Nutt, H., Berghede, K., Odah, S., and Ballard, G. (2020). LPS® Process Benchmark 2020: Location Based Planning Report. *Lean Construction Journal* 2020 pp 100-118 (submitted 10May2020; Accepted 15August2020) www.leanconstructionjournal.org

LPS® Process Benchmark 2020: Location Based Planning Report

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Introduction

The task of this team was to explore location-based planning systems and how they work with LPS®. Location based planning systems is used generally here to include Line of Balance (LOB), Location Based Management Systems (LBMS) and Takt Time Planning (TTP) practices. Location based planning adds another dimension to the question of work-structuring, specifically related to the breakdown of space to support production planning for flow. Space is important especially in construction production planning because, unlike manufacturing where the work moves to the people, on a construction site the people move to the work (Ballard and Howell, 1998). In other words, people and equipment require space to access, deliver materials and perform assembly work for all areas of the project. Space is thus a resource that must be coordinated to avoid conflicts in the progression of work through an area or flow unit of production. One of the early promises of BIM clash detection was not only clashes between elements of the final assembly but clashes between crews trying to occupy the same space to perform their work (CIFE). The breakdown of areas on a project both influences and is influenced by logistics, work phases, work sequences, assembly methods, work density, and systems and architectural design. The goal of location-based planning is to optimize the production plan to meet the goals of the project such as schedule, cost, manpower leveling, risk reduction, quality and safety. Production plans are optimized by applying: 1) WIP minimization through both reduction in area size and leading with or keying the pace to the bottleneck task; 2) Balancing tasks to minimize bottlenecks using many methods including area breakdown; and 3) Minimizing variation in task work density through area breakdown.

The location based planning team set out to answer the following questions: 1) What are the current and best practices in introducing and performing location based planning; 2) What are the impacts of and risks in location based planning; 3) How do location based planning and LPS® practices work together; 4) How is location based planning aligned with project control and supply chain; 5) Can location based planning be aligned with design work; and 6) What are the impacts of, barriers to and risks in aligning location based planning with design?

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To answer these questions the team engaged in a literature review, interviewed practitioners using location-based planning systems, and reviewed case studies of projects using location-based planning systems.

Literature Review

The following literature review was conducted to identify gaps in knowledge (know-that and/or know-how), document what it is and why it is important.

History of Location Based Methods

Location based methods for planning and control have a long history. In the late 1920s, builders of the Empire State Building used location-based quantities and a kind of flowline diagram to plan and control the work. Their goal was to establish a production line of standard parts (Willis and Friedman, 1998). In the 1940s, the Goodyear Company developed a systematic method for location-based planning called Line of Balance (LOB). LOB was deployed for industrial programming by the US Navy in WWII (Lumsden, 1968) but also applied to repetitive construction. LOB was a graphical technique that relied on repetition, so it was implemented in highly repetitive building projects, such as housing development programs (ibid.), road construction, etc. Suhail and Neale (1993), Arditi, Tokdemir and Suh (2002), and others continued modelling location-based planning using LOB lines consisting of Critical Path Method (CPM) networks with tasks that are repeated between locations.

The flowline method (a term coined by Mohr in 1979) was based on work by Selinger (1973, 1980) and his supervisor Peer (1974). A difference is that LOB diagrams do not explicitly show the movements of crews because tasks are presented as dual lines, whereas flowlines represent each task as a single line. Flowline thus requires more detailed planning because it is necessary to be explicit about resources use. Mohr (1979) discussed the detrimental impact of work breaks on production, and the risk of return delay when crews leave the site.

The next developments attempted to integrate CPM and location-based models in such a way that they could be computerized and allow for non-repetitive construction. Russell and Wong (1993) developed a method termed representing construction that allowed for multiple types of CPM logic within a location-based model, free location sequencing and non-repetitive tasks in addition to other features. They allowed for work to be continuous or discontinuous, part of workable backlog or cyclic. Logic could be typical or non-typical. Harris and Ioannou (1998) reconciled the work on location-based planning done by others and highlighted that one cannot minimize the duration of a schedule while maintaining continuity of resource use at all times.

Much work related to methods of location-based planning has been done by Kiiras (1989) and Kankainen (e.g., Kankainen and Sandvik, 1993). That work was based on planning to manage schedule risk through continuous flow of work and control aimed at reducing interference. Over 30 action research case studies were documented in masters' theses.

Frandson and Tommelein describe the practice of another location-based planning method, Takt time planning (TTP).

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LBMS Planning Method

Kenley and Seppänen (2010) developed their Location Based Management System (LBMS) by building on the work of Kiiras and Kankaninen. Their innovations on the planning side include (1) layered logic and (2) calculations adapted from CPM that make it possible to optimize the schedule while allowing the enforcement of continuous work. Flowline remains the means to visualize schedules.

As starting data, LBMS requires the Location Breakdown Structure (LBS), tasks, quantities for each location and task, labor consumption rate for each quantity item, workhours and workdays (calendar) for each task, optimum crew composition for each task and logic between tasks. Tasks can include several locations of similar, repetitive work in sequence of production. By default, the schedule calculation is based on achieving continuous flow by delaying the start date of early locations (Kenley and Seppänen, 2010, pp.123-162).

Kenley and Seppänen (2010, pp.204-213) present guidelines for defining the LBSs of a project. LBS is a critical planning decision because it impacts the quantity take-off, the number of logic relationships required to schedule a project, as well as variation of quantities between locations. LBMS calls for physical, clearly defined locations so that there is no ambiguity about location boundaries. Kenley and Seppänen (2010) propose that the same LBS should apply to all or most trades, and certainly to all trades in the same phase. For interior work, they recommend dividing locations by type of space (e.g., office vs. corridor), because different trades' working different functional spaces with different logic and different quantities. These spaces can be grouped by location and then type (e.g., North patient rooms vs. North operation rooms). Finally, they propose eliminating implicit buffers by planning small locations and using finish-to-start relationships. Implicit buffers arise when locations are large enough for multiple trades and finish-to-start relationships are used because it would be possible to start the successor earlier without causing interference. Seppänen, Ballard and Pesonen (2010) proposed that LBS be defined in a collaborative process involving trades in Last Planner® phase planning meetings.

Tasks are defined based on work (1) that can be completed by one trade in a location before moving on to the next location, and (2) that has the same external dependencies to other tasks (Kenley and Seppänen, 2010, p.216). Tasks and dependencies can be planned collaboratively in phase planning meetings. Typically, logic will be defined separately for each space type (e.g., corridors, office rooms, operation rooms, etc.) because the required logic may vary (ibid, p.219). In practice, this requires a different phase plan for each space type (but not for different locations including several spaces with the same type).

Seppänen, Ballard and Pesonen (2010) recommend that between two phase planning meetings trades collect quantity data and labor consumption rates. Trades estimate quantities for each identified task in each location and labor consumption (manhours/unit) for each quantity line item. A task can contain multiple quantity line items if there are different types of work performed by the same crew in the same location (e.g., large vs. small diameter ductwork). The selected labor consumption should be the optimal rate for production of the work for optimal crew (the natural rhythm as defined by Arditi, Tokdemir and Suh, 2002). This rate assumes that all the prerequisites of working will be available, and workers will be able to work continuously without interference from others (Kenley and Seppänen, 2010, p.218). The goal of LBMS control mechanisms is to ensure that these optimal conditions are achieved for as many trades as possible, prioritizing tasks with high manhour content.

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Optimization is done collaboratively with trades in the second phase planning meeting. The starting point of the meeting is a location-based plan with one optimal crew for each task. This will result in a plan with tasks, some progressing at a gentle slope and others with a steep slope in a flowline diagram. In the meeting, workflow is optimized by starting with trades that have the gentlest slopes, so-called bottleneck trades (Seppänen, Ballard and Pesonen, 2010). The available optimization tools in order of desirability are (1) changing slopes by changing the number of crews or scope, (2) changing location sequence, (3) changing soft logic links, (4) splitting tasks (planned breaks), (5) making tasks discontinuous, (6) splitting tasks into smaller tasks with separate crews across multiple locations or (7) improving task performance through waste reduction. The goal is to find a common slope for each phase (Kenley and Seppänen, 2010, pp. 221-230).

Finally, meeting participants analyze schedule risks (the likelihood of a delay occurring) and add time buffers so control actions can be taken if needed. The goal is to find a schedule with minimum cost that achieves the duration target and has an acceptable risk level. They may analyze the risk level through Monte Carlo simulation or qualitatively based on decisions taken to achieve the required slope. Risk is minimized first by trying to minimize variation. To account for any remaining variation, buffers are added between the tasks to protect hand-offs. Buffers can be time buffers or capacity buffers in the form of a larger crew size or an available overtime allotment. Their size depends on variation of the preceding task, the dependability of the trade, and the total float of the task (Kenley and Seppänen, 2010, pp. 233-239). Simulation can be used to inform buffer sizes. Where variation is unknown, buffers can be placed at the end of the sequence to be added where needed in the sequence as variation is discovered. In terms of social process, Seppänen, Ballard and Pesonen (2010) propose that buffer sizes are discussed in the optimization meeting.

TTP Planning Method

One source of variation that is driven out through the design of zones is the variation in work density. "Work density" refers to the situation in an area on site based on (1) the amount of work required by one trade in a particular area, (2) the trade's crew sizing and capabilities, and (3) the trade's means and methods (when prefabricating off site, the work density decreases). As such, some areas have a higher work density than others (e.g., compare electrical work in a lobby compared to an operating room). Different trades will have different work densities as well. Thus, through data collection and design of the zones this work density variation from zone- to-zone and trade-to-trade can be reduced.

The data to gather in conversation with the trades is specific to them, their work, and the project context. How do they want to move through this project's space? What alternatives are available? What are the material and manpower constraints, or work method alternatives? What work needs to be performed before they start work? What is the sequence of work internally (e.g., electricians want to set trapezes, run conduit, and then pull wire)? Can the sequence be split, or can the work be performed in a later phase (e.g., does the electrician have to pull wire immediately after the conduit is run)? Trades may color up plans in order to show their desired workflow, what can be completed and when and under which assumptions. In order to understand the set of options deemed feasible for a trade, though perhaps not optimal from their perspective, alternatives must be discussed with each trade so as to allow for a set-based approach in developing the phase schedule. Each trade's set of options can then be tested against the sets of options available to other trades, so as to develop a combined plan that is better for the project

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as a whole than could have been obtained had each trade individually offered only their most-preferred option, or had the GC pushed a schedule on the trades to comply with. A GC schedule embodies too many assumptions and constrains the trades' abilities to do what they do best. Better plans can be developed when the team is incentivized to address the "Who pays and who gains?" question with overall project optimization in mind.

The trade representative in the conversation must be able to provide this level of detail, e.g., the foreman able to commit to doing the work. The benefit to planning early with these details is that people develop deep understanding of both their production capabilities and the resulting plan from the collected information.

LBMS Control Method

The control method of the LBMS includes monitoring progress, calculating performance metrics, and forecasting future production based on actual production rates. Alarms are calculated when there is a risk of interference between trades (Seppänen, 2009). The forecast is adjusted to prevent production problems by planning control actions (Kenley and Seppänen, 2010, p.254). The analysis of alarms can be done by a dedicated production engineer who identifies any deviations, prepares material for team review, and facilitates a control action planning session with trades to get commitments to implement control actions (Seppänen, Evinger and Mouflard, 2014). The development of the forecasting method and empirical research on its effectiveness in addressing production problems has been researched by Seppänen (2009) and Seppänen, Evinger and Mouflard (2014). It should be noted that this system is based on having time to react with control actions before interference happens. This requires buffers in the location-based plan.

LBMS control includes tracking of actual production rates and labor consumption at least weekly, but preferably daily for any tasks affected by committed control actions. Progress data is self-reported by trades and validated through site walks by the production engineer and superintendents (Seppänen, Evinger and Mouflard, 2014). The root causes for any deviations are analyzed. Main deviation types are start-up delays, production rate deviation, splitting of work to multiple locations, out-of- sequence work and interrupted work (Kenley and Seppänen, 2010, pp.346-348). The impact of deviations is analyzed by the production engineer using the schedule forecasts and alarms and validated with the superintendent(s). Finally, the production engineer initiates a collaborative control action process involving all affected trades to get back on track (Seppänen, Evinger and Mouflard, 2014). Possible actions include changing the production rate, changing the work content of the task, breaking the flow of work, changing the location sequence and overlapping production in multiple locations (Seppänen and Kankainen, 2004). Impacts to workflow, while control actions are taken, can be mitigated. For example, resources can be assigned to work on workable backlog tasks if they would otherwise need to leave the site (Seppänen, 2014). Additionally, having go-back work within the location which become part of a separate sequence.

If there is insufficient time to react with control actions or control actions are not taken, an alarm can turn into an actual production problem. Production problems can be (1) start-up delays (a trade is unable to mobilize when committed), (2) discontinuities (a trade demobilizes), or (3) slowdowns (a trade's production rate decreases due to interference) (Seppänen, 2009). If (1), the forecasts are used to pull the trade on site when locations are available. If (2), the forecasts are used to find out a suitable return date. If (3), one of the trades will get to own the location and the other(s) must work on

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workable backlog or demobilize. All these decisions are made collaboratively with the trades based on the production engineer's input.

Research Methodology

An explanation of our research methodology follows; how we tried to reduce those gaps in knowledge identified in the literature review.

A team of Lean leaders came together to brainstorm enhancements that could be made to the Last Planner System® since its inception 20 years ago in 2000. This team was comprised of Academics, Consultants, Design Professionals, General Contractors, Owners, Researchers, and Trade Partners. All participants held common attributes: extensive experience implementing the LPS®, advocacy for process improvement to maximize value, and a desire to share lessons learned.

This brainstorm resulted in a series of topics that were not addressed or included in the original Last Planner System® ("LPS® Process Benchmark 2016"), and the team agreed to pursue further research:

- No formal benchmarks within LPS
- Users are not forced to have a critical conversation around project batches of work for planning
- There is no common language amongst project teams
- There is a lack of common expectations of hand-offs.

The team split into four sub-groups to research enhancements to incorporate in a refined iteration of LPS ("LPS Process Benchmark 2020".) One such group explored Location-Based Planning (LBP) – a process to determine smaller batches of work, resulting in increased predictability, schedule reliability, and team alignment.

- We met every 2-3 months for ~6 months. The outcome of these meetings was an A3 describing the problem statement, current state, ideal state, and action items to reduce the identified gap.
  - Problem Statement: Last Planner System Process Benchmark 2016 does not develop a work structure for design and construction phases.
  - Current State: Phases of projects are not broken down into useful parts, which provide a better opportunity for design and construction to have alignment.
  - Ideal State: A common language exist between all relevant teams, which allows for improved planning and project alignment.
  - Action Items: Develop questionnaire for subject matter experts, perform case studies, develop how to guidelines for improved version and update the benchmark.
- First, we created simple "How-to Guidelines" to provide steps required to implement Location-Based Planning based on our experience.
- To validate and inform these Guidelines, we identified Subject Matter Experts across the industry from whom we should seek feedback.
- We developed a series of questions to ask SME's to ensure consistency and set up phone calls to interview each SME.
- We held interviews – all audio was recorded with Interviewee's consent – and later transcribed them for reference.

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Interviews

The experience level of our subject matter experts is below.

- General Foreman – 33 years, Mechanical Contractor
- Superintendent – 20 years, General Contractor
- Superintendent - 43 years, Drywall Contractor
- Construction Executive – 20 years, Electrical Contractor
- General Foreman – 32 years, Mechanical Contractor

Interviews with subject matter experts (what does the data tell us?)

The team interviewed 5 subject matter experts in both the CM and trade partner roles with experience on a variety of projects using location-based planning methods. The results of those conversations are organized by the research questions established by the team.

The methods used by the SMEs combined practices from both Takt time planning and Location based management. The process described for establishing areas was consistent with the methods described in the literature review on LBMS planning method. Of particular note was the consistency in the order for breaking down the project to establish areas. The project was first broken into phases of work, where phases refer to work between typical project milestones involving a group of interacting trades and tasks. Then work was broken down into area types with similar work dependencies. Those area types were then broken down into a preliminary area breakdown, which was refined based on any new information determined as the project progresses from actions such as first run studies, mock-ups, time studies, further investigation into scope, input from other stakeholders, actual production rates, and etc.

Collaborative sessions with all trades involved in a given phase of work were the preferred method for establishing area breakdown. The SMEs also heavily emphasized the importance of using visuals for better communication during the area planning sessions, such as plans, coordination drawings, line of balance diagrams and models, in addition to the criticality of having good detailed quantity, labor consumption, and optimal crew size data. In addition, the SMEs mentioned the following as factors to consider in area breakdown: 1) Logistics for the flow and placement of resources for the area and the flow of waste from the area; 2) Systems considerations such as working out from or to risers, how to treat vertical work, and ending at valves or fire dampers for testing.

However, when the CM was not facilitating the area breakdown area determinations can be made by the trades individually and may not be coordinated. SMEs from trade partners focused on balancing the work density between areas and leveling manpower requirements while SMEs from CM firms mentioned a variety of buffering strategies for dealing with variation in work density between areas while also being concerned with leveling manpower requirements. Those buffering strategies included: 1) using overtime for higher work density areas; 2) having crews working on backlog work with float so that manpower can be pulled from those tasks to supplement other crews working in higher work density areas.

Methods of area breakdown optimization were also consistent with the description of LBMS in the literature review. SMEs mentioned: putting bottleneck trades first in a sequence to more easily control WIP; using bottlenecks to determine pace and area size, using multiples of the ideal crew size to balance the pace of work between tasks; and considering the sequence of work progression through the areas for WIP control. A topic where the SMEs provided additional information was in area sizing. One trend in area sizing based the area size on a week's worth of work or multiple of a week to align with

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the LPS weekly work planning cycle. A similar method not mentioned by the SMEs is basing the area size on a day's worth of work to align with the LPS daily check-in cycle. Another trend in area sizing was to progressively divide a site or floor plate in factors of 2, i.e., halves, quarters, eighths, and etc. Likewise, areas where refined splitting each area in two areas, as actual production data was established and stabilized.

Findings

From the interviews the following were found to be helpful in effective Location Based Planning (LBP):

Effective LBP Practices

Align the Information Supply Chain

Getting a design team to understand what location based planning is and why it is a powerful tool for project delivery: you have an opportunity for them to finish their design to the quality you need in a structured set of packages individually delivered in time to support your construction phase location-based plan. Additionally, you have the opportunity to align system breaks with the LBP such as MEP loop and valve locations or expansion joint locations.

Focusing on factors outside the work itself to connecting them to LBP. Such elements as:

- Ensuring all required submittals are ready
- Ensuring all design, inspection and constructability questions are answered
- Ensuring all logistical material supplies and storage questions are answered
- Ensuring vendors outside the project site that supply materials to the project are on-board with the LBP plan and can support it.

Clarify Conditions of Satisfaction

- Individual trades first develop a fairly complete understanding of their own work.
    - What is their scope?
    - What are the quantities?
    - What are their production rates?
    - What areas of work / tasks are repeatable?
    - How would they like to build their work?
    - What they need to be complete before they go into these areas?
- Taking the time to be explicit and clear about what each trade's conditions of satisfaction are for being able to start their work in zone when they enter it.
- Taking the time to be explicit and clear about exactly what work will be finished to what standard as each trade leaves each zone.
- Taking the time to understand the work and share how each sees their work creates empathy and cohesion.

Collaboratively Plan Work & Clearly Communicate Plan

- GC facilitating the discussion and building the schedule from the ground up with the trades:

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- The GC may have a tentative high-level master schedule with major trade specific milestones based on their experience, but this is to get the conversation going.
- GC respectfully challenging trades on production rates to uncover who is being unreasonably optimistic and who is being unreasonably conservative – therefore good knowledge of actual quantities and actual proposed crew sizes and skill mixes is needed.

- Taking the time to respectfully challenge each other assumptions uncovers opportunities and problems.
- Trades using visual methods to describe to their fellow trades their work, quantities, production rates and how they would like to flow their team through their work.
    - Typical method is to color up zones and highlight systems with highlighters on printed plans.
    - Team created 'color-ups' that show what work is being done where, when by which trade team.
    - This is typically easily turned into a colored, easy-to-understand line-of-balance and/or takt plan in an Excel sheet.

Embrace Continuous Improvement

- Using first-run studies to test out production assumptions well ahead of the main build work.
- Treating the first few cycles as learning cycles necessary to finalize the plan – creates great improvement in the plan. Examples: resources, sequences, material flow, durations can be tweaked. It is good practice to add buffer for the first few cycles to accommodate early learning.
- Treating the first few cycles of the build and learning cycles and observing them closely – in order to quickly correct the plan, or behaviors.
- There should always be learning from variances, but it is particularly critical in the earliest stages as this is where the biggest corrections are needed and where team buy-in to the process needs to be maintained and sustained.

Develop a Contingency Plan to Address Variance

- Identifying workable backlog to allow the team to adjust to variation in the complexity of the work from zone to zone with less variation in crew sizes.
- Creating a separate team to deal with small amounts of constrained work and otherwise unfinished work in a zone allows the main team to keep moving to the next zone without disrupting the flow of the whole team. This could be called a 'go-back work' team.
- Having an allotment for overtime to be used to protect zone hand-offs.

Outcomes of Effective LBP Practices

Heavy investment in the time and work to get the LBP plan right is well worth it. You get back way more than you invest:

- Far greater certainty across the team on how much of the project is actually complete:
    - You have to fully complete each zone before moving on, so it is easy to visually show how complete the project is

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    - You have an agreed duration per zone, so it is easy to know if the trade or project is ahead or behind schedule
    - The zones and durations are typically in the range of days (small projects) or a few weeks (large projects), so you have many opportunities to make up time if a zone starts to track late or finishes late.
- The discipline of this approach forces much earlier discussion of unclear scope and project boundary issues. For example: where the boundary is between a Core & Shell project and a simultaneous or overlapping T.I. project.
- Far faster identification of scope and schedule issues:
    - As soon as the first crew is through the first zone, you know to the day how early or late you are
    - This continues to be true as every crew leaves each zone, and you get information from the next crew as to whether the zone they are entering is fully ready for their work
    - Creates the opportunity for frequent small batch correction to variances.

Project References

A significant part of our research derived from 5 subject matter experts. All were on various projects with different delivery methods, contract sizes, with each holding leadership roles that impacted how work was put in place. Below is a brief project description.

Project 1: 1.1 Million Square Foot Campus Project, Sunnyvale, CA. Design-Assist delivery method with functioning Big Room, use of Last Planner System, IPD behaviour, with Cost Plus, GMP contract. The general contractor took the lead on promoting the right behaviours and encouraged full participation from all trade partners. The owner was equally engaged in the project and daily issues. With the help of a progressive consultant, the teams met weekly for Pull Planning and coordination, weekly Gemba Walks, and Daily Huddles. Visual aids were utilized to communicate progress, illustrate complex details, and promote comradery.

Project 2: 1 Million Square Foot Hospital Project, San Francisco, CA. Full scale IPD contract with major MEP's as trade partners. Design-Assist delivery method with EOR collocated in Big Room. Effective use of all primary Lean Tools, including Last Planner System, Daily Huddles, Gemba Walks and use of visual aids. Highly collaborative owner, GC, and major trade partners with a positive one team environment.

Project 3: 450K Square Foot Hospital Project, San Francisco, CA. Full scale IPD contract with major MEP's as trade partners. Design-Build delivery method with EOR collocated in Big Room. Use of Lean Tools with highly engaged Project Team.

Project 4: 46-story office building in San Francisco, CA. Cost Plus, GMP contract, with Design-Build delivery method. Use of some Lean Tools, including Last Planner System and Big Room for major MEP's.

Project 5: 21-story office building in Sacramento, CA. Cost Plus, GMP contract, with Design-Assist delivery method. IPD behaviour from Project Team with use of Lean Tools, including Last Planner System®, Big Room, Daily Huddles and use of visual aids for coordination.

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Guidelines

The key differences between LPS® Process Benchmark 2016 and LPS® Process Benchmark 2020 correspond to work structure, trade handoffs, and trade clashing:

	LPS Process Benchmark 2016	LPS Process Benchmark 2020
Work structure	None specified	Location based work structure
Handoffs between 'trades'	Completed tasks	Completed areas
Avoiding 'clashes' between trades	Task by task	Area by area (trades have areas to themselves)

A key issue in planning any type of production is coordination between interdependent players. Thinking about the construction work in a project, there are three key elements to coordinate: design, deliveries and site production. Design provides essential information and offsite suppliers provide essential materials. Site production combines information and materials to construct whatever is being built, which requires coordination of the interdependent trades. Since site production is the customer for both design and offsite suppliers, the work plan for site production should be the starting point in optimizing work plans for project delivery across design, supply chain and site production. Guidelines are provided below for each of these.

- Develop a provisional location-based plan to include in requests for proposal/bid, with words to the effect that the plan will be reviewed and hopefully improved in collaboration with bid 'winners'.
- How does location-based planning fit into the Last Planner System?
  - Location-based planning coordinates the work of everyone involved in the project by specifying not only when each player (designer, constructor, supplier) needs to perform what work, but also where that work is located. This is accomplished using visual controls, which are known to be the most effective means for coordination.
  - Location-based planning will help initiate appropriate planning conversations based on a scope of work. Work that is broken into small batches and planned will promote better alignment. Location-based planning becomes an additional step in the Last Planner System to force these types of conversations. As a result, teams will see this integral step of collaborative planning as part of the process to execute the Last Planner System.
- When should location-based planning be used?
  - Location-based planning creates a more visual plan. Visual management is known to reduce variation in productions systems, especially related to communication. Thus Location-based planning can have benefits for any project where clear communication across a large number of stakeholders is important.
  - Location-based planning should be used when there is a significant amount of systems, floors, areas or complexity in a project, where it becomes prudent to collapse the work into smaller batches to better plan and manage the flow of work.
  - After determining that location-based planning is appropriate for a project, plan out the physical breakdown structure as soon as the team understands the schematic design, and project phases and priorities.
- Who is involved?

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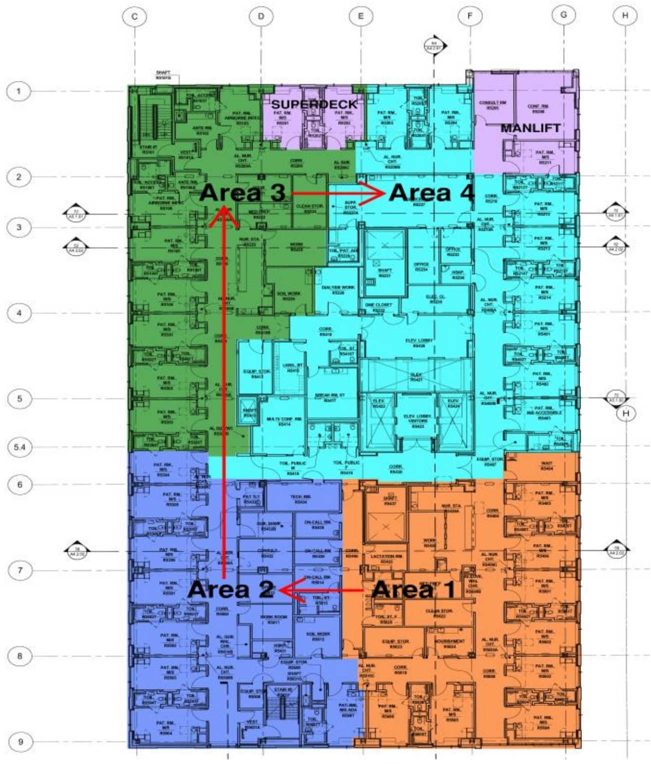
  - All major Trade Partner Project Managers, Superintendents and Foremen, General Contractor Superintendents, and Designers and key Suppliers when possible.
- What to plan?
  - Hold separate planning sessions for each construction phase of work with applicable scope drawings and models.
  - Note: Plan commissioning and testing by sub-system and system as opposed to location.
- How to select production areas within a construction phase, e.g. interior framing/utilities rough-in?
  - Choose areas that best level out the workflow and equally distribute scopes for each trade.
  - Note: Each trade should optimize their resources to meet their volume of work in each area.
- What is the process for producing a location-based plan?
  - When defining areas, dividing lines should normally follow natural breaks in the building architecture and systems breaks.
  - An exception is when doing so makes the variation in trades' amount of work from area to area so extreme that the loss of capacity cannot be sufficiently recovered by removing some areas from the location-based plan and reserving it as fallback work (see 11. following).



  - It is often helpful to do a modified pull plan in order to determine the sequence of trades; especially when trades have to return to an area later in time.
  - For a possible area or system:
    - Estimate quantities for each trade.
    - Get buy-in from key stakeholders.

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   - Develop plan to execute on work.
   - Use the PDCA Cycle to refine the plan.
- What does a location-based plan look like?
  - It can look like a completed Pull Plan. Essentially, the location-based plan identifies responsible parties, and how work will be executed.
  - What are the different types of location-based work plans?
    - Areas tend to be different for different phases of construction. For example, in the structural phase of work for a steel building, the installation sequence in substructure is likely based on the desired sequence for superstructure. Therefore, pile caps may be needed in the SW corner moving clockwise in units that enable erection of parts of the superstructure that are self-supporting. Alternatively, during the interior framing phase of work, areas are likely to be specified in terms of space enclosures: rooms, corridors.
    - The simplest location-based work plan specifies areas (collections of pile caps) to be completed in a prescribed sequence.
    - The next simplest location-based work plan (LBMS) also specifies areas to be completed in a prescribed sequence but adds consideration of the relative rates of completion of involved trades, in an attempt to avoid clashes. [see Fig. 1]
    - The third type of location-based work plan is called takt planning, which does the same as the above, but adds an explicit release of areas between trades, creating a 'parade of trades' moving through the same sequence of production areas and completing each area within a specified (takt) time; e.g. 5 working days [see Fig. 2]
- How to buffer a location-based work plan to accommodate expected variation?
  - All buffer types can be useful: capacity, time and inventory.
    - Capacity buffers involve having more capacity available than is needed to do the planned work. Even when there is no difference in the amount and type of work for a trade in an area, there is normally some variation in production time. That type of variation is routinely accommodated by having slightly more capacity available than is normally needed, as recommended in the Last Planner System. If, in addition, there are differences in the amount of work to be done, more capacity is needed to accommodate that variation.
    - Time buffers can allow recovery from delayed completions that were not avoided (see 13d. following), and to take time to reconfigure the location-based work plan and restart (see 14. following). These schedule buffers should be placed at the end of a construction phase and used as needed.
    - Inventory buffers can be provided by reserving specific areas as fallback work, or workable backlog, for each trade in each construction phase. While this removes some areas from the location-based plan, inventory buffers allow productive use of otherwise lost capacity.
    - Other uses for otherwise lost capacity include problem solving (e.g., 5 why analysis of plan failures or safety incidents), training, and first run studies

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(designing methods for performing construction operations to be tested in the first instance of that type of operation).

- How to control location-based work plans?
  - Align project controls to the same areas and flow of work.
  - Keep communication and documents as visible as possible; build a common language around production areas. [show examples]
  - It is critical for day-to-day work to remain disciplined to and respect the production areas for the system to be successful.
  - Despite best efforts, failures to deliver areas as planned may occur, so a procedure is needed for handling them.
    - First, determine why the work is delayed. Is there a design or delivery constraint that needs to be solved before the work can be completed?
    - If not, consider these two options for completing the work 'now'. Option 1: two trades that working in adjacent areas can coordinate across area boundaries. Trade A is scheduled to release the area to Trade B but has not completed the work. Supervisors for those two trades may find a way for Trade A to complete its work after Trade B begins its work in the area without the two interfering with one another. This practice is a good proactive method to create an additional time buffer. Having trades find ways to plan their work in smaller batches then the location areas themselves allows for release of partial areas if needed creating the time buffer. For example, the Trade A's incomplete work may be in a part of the area where Trade B will not be working immediately. Trade B determines whether this is feasible. If infeasible, move to Option 2: Trade A must complete the work ASAP using overtime or weekends.
- Can location-based work plans be changed?
  - Once a given location-based work plan is put in place, experience may reveal needed changes. If all key stakeholders agree, production areas may change to incorporate learning and best practices.
- How to pull the design schedule?
  - Conversations between design and construction should follow the reliable promising process, with construction making requests and design responding. The objective is to agree on the plan that is best for the project and align the information flow from design with the production schedule.
  - The development of design can be planned to release information needed for procurement and construction; not necessarily Released for Construction, but rather released for specific uses by Construction, e.g., selection of lifting equipment.
  - The detailed engineering phase of design can be structured based on locations.
- How to pull the schedule of deliveries?
  - Developing production plans that align design, procurement, offsite suppliers and onsite construction looks a bit like the design problem of agreeing criteria for interdependent disciplines: mechanical, electrical, structural, architectural. This interdependency requires collaboration in planning. It doesn't work to simply have construction declare its desired

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work structure for a given construction phase and dictate it to everyone else. Designers and offsite suppliers can only do what is feasible. The objective is to find that balance between the 'perfect' plan and feasibility that is best for the project.

- The challenge in pulling deliveries increases with the number of different offsite suppliers, especially those that engineer-to-order and fabricate their products. Engaging these key suppliers in the planning conversations from the very beginning is highly advised, and of course requires that those suppliers have been awarded contracts, or perhaps are among the client's or construction manager's preferred suppliers.

Fig. 1

Foundation Labor breakdown by Pour

Pour #	Approx CY QTY	Man Days	Est. Hours	Act. Hours	% Complete
1	684.0	141.8	1,134.0	756.3	100%
2	456.0	135.5	1,084.0	588.5	100%
3	585.0	135.4	1,083.0	676.3	100%
4	603.0	128.5	1,028.0	791.5	100%
5	747.0	140.0	1,120.0	694.5	100%
6	765.0	135.4	1,083.0	638.8	100%
7	775.0	129.8	1,038.0	366.8	100%
8	474.0	128.5	1,028.0	127.5	45%
9	206.0	100.6	805.0	42.0	5%
10	326.0	110.0	880.0	256.8	60%
11	454.0	123.5	988.0		
12	434.0	126.1	1,009.0		
13	524.0	135.4	1,083.0		
14	562.0	129.3	1,034.0		
15	607.0	139.5	1,116.0		
16	676.0	148.9	1,191.0		
	8,878.0	139.2	16,704.0	4,938.8	51.98%

Figure 1: Starting with the Plan

Fig. 2

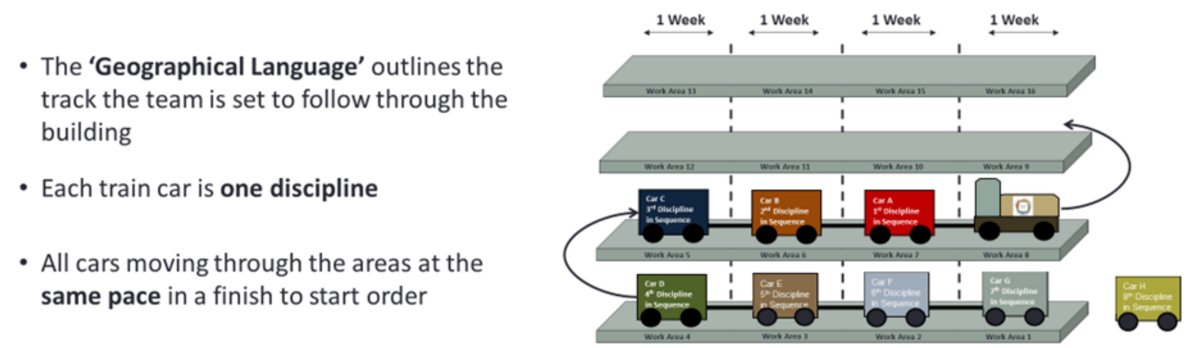

Figure 2: Takt planning

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Conclusion and Recommendations for Future Research

After review of our research findings, below is a list of conclusions. Note: Some conclusions were recognized prior to research, and our findings simply confirmed them.

Projects perform better when General Contractors utilize the experts (i.e. design and trade partners) they hire to assist them with schedule accuracy and coordination. To optimize experts' contributions, General Contractors should educate design and trade partners on using Lean tools and processes.

Align all trades to the same work structure to develop a strong production system. Projects that are broken down into the parts that will be used for planning, material flow, information flow, and safety reviews are much better equipped to succeed. This should be done early and with the right people who can clarify the build sequence.

The ideal state is to make sure that there is a common understanding of the scope and batches so that production areas can be established prior to any detailed phase planning and lookahead planning. Doing so will allow all resource flows on the project to use the production areas to align their efforts. Additionally, collaborative planning builds cohesive and emphatic teams:

- Design partners and vendors should sit in construction planning meetings to better understand how to provide the right information at the right time.
- Trade partners learn from each other when sharing their preferred sequence and methodology of installation, thereby opening the channel of communication to optimize flow for the entire project.

Successful project teams have a learning culture and are willing to test small and fail early and often. Embracing and encouraging a culture of continuous improvement is crucial to developing a reliable and sustainable systematic plan.

Recommendations for Future Research & Action

Based on findings, we have outlined recommendations to help scale the process of location-based planning across more projects:

- Develop a document that includes How-to Guidelines for location-based work structures planning and impacts to LPS upstream (phase planning) and LPS downstream (lookahead planning) steps.
  - Leverage content from Interviews
  - Consolidate Findings by project type, scale, and region to identify trends
  - Seek feedback from and engage Design Partners to ensure the design community is represented accurately and wholly in this research.
- Update standard LPS training material to include location-based work structures.
- Update standard LPS definition to include the location based-work structures step into the current benchmark.

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Appendices

The following are the questions asked of the interviewees:

Background

1. What is your name?
2. Who is your current employer?
3. Who have you worked for previously implementing LPS?
4. On how many projects have you personally implemented the Last Planner System?
    a. Note this means implementation of most of the Should-Can-Will-Did process as outlined in the P2SL Benchmark Document
    b. What is the range of size of these projects?
    c. What, if it's possible to say, was the approximate average value?
    d. What types of project? (e.g. Health, Education, Commercial etc.)
5. For how many years have you been implementing LPS – from when you first started to implement a part of it, until today?

General Questions

1. Can you name a few ways you have officially incorporated a location or zone into your planning for designing or installing work?
2. How has that type of planning assisted in structuring the work amongst the impacted design teams or trade partners?
3. What best practices/lessons learned have you gained from Location Based Planning?
4. How does using The Last Planner® System along with incorporating a location or zone type planning effected your scheduling of work?
5. What are some key factors for executing Location Based Planning successfully?
6. What are some key factors for not executing Location Based Planning successfully?
7. How have other design teams or trade partners responded to implementing Location Based Planning?
8. What are your suggestions on how to best introduce Location Based Planning to a project team?
9. What are your suggestions on how to best align the work scope amongst the design team and/or trade partners when using Location Based Planning?
10. Can this step be utilized in the design phase effectively? If yes, please list a few ways.

Specific Questions about Interviewees Current Practice

11. Describe your project team's planning process
    a. How is the work product organized? By "location", by "team", by "system"?
12. Do the areas identified in the design phase of work and in the construction phase of work differ?
    a. What challenges arise as a result of the difference?
    b. What opportunities have you found in aligning areas for both design planning and for production planning?

2. Who do you involve determining areas for design planning? For production planning?

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3. What tools do you use to determine areas for design planning? For production planning?
4. Do you hold separate sessions for each phase of work with applicable scope drawings and models? Do you hold interdisciplinary planning sessions? How do these planning sessions inform each other?
5. How do you optimize areas that work best for installation?
6. How do you choose areas that best level out workflow and equally distribute scopes for each phase?
7. What tools aid in building a common language on the project?
    a. How do you leverage visual management to build a common language and align around common expectations on the project?
8. Have you observed deviance from the agreed-on design areas / production areas established by the project team? If so, how did you correct this deviance? If not, what are some lessons learned that you could share to ensure no deviance?
9. Have you changed production areas based on project team participants' feedback? If so, please provide an example(s) and explain how the team determined this was a good change.
10. How have you worked with operations staff, vendors and suppliers to align project controls and overall supply chain to the same areas and flow of work?

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