 LITERATURE REVIEW

### 2.1 Production System Design

In manufacturing industry, the production system design is the study of alternatives of production organization in order to choose the most appropriate strategy to achieve the desired results (Meredith & Shafer 2009).

In construction, the design of the production systems has three main goals (Koskela 2000): 1. Deliver the project; 2. Maximize value; and, 3. Minimize waste. PSD represents the most basic form and opportunity for minimizing the effect of variability on production, at the same time it contributes to achieve the major project goals (Ballard et al. 2001).

Usually, PSD refers not only to the work structuring, which is a necessary activity to study the workflow, but also, to a set of decisions that cover the whole project strategy. PSD should take place, necessarily, before the construction stage in order for the project team to be aware of alternatives for production organizations and its consequences for budget, time, and workflow. One of the PSD outputs is the master plan that will be used when the system starts its operation (Schramm et al. 2004). Then, the project team will be able to adapt the production system in case of variabilities and uncertainties, i.e., minimizing their effects on production, and delivering value for client.

### 2.2 Phase Scheduling

Phase Scheduling, also known as pull planning, is a collaborative design activity to structure the process of a project phase and produce a plan for completing it (Ballard 2008). PS aims to maximize the value generation among the stakeholders and client through a transparent and collaborative process of decision making, in which people involved can use sticky-notes (amongst other means) on a wall (or other physical and digital media) to plan their activities, define the network of activities and the handoffs, insert the buffers, and also, to guarantee the completion of the work on time (Ballard 2008).

In order to plan a phase, the PS participants use the work structuring to breakdown the phase activities into processes and operations, and then, define the handoffs between the crews of sequential activities, and between project phases.

### 2.3 Work Structuring

The term Work Structuring was introduced in construction by Ballard (1999) to designate the production system design. However, there are some differences of focus between the two. Work structuring can be defined as process design (Ballard 1999). It is “the development of operation and process design in alignment with product design, the structure of supply chains, the allocation of resources, and design-for-assembly efforts” with the goal of making “work flow more reliable and quick while delivering value to the customer” (Ballard 1999).

Work structuring is used before the production stage, but it can be used any time during the construction (Ballard 1999). It breaks down the product and the process into parts, sequences and assignments to realize the work flow with less variability, to reduce waste while increasing the value (Ballard 1999). To achieve this goal, the work structuring deals with three main concepts:

- **Production unit** – “a group of direct production workers that do or share responsibility for similar work, drawing on the same skills and techniques” (LCI, 2004 cited in (Tsao 2005);
- **Work chunk** – “A unit of work that can be handed off from one production unit to the next” (Tsao 2005);
- **Handoff** – “The combined (1) completion of a work chunk by a production unit that allows a subsequent production unit to further transform the work chunk or execute a different work chunk as planned, (2) declaration of completion of the work chunk by the production unit and release to the subsequent production unit, and (3) acceptance of the released work by the subsequent production unit” (Tsao 2005).

Based on these concepts, work structuring tries to answer the following questions (Ballard 1999): 1. In what chunks will work be assigned to specialists?; 2. How will work chunks be sequenced?; 3. How will work be released from one production unit to the next?; 4. Where will decoupling buffers be needed and how should they be sized?; 5. When will the different chunks of work be done?

## 2.4 Discussion about Managerial Activities in Lean Construction

Comparing the Production System Design with Phase Scheduling and Work Structuring, it seems that the first one focuses on strategic decisions about the construction project with concerns about project’s viability, budget and lead time, which are consequences of the production system organization. In contrast, the PS tries to ensure that phase activities are clearly defined in handoffs for participants and the phase lead time fits into the master schedule. On the other hand, WS focuses on the process view and it is used in both design processes, PSD and PS, considering the information available for the decision making to break down the work in work chunks, handoffs, and production units, and in order to make the workflow smooth (Figure 1).

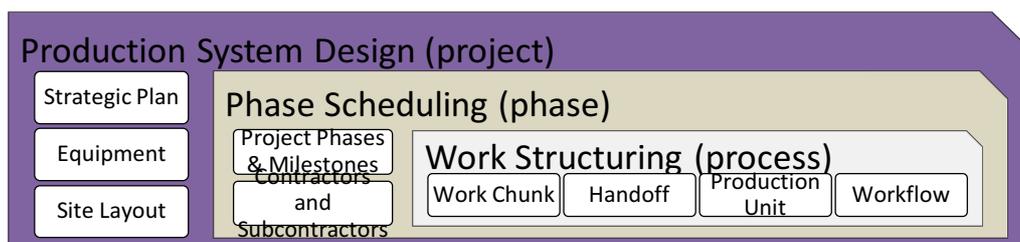


Figure 1: Work structuring is part of the decision scope of production system design and phase scheduling.

## 2.5 Location-based Planning Tools

There are different types of methods to plan construction activities: those based on activity or those based on location. Examples of methods to plan construction based on activity are the well-known Critical Path Method (CPM) and PERT. Both methods are frequently criticized by lean researchers, due to their incapacity to deal with the construction complexity.

Methods originally developed in the manufacturing industry were adapted for construction, such as Line of Balance, Flowline and Takt-time planning. The adaptation occurred by changing the vertical axis unit: from units produced to location (Kenley &

Seppänen 2010). The term location-based schedule was proposed by (Kenley 2004). It occurred due to the construction industry having resources, namely manpower and equipment, flowing through the fixed location units, differently from the manufacturing, where production units flow through the fixed resources.

### 2.5.1 Line of Balance

Line of Balance (LOB) is a planning technique developed by Goodyear Company in the 1940s and then used in the manufacturing industry for repetitive process. Next, it was developed for an industrial program by the US Navy in the 1950s (Arditi et al. 2001). Currently, the line of balance is also used by the construction industry, especially in repetitive projects, such as high rise buildings, tunnels, roads, and so on.

The LOB is a diagram that represents units in the vertical axis, and time in the horizontal axis. Initially, the tasks were represented as dual parallel lines. As the LOB is based on activity-on-arrow (AOA) networks, the task lines represent an activity between two event nodes (the delivery of production unit) (Yassine et al. 2014), hence, the line slope means the delivery rate. Because this method is focused in the delivery of completed units, the delivery rate starts counting “when the first unit has been finished” (Yassine et al. 2014).

The LOB technique allows the project team to achieve continuous workflow and uninterrupted flow for crews through the location units. This technique is appropriate for planning projects with repetitive nature by taking advantage of continuity of work (Mendez & Heineck 1998). The main idea in the LOB is that all activities can be performed in only one production rate, i.e. a parallel programming between the activities (Mendez & Heineck 1998) to reduce the work in progress.

The LOB is being used to devise the production system design, as well as the master plan of construction projects (Kemmer et al. 2008; Schramm et al. 2004). It also can be detailed in different forms, i.e. the time units can be days (Valente et al. 2014) or weeks (Seppänen et al. 2010) according to the level of uncertainty in defining the tasks duration.

### 2.5.2 Flowline

Flowline is a term coined by Mohr (1979), however, the method was developed earlier by Selinger (1973) and (Peer 1974). The flowline consists from a derived method from the Line of Balance, however, the activity is represented by a single line, which Kenley and Seppänen (2010) consider a much cleaner representation than line of balance. In order to visualize the crews' workflow, the activity flowline can be broken down into crews' lines (Kenley & Seppänen 2010).

The flowline can also be designed for normal construction projects, rather than the repetitive ones, by breaking down the project locations in equal sizes or work content (Kenley & Seppänen 2010). As the flowline is rooted in activity-on-node (AON) representation, which is used to draw the CPM network, the tasks represents the start and end of a process and the logical link among tasks (Yassine et al. 2014). For that reason, the slope of a line represents the production rate, which is the total quantity of units divided by the total duration (Yassine et al. 2014). The task is graphically represented by starting in the point of the first unit location (Y-axis) and start of duration (X-axis); finishing in the point of the last unit location (Y-axis) and end of duration (X-axis) (Kenley & Seppänen 2010).

### 2.5.3 Takt-time Planning

The takt-time planning (TTP) in construction is derived from the takt time used in lean manufacturing to plan the production system by setting its rates according to the demand

rate. The use in construction started recently, with some works on its application in the development of the production system design, more specifically, the Phase Scheduling (Frandsen et al. 2013; Linnik et al. 2013).

Frandsen et al. (2013) define Takt time as the “unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate)”. The main aim of the TTP is to design the production system for continuous workflow, keeping the trades in a balanced pace of work (that match the demand rate) through a sequence of zones (Frandsen et al. 2013).

The zones are “physical and clearly defined locations” to avoid ambiguity about location boundaries, the same as in the Line of Balance (Frandsen et al. 2015). In a production plan devised using the TTP method, the trades must complete their work in the assigned zone in an amount of time set by the takt time (Frandsen et al. 2015).

To develop a production plan using TTP, it is necessary to define zones and takt time, the trades sequence and duration, and balance their workflow (Frandsen et al. 2013). All these steps are devised with the participation of trades and general contractor in an iterative fashion, and decision are made collaboratively by communicating and exploring production systems alternatives (Frandsen et al. 2015).

## 2.6 Discussion about Location-based Planning Tools for Construction

When comparing the three methods for construction planning, all have a number of similarities: they aim for continuous workflow and for setting a unique production rate for activities in order to reduce the WIP. However, as visual tools, they have different graphical representation of construction activities (see Figure 2).

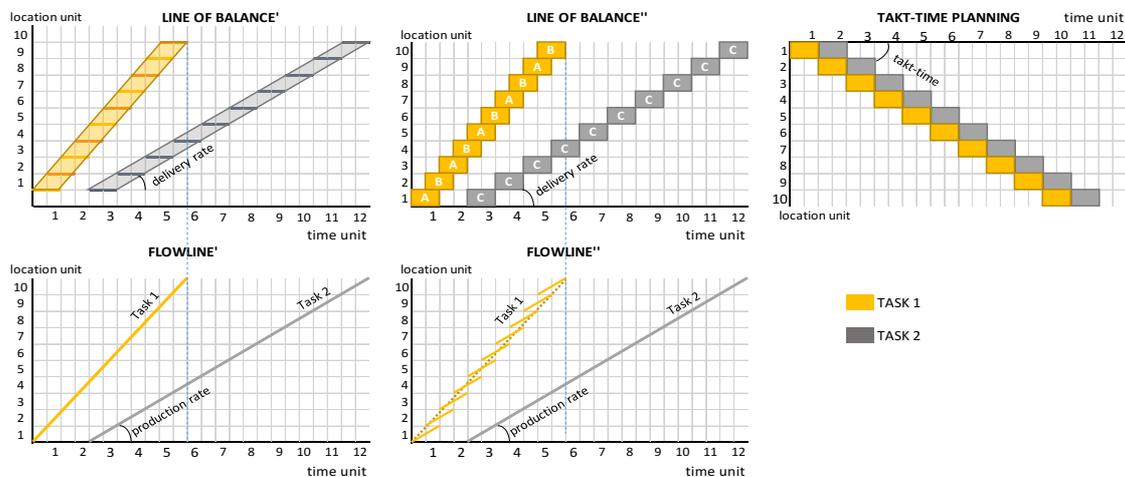


Figure 2: Different construction planning techniques based on location.

In the LOB method, workflow is visualized by dual parallel lines that represent an activity. The crews’ workflow became clear in the current LOB, by using boxes with the name of the crew. In turn the flowline represents an activity by a single line starting in the beginning of first day and finishing at the end of the last day.

In relation to the lines/boxes slope, Su and Lucko (2015) point out that the line of balance presents the delivery rate, whilst the flowline shows the production rate. The difference between them are: the delivery rate starts counting after the first unit completion, whilst the production rate starts counting from the beginning of activity execution (Su and Lucko 2015). In TTP, the boxes slope represents the takt-time, or customer demand rate, or phase demand rate when applied in the phase scheduling.

Buffers are used in different ways: the LOB uses time buffers between critical activities,

as well as the flowline. Further, the TTP incorporates buffers in the crew's production capacity (i.e., the activity cycle time is shorter than the takt time) (Frandsen et al. 2015). Although Frandsen et al. (2015) expose that LOB uses buffers only between activities, Valente et al. (2014) used buffers inside the crew's production capacity, yet, not balancing the workers operational time. A comparison is presented in Table 1.

Table 1: Comparison among the lean tools for construction planning.

	<b>Line of Balance</b>	<b>Flowline</b>	<b>Takt-time Planning</b>
<b>Crews' workflow visualization</b>	Formerly: No Currently: Yes	Depends on the level of plan detail	Partial (crews can work in two locations at the same time, or executing work backlog)
<b>Task visualization</b>	Formerly: two parallel lines; Currently: boxes	One line	Boxes
<b>Task duration per location</b>	Location quantities divided by standard crew's productivity	Location quantities divided by standard crew's productivity	Equal to takt-time or shorter
<b>Tasks representation</b>	Formerly: Start and finish dates of first and last units; Currently: start and finish dates by unit	Start date of the first unit and finish date of the last unit	Start and finish dates per unit
<b>Use of buffers</b>	Buffers inside the work package duration; Buffers between critical activities	Buffers between activities	Buffers inside the work package duration: difference between takt-time and cycle time
<b>Pace achievement (balancing the lines)</b>	Adding or reducing the number of crews to execute an activity; Changing the crews' composition and amount of service inside the work package	Changing the crews' composition	Changing the crews' composition and amount of services inside the work package; Distributing the workload among crew's members; workable backlogs
<b>Slope of line represents</b>	Delivery pace	Production pace	Takt-time: available production time divided by demand
<b>Level of detail of plan</b>	Flexible	Flexible	High
<b>Collaboration</b>	Varies according to the level of plan	Varies according to the level of plan	Highly necessary

Project uncertainties also influence the way these methods are implemented. In low complexity projects, or in projects with known partnerships, the uncertainty is lower and the interdependencies are known. In this scenario, buffers between activities can be reduced, and TTP can be applied. However, in scenarios where the project has high uncertainty, it is recommended to protect the production from cascading delays, that could be avoided by allocating buffers between activities, such as the LOB and Flowline do it.

### 3 CONCLUSIONS

In this paper, the authors compared the lean construction activities to design a production system, and the mainly location-based tools to represent the work structured. It became clear that the WS is the design of construction processes which can be used by both PSD and PS. The level of detail of the WS varies according to the information availability whether the moment of decision making.

Comparing the three location-based methods, it was found that the line of balance and flowline are very similar tools, and both evolved in construction, becoming flexible to be applied in any level of uncertainty of work structuring. Both protect the production system against variability and delays through the allocation of buffers between activities. Both methods try to achieve the same production rate, however, without forcing it, as the Takt-time planning does. The latter is the most recent method applied in construction and it requires more work backlog in order to avoid the crews' idleness or demobilisation. Crews must work in the same pace or shorter than the takt-time. No buffers are allocated between activities, which increases the risk of cascading delays in projects with high level of uncertainty. It has been used in phase scheduling, and collaborative participation of contractors to develop it is necessary.

A final summary of these comparisons is presented in Figure 3, where the location-based tools are positioned according to their potential use in production system managerial activities. Differences among the tools were identified for lean construction practitioners to be able to choose the most suitable one according to the project context. The results will be used in an ongoing research about integrating the design and construction planning and control system in projects with overlap between these stages.

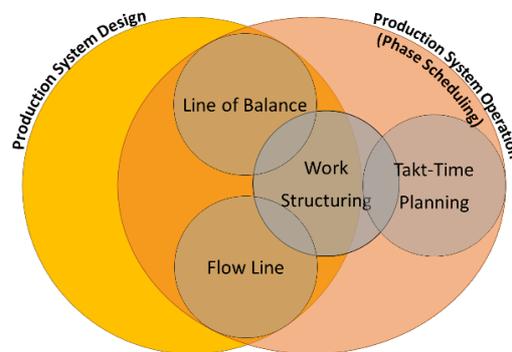


Figure 3: Position of lean tools in relation to planning activities in lean construction management.

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