

Current Process Benchmark for the Last Planner® System

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Outline of the Current Process Benchmark for the Last Planner System

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A. P2SL Current Process Benchmarks

The University of California Berkeley's Project Production Systems Laboratory (P2SL) periodically publishes a description of the current benchmark in each project management process that is a subject of research. This reports on the current benchmark for the Last Planner System (LPS) for project production planning and control.

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Current process benchmarks are developed with industry practitioners to best incorporate the latest advances in both theory and practice. Consistent with the lean philosophy of continuous improvement, each publication of a process benchmark includes a description of the research needed to surpass it.

We understand LPS, at the level of functions, presuppositions, principles and processes, to be a specification for project production planning and control--not a specific way to plan and control production on projects, but the requirements any specific 'way' must meet in order to be valid. That said, this benchmark can be understood as a "Current Benchmark for Project Production Planning and Control Systems".

We do not want to be overly prescriptive in our description of any management process, including LPS, both because we do not want to discourage experimentation and because it is impossible to specify exactly what needs to be done in every possible context. Our goal is to be sufficiently descriptive of the System so that users can understand its fundamentals; namely, functions, presuppositions, principles and processes, and so be better able to specify methods and tools to accomplish the functions consistent with these fundamentals.

To that end, in the following we first provide a brief history of the development of the LPS, explaining why it was invented and why it is needed. The subsequent sections describe the functions LPS is designed to perform and its presuppositions (what's held to be true about the world in which functions are to be performed), From these, principles (behavioral guidelines for executing functions given the presuppositions) are inferred. Next processes are described to explain how the functions are linked together to make a system, and finally we describe the methods used to perform the functions within processes consistently with presuppositions and principles.

Recognizing that a standard practice must extend to the level of tools, and that each organization needs to have standards for project production planning and control, we list the elements to be specified in developing a standard. (See the section below on Implementation).

Readers of this document may come at from different angles. The structure was established for readers who want to have a sufficient understanding regarding the WHAT and WHY of the Last Planner System to be able to make reasoned decisions whether to embrace it, or to evaluate their own implementations of the System. Those looking more for HOW to do it may want to first read Sections F, G, H and K (Processes, Methods, Design and Deployment, and Frequently Asked Questions), then return to the remaining sections.

We understand that the Last Planner System can and is being used in a variety of applications, but in this work, we assume that it is applied in a construction project, both in designing and constructing. Methods used only in designing or constructing are tagged as such.

A glossary of terms is located at the end of this document. Terms in the glossary are italicized on first use.

B. Why Last Planner?

A distinction is commonly made between 'planning', in the sense of designing ways to achieve objectives, and 'control', putting plans into action to cause objectives to be



achieved. The Last Planner System (LPS) was created, in the early 1990s, as a system for project production control. *Production control* was thought to be a missing piece in an otherwise complete project management toolkit, which was dominated by *project controls*. The job of project controls is to set cost and schedule targets in alignment with project scope, and to monitor progress toward those targets. The job of production control is to steer toward targets; to do what can be done to move along the planned path, and when that becomes impossible, to figure out an alternative way to achieve targets.

Both are needed. They are two sides of a coin. Project controls without production control is like driving while looking in the rear view mirror. Production control without project controls is like driving with no destination and no awareness of remaining distance or fuel.

The initial equation of LPS with production control has changed over time. Growing awareness of traditional scheduling's failures in setting detailed time and cost targets provoked partial addition of that function to LPS in the late 1990s; "partial" because *pull planning* may be used to detail plans at every level of *task breakdown*, but project cost and schedule targets (budgets and completion dates) are set outside the Last Planner system.

The inspiration for LPS was the discovery of chronically low *workflow reliability* in construction projects. Consequently, the first step in its development was to improve workflow reliability, to increase the match between DID and WILL; i.e., to learn how to do what we say we're going to do. Beginning in the early 1990s, that was done through meetings with front line supervisors to produce coordinated weekly work plans, following the rule to include on weekly work plans only tasks that are well defined, sound, sequenced, and sized to performer capabilities³.

That was successful. *Percent Plan Complete* (PPC) improved as did labor productivity. But it also became apparent that PPC could be 100%, productivity excellent, and a project still be falling behind schedule. Recognizing that project progress toward scheduled completion dates rises and falls with PPC only when tasks are made ready in the right sequence and rate⁴, a *lookahead planning* process was added to LPS so what SHOULD be done CAN be done when needed⁵.

Once lookahead planning was in place, both project cost and schedule performance improved, but it became apparent that scheduling could be done better. Too often, what SHOULD be done according to the project schedule either could not or should not be done to best accomplish project objectives. This took LPS beyond its original production control functions. Once effective lookahead planning revealed the inadequacy of scheduling, *pull planning* was added to LPS, initially to detail the milestone-level master schedule, phase by phase (*reverse phase scheduling*). Soon collaborative pull planning came to be used to

³ See e.g. Ballard & Howell, 1998.

⁴ Whether or not the rate of progress is adequate is a function of the amount of capacity relative to demand. See Presuppositions below.

⁵ Lookahead planning was done in construction well before Last Planner, but has tended to be a dropout from a higher level schedule, assuming that all tasks will be fully sound and capacity to perform them will be sufficient. As such, traditional lookahead planning served as an early warning of mobilization—'You're going to start the walls in the basement three weeks from now, right?'. This is not a question to which "no" is an acceptable answer! The lookahead planning process in the Last Planner System has the job of identifying and removing any remaining constraints on scheduled tasks in the lookahead period. If constraints cannot be removed, the task is rescheduled for a later date when constraints will have been removed.

at every level of *task breakdown*: project (master schedules), phase, process, operation and step.

Last Planner System Insights

Through the years, reflection on implementation experiences has produced important insights. Here are a few; some of which, like the first below, were greatly influenced by the thinking of others:

- To prevent reoccurrence of breakdowns requires understanding what happened. That includes understanding why people did what they did in the circumstances as they experienced them. If people fear punishment, they will not participate in the search for causes and countermeasures. (See Deming, 1986; Dekker, 2006)⁶
- There is always a trade-off between time and cost, but the level at which the trade-off is made changes with work flow reliability, and LPS, properly implemented, improves work flow reliability.⁷
- The principles of LPS apply to all types of work that require coordination between humans.
- From the perspective of continuous improvement, LPS's job is to stabilize operations so they can be further improved, both individually and in the processes which they comprise, but it also improves productivity. Many, perhaps most, people are satisfied with that and don't exploit the opportunity for more fundamental improvement in performance.
- The industry unknowingly plans for productivity at approximately 50% PPC. (Liu, et al., 2010⁸)
- 5 Whys Analysis is practical and brings unexpected benefits, especially when data is stored and mined.
- Work structuring precedes production control and culminates in schedules. Location-based work structures have been successfully combined with Last Planner system production control, which does not presuppose any specific work structure⁹.
- Currently, the three least implemented components of LPS are design of operations, measurement of lookahead planning performance, and learning from breakdowns. Many only do weekly work planning. Some only do collaborative phase planning. LPS is a system of interconnected parts. Omission of a part destroys the system's ability to accomplish its functions.

⁶ Deming, W. E. (1986). Dekker, S., 2006.

⁷ Queuing theory underlies this phenomenon, which is well illustrated in the Production Flow Graph, Figure 3-17 in *Factory Physics for Managers* by Pound et al. Simply stated, as capacity utilization approaches 100%, wait time accelerates without end. Application to LPS was made in Howell et al., 2001.

⁸ A correlation analysis between labor productivity and PPC is reported in Liu et al. (2010). When the equation for the line of best fit for that data set is determined, substitution of a PPC value of 50% in that equation yields a performance factor (the ratio of actual to budgeted productivity) equal to 0.98 (from unpublished lectures by Glenn Ballard).

⁹ Location based work structures (including takt time planning) have been successfully used with LPS. To the extent that reliable release of locations (takt zones) is achieved, that simplifies management of flows and shifts the focus from coordinating work between specialists (design squads or construction crews) to coordinating work within those squads or crews. See Seppanen, et al. (2015) and Frandsen & Tommelein (2016).

C. What are the functions of the Last Planner system?

Functions are the proper work of the system; its jobs.

1. Specifying what tasks should be done when and by whom, from milestones to phases between milestones, to processes within phases, to operations within processes, to steps within operations.
2. Making scheduled tasks ready to be performed
3. Replanning/planning to complete, to achieve project objectives
4. Selecting tasks for daily and weekly work plans—deciding what work to do next
5. Making release of work between specialists reliable
6. Making visible the current and future state of the project
7. Measuring planning system performance
8. Learning from plan failures¹⁰

Many, perhaps all of these functions, have been recommended by others in some form or fashion, but never, to our knowledge, all together in a single system. Further, a few are perhaps (almost) unprecedented; e.g., the explicit focus on making work ready, on work flow reliability, specification of selection criteria for tasks to be placed on near-term work plans, system transparency, and measurement of system performance.

D. Presuppositions and Conventions

Presuppositions are what is assumed to be true about the world in which the production planning and control functions are to be performed. Since production systems are both social and technical, the relevant presuppositions concern the social, the technical, or their combination.

1. Production systems are both social and technical.
2. All plans are forecasts and all forecasts are wrong. Forecast error varies with forecast length and level of detail.
3. Planning is dynamic and does not end until the project is completed.
4. Involving those who will directly supervise or perform the work being planned results in better plans and greater ability to adapt plans when needed.
5. Operational performance (safety, quality, time and cost) varies with the degree of planning and preparation.
6. Willingness to invest in planning and preparation varies with the reliability of workflow, the predictable release of work from one 'specialist' to another. Workflow reliability is measured by PPC (percent plan complete). To illustrate the point, suppose PPC is 40%. That discourages front line supervisors (last planners) from investing time and energy in planning and preparing to perform tasks that are less than a coin flip likely to turn up heads. By contrast, when PPC is 70-80%, front line supervisors have a better chance of their planning and preparation paying off.

¹⁰ NB: Planning system performance and plan failures (failures to successfully execute planned tasks) may result from causes outside the immediate control of those planning and executing design and construction tasks. The whole management and execution system influences performance. Analyzing plan failures is one way to reveal needs and opportunities for improvement in the larger system.

7. Making commitments publically promotes care in making commitments and increases efforts to deliver on commitments that are made. It also increases collaboration between trades, willingness to share assumptions, best path forward, coordination and general quality of the work.
8. The probability that commitments can and should be kept is increased when both parties, customer and supplier, practice *reliable promising*—they take their promises seriously and engage in a conversation to align the interests and capabilities of both parties.
9. An essential prerequisite for reliable promising is that suppliers can say “no” to a request by appeal to task appropriateness (*sequence*), or readiness to be performed (*task definition, soundness, or size relative to capacity of performers*).
10. Actors within a project production system can make choices that help or hinder achieving project objectives; i.e., actors have discretion.
11. Understanding project objectives and the current and future state of the project helps actors make better choices.
12. Perfect planning may not be possible, but it is possible to never make the same mistake twice.
13. *Variation* in production systems can be reduced but never eliminated, so *buffers* are required to absorb that variation and protect targets.¹¹
14. Workflow reliability, as measured by PPC, rises when commitments are made only to tasks that are sound, sequenced, and properly defined and sized (See Principle 6 below).
15. Productivity rises and falls with PPC. The level of productivity increase or decrease is limited by the extent to which capacity exceeds demand, resulting in labor hours not expended on production.
16. Progress rises and falls with PPC to the extent that tasks are made ready in the right sequence and rate. The rate of increase or decrease is a function of the extent to which capacity falls short of demand. If there are fewer labor hours available than needed to perform scheduled tasks, that will reduce the rate of progress from what it could have been.

Conventions are neither true nor false. The following convention is useful when talking about work on construction projects.

- Tasks can be broken down into many different levels of detail. Lacking a generally recognized taxonomy for task breakdown, the following is proposed: Projects consist of phases, phases consist of processes, processes consist of operations, operations consist of steps, and steps consist of elemental motions¹².

¹¹ Strictly speaking, variation of the type mentioned here is one of two types. Buffers are appropriate for variation that can be described by statistical distributions; what might be called the ‘predictably unpredictable’. An example is processing durations. Another type of variation consists in low probability/high impact events that disrupt production systems—‘emergencies’, ‘black swans’. They must be handled by building flexibility into plans and enabling team responsiveness and flexibility. *Note thanks to Hajnalka Vaagen, NTNU.*

¹² Motion analysis, the method of analyzing worker movements in terms of elemental motions (therbligs) was developed by Frank Gilbreth in the early 1900’s. Therbligs is a jumble of the letters in his last name. Elemental motions are what robots are programmed to do; e.g., grasp, lift, rotate. Motion analysis is not yet visible in construction, but may first appear as robotics are introduced in fabrication shops.

E. Principles and Rules

Principles (also called rules) are guides to acting in the world to perform production planning and control functions consistent with the presuppositions about the world.

1. Keep all plans, at every level of detail, in public view at all times.
2. Keep *master schedules* at *milestone level of detail*.
3. Plan in greater detail as the start date for planned tasks approaches.
4. Produce plans collaboratively with those who are to do the work being planned.
5. Re-plan as necessary to adjust plan to the realities of the unfolding future.
6. Reveal and remove *constraints* on planned tasks as a team.
7. Improve workflow reliability in order to improve operational performance.
8. Don't start tasks that you should not or cannot complete. Commit to perform only those tasks that are properly defined, sound, sequenced and sized.
9. Make and secure reliable promises, and speak up immediately should you lose confidence that you can keep your promises (as opposed to waiting as long as possible and hoping someone else speaks up first).
10. Learn from *breakdowns* (unintended consequences of actions taken).
11. Underload *resources* to increase reliability of work release.
12. Maintain workable backlog; a *backlog of ready work* (tasks ready to be executed) to buffer against capacity and time loss.

F. Processes

In this section, we use two diagrams to show the relationship between levels of planning and the various functions performed at each level.

The structure of the diagram in Figure 1 is based on Should-Can-Will-Did. Master and phase schedules specify what SHOULD be done when and by whom. The job of lookahead planning is to make scheduled tasks ready so they CAN be performed when scheduled. Commitment plans are formed by selecting from ready work, expressing what WILL be done in the plan period. Plan failures (aka broken promises) are identified by comparing DID to WILL, then analyzed in search of countermeasures to prevent reoccurrence. The methods and metrics used to perform these functions are listed on the right hand side of the diagram. See the glossary for definitions of Percent Plan Complete (PPC), *Tasks Made Ready* (TMR) and *Tasks Anticipated* (TA).

Figure 2 shows how one level of planning feeds the next. Function #1 occurs at these task breakdown levels: project, phase, process, and operation. The master schedule is expressed in phases. The phase schedule is expressed in processes. The lookahead schedule is initially expressed in processes, but after task breakdown, the lookahead schedule consists of operations. Operations designs (how they are to be performed) are expressed in steps to be carried out by individuals or teams. Note: the work plan that immediately drives production is the product of selection from eligible tasks in *workable backlog*. The tasks in commitment plans are operations. Execution of operations in accordance with their design is controlled by the front line supervisor (last planner) and those executing the work.

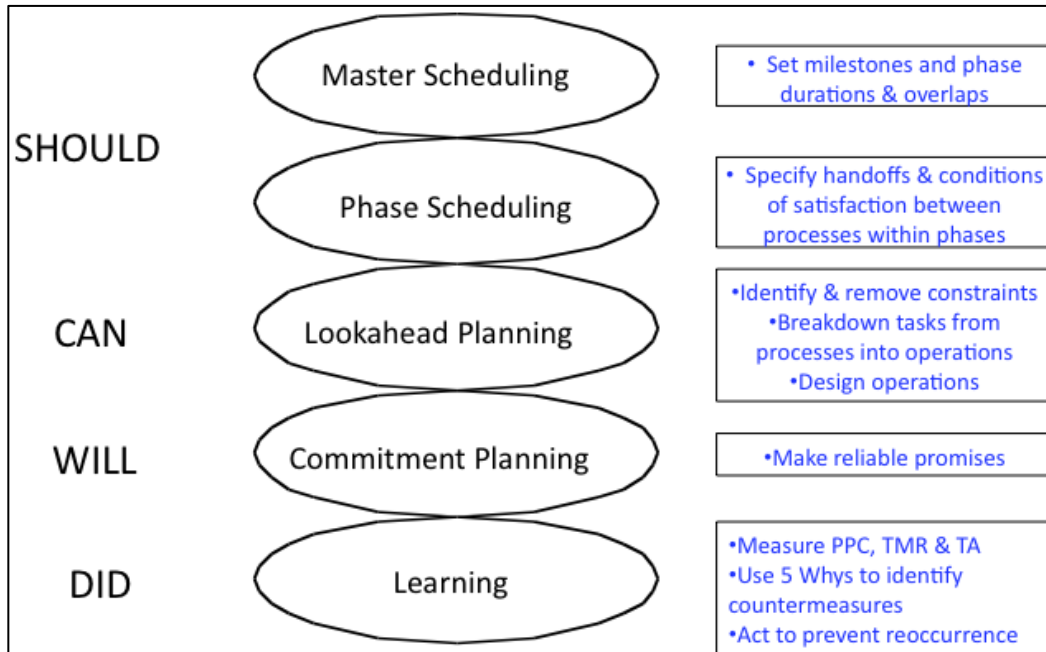


Figure 1: The Last Planner® System of Production Control: SHOULD-CAN-WILL-DID

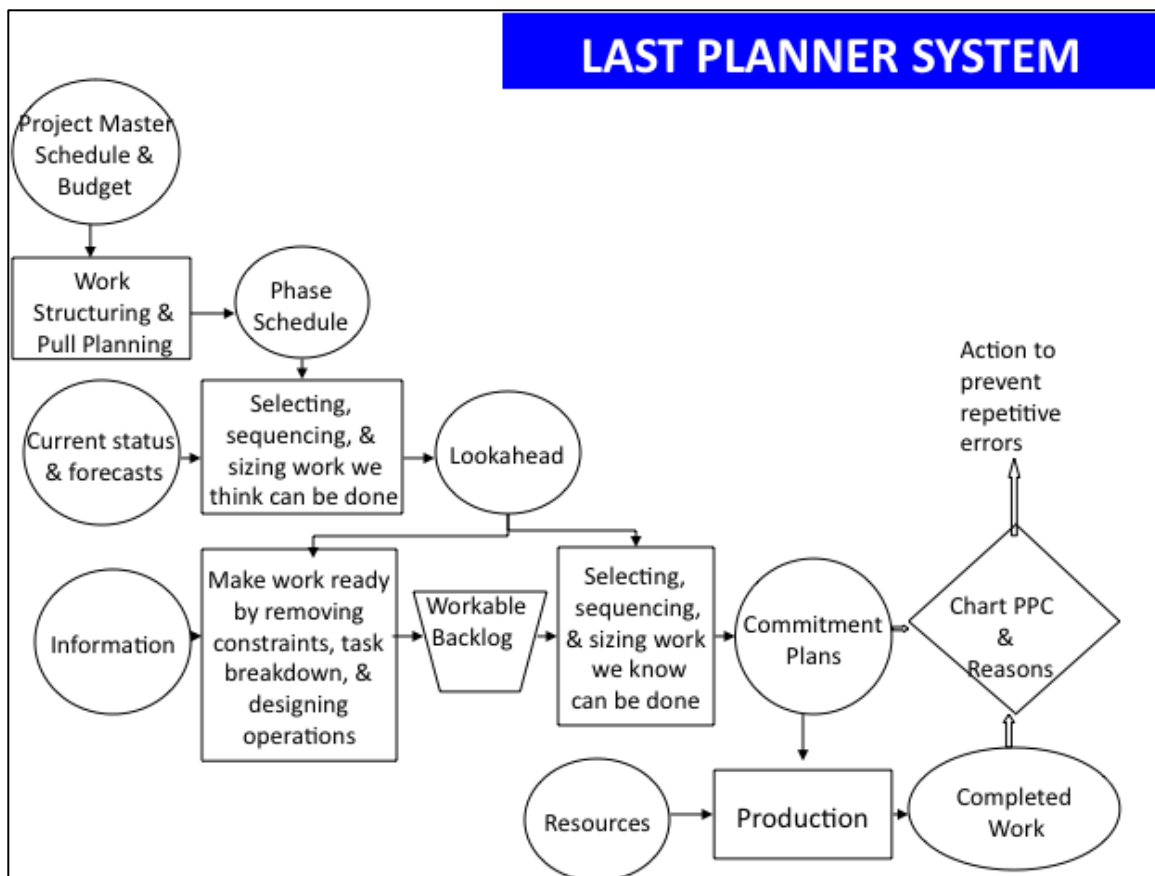


Figure 2: Relationships between planning levels in the Last Planner system

G. What methods are used to accomplish functions?

Methods and tools are products of invention and are judged by their consistency with principles and utility in performing functions within specific circumstances. Walter Shewhart invented Plan-Do-Check-Act in the 1930s¹³. More recently, pull planning was adapted from earlier collaborative planning approaches. The taxonomy offered here for task breakdown was invented to provide a standard language to distinguish between levels of detail. It is reasonable to expect that inventions will continue to emerge, and when that happens, this Current Process Benchmark for LPS will be modified accordingly. What follows are the best, proven methods of which we are currently aware. We first list the methods, then describe each method.

1. For specifying Should
 - a. *Pull planning*
2. For lookahead planning/make ready
 - a. Constraints analysis and removal
 - b. Task breakdown: Commitments are made to execute operations to the conditions of satisfaction of immediate and ultimate customers. Scheduled tasks are broken down, as needed, into operations.
 - c. Collaborative design of operations--what steps in what sequence performed by whom using what:
 - i. *Virtual prototyping*
 - ii. *Physical prototyping (construction operations)*
 - iii. *First Run Studies*
3. For increasing workflow reliability
 - a. *Reliable promising* - Disciplined approach to commitment making in which both requester and performer interact in conversation to ensure it is clear to both what is being requested--what is to be done to what conditions of satisfaction (e.g., time of completion).
 - b. *Visual controls*
 - c. *Underloading resources*
 - d. *Daily huddles*
4. For Learning from Plan Failures
 - a. *Analysis of breakdowns* to understand why they occurred and to identify the level of cause at which countermeasures can be effective in preventing reoccurrence.
 - b. *PDCA: Plan-Do-Check-Act*
 - c. *DCAP: Detect-Correct-Analyze-Prevent*
5. Metrics
 - a. Percent Plan Complete (PPC)
 - b. Tasks Made Ready (TMR)
 - c. Tasks Anticipated (TA)
 - d. *Frequency of Plan Failures*

¹³ Steve Ward contests this explanation: “He did not. Shewhart’s original version was “specification, production, inspection” This was adapted into PDSA and taught by Deming to the Japanese in the 1950’s. JUSE formed a translation of the concept into PDCA. Deming later (1980’s) declared that PDCA was a “corruption” of the original concept and said the “Shewhart Cycle” should be Plan Do STUDY Act.”

Pull Planning

Pull Planning is a technique that is used as part of LPS to develop a plan for doing work at any level of task breakdown, one of which is a Phase Schedule (The levels are Project, Phase, Process, Operation and Step). Pull Planning can be used to plan work in any time horizon, or to sequence activities as part of a production plan.

Use of pull planning to produce phase schedules should occur at least one lookahead period ahead of scheduled start so tasks can be made ready. Lookahead periods typically range from 3 to 12 weeks, depending on the lead time needed to remove constraints (see item D in Frequently Asked Questions).

Pull planning sessions should involve all who are responsible for delivering the work and with authority to make decisions, plus others who can provide needed information; e.g., safety, quality, logistics, auditory engineering specialists. One of the keys to a successful pull plan is to have those experts collaboratively working together to develop the sequence of activities that produces an acceptable work flow.

Pull planning involves the identification and definition of the milestone, or key event that the team will be pulling to; e.g., releasing subsequent work activities. Identifying the conditions of satisfaction of the milestone is critical to a successful pull plan. To assure that shared understanding, the first step in pull planning is to co-create with the team a description of the milestone from which to pull—what's included and excluded, what work it releases, etc. The completion of one milestone sets the stage for the beginning of another one.

After the milestone or key event is clearly defined and the conditions of satisfaction are agreed, the team begins to work backwards from it. Sticky notes (physical or virtual) are posted by performers and requests are made of other performers for prerequisite tasks. Performers negotiate the conditions of satisfaction for the hand-offs between the tasks posted. Participants must deeply understand their own work, and alternative ways of carrying it out, in order to be able to develop the best plan for all parties involved in the work being planned. As noted by Steve Ward, this is an area of weakness when specialty contractors are engaged late in the project and do not have sufficient understanding of the work to contribute effectively to planning.

What someone really needs may not be stated, and have to be drawn out by others asking questions. Too often, we ask for everything when we only need one part of it in order to accomplish our task. Completing the work of one discipline or trade creates the conditions for other work to begin. Participants also have to understand what conditions they have to meet in order for them to start their own work so they can make requests of others.

While a higher level pull plan may be developed for an entire project phase, unless they are relatively simple and short, there may be multiple detailed pull plans developed for different areas, systems, or time periods.

Pull planning, like all planning, is subject to differences between assumptions about how the future will turn out and what actually happens. One advantage of pull planning is it creates a team able to respond flexibly to such differences.

Constraints Analysis & Removal

In order to ensure most effective and efficient use of capacity, the work that SHOULD be performed by a certain date must be available to be performed (CAN) without any blockage or interruption, i.e., constraint.

Constraints can be either physical (availability of plotter before printing, rebar installation prior to concrete placement) or informational (soils report before foundation design, engineering details before fabrication, permit before hazardous work). These can be identified as part of the process/operations design or as they manifest throughout the execution of a project. *Activity Definition Model* provides a robust framework in which to think through this process.

Responsibility for removing constraints is spread throughout the team. Typically design squad bosses and foremen of construction crews are responsible for having labor appropriately skilled and in the quantities required. Construction engineers may be responsible for removing design information constraints; materials managers for material constraints, etc. It is important to identify the departments and individuals who will be the go-to guys for each type of constraint.

However, it is important to note that the timing rules for identifying a constraint may be very different from resolving it, especially those related to dynamic capacity. Resolving the constraint too far in advance (such as advance delivery of material, equipment, or release of design) may end up generating work-in-process and inventory that prevents effective execution of work and creates potential rework (the very thing that LPS is geared to improve).

Task Breakdown

The task breakdown convention used in LPS understands projects as composed of phases, phases of processes, processes of operations, and operations of steps. (See Glossary for an example). Processes are connected work performed; e.g., detail-fabricate-preassemble-deliver-install. Suppose the lookahead window on a project is six weeks, at which time identification and removal of constraints begins. Some constraints may apply to all operations within a process; e.g., materials and information, while others are specific to individual operations. The transition from processes to operations should occur no later than 3 weeks ahead of the scheduled start date for a task to allow time for operations design and identification and removal of constraints that are revealed by that design; e.g., specific skills and permits needed, location and type of equipment, etc.

Collaborative Design of Operations

One fundamental element of LPS is the involvement of the last planners, so-called because their plans directly drive execution, as opposed to serving as inputs to other planning processes. These front line supervisors are most knowledgeable about how to optimally execute the work within the given environment. Design of operations is another application for pull planning, and involves not only the last planners, but also the craftworkers who are to execute the first instance of the operation (first run study), higher level supervisors in the chain of command, and specialists for material sourcing, design buildability, quality, safety, logistics, equipment, etc.



Reliable Promising

All work gets done through language and in the way people speak, listen and collaborate with each other. Reliable promises are the result of the commitments we make to each other out of respect for each other's concerns.

Projects are a network of commitments. Projects extend well beyond the site, even when they have reached the construction phase. Consequently, commitments are made between individuals in the various organizations on and off site.

Before making the promise, the performer makes a reasoned assessment of their capability and capacity to act on the request within the requested timeframe. A fundamental tenet of reliable promising is the acceptance of "No" as an appropriate response to a request. For example, last planners make reliable commitments to following disciplines or trades to complete specific work tasks by a specific time during the next work cycle. Prior to making the commitment, the last planner confirms that the task is well defined, is sound - has no unresolved constraint, is in proper sequence, and is appropriately sized¹⁴. These commitments are documented on the commitment plan. Last planners and others make commitments to attend LPS meetings and to come prepared.

People in the extended project network also respond to the requests of others. In order for someone to say yes to a request they must have the ability to say no. If they cannot say no to a request, then they cannot make a promise. This is a huge cultural change from traditional practice and requires persistent and persuasive coaching to both make the change and to sustain it.

In LPS, promises are documented in a variety of ways; for example, in the pull plan, constraint log, the weekly work plan, in supplier's commitments to deliver at a certain time, in fabricator's commitments to manufacture to agreed specifications, etc.

Visual Controls

The purpose of a visual control for a production system is to provide clear visual indicators depicting the status of the system at an appropriate level for the audience to achieve shared understanding so that necessary actions can be taken. Therefore a visual control for a production system must convey in simple visual cues (1) appropriate measurements (not project controls), (2) up-to-date information (not print-out of last week's information), or (3) what's really possible (not a schedule printed on the wall). Simple graphs and charts posted in public places can be very effective.

Modern production systems utilize sensors to provide real-time information and often times provide direct access to mechanisms to address any variations in the production.

Daily Huddles

Brief, typically stand-up, meetings each day by groups of interdependent players, at which each, in turn, shares what commitments they have completed, what commitments they need help with or cannot deliver. This can be done within a design squad or construction crew, and between front line supervisors of design squads or construction crews.

¹⁴ See task sequence, task soundness and task size in the Glossary.

Countermeasures

Analysis of breakdowns is done to find countermeasures expected to completely or partially prevent reoccurrence of the breakdown. Often, the initial reason provided for an incomplete task does not provide sufficient insight into why the task was not done. It may require several interviews to get to effective countermeasures using the 5 Whys technique.

Timely generation and implementation of countermeasures reduces accidents, rework, and plan failures. The return on investment makes this something everyone should do, and allocating capacity for such analysis is a vital management act.

Capturing reasons for breakdowns over time provides teams with trends, which can be used to develop strategies to prevent re-occurrence of the same failures in the future. It should not be a “blame and shame” tool or be used as a weapon.

Countermeasures developed through analysis of breakdowns are tested using Plan-Do-Check-Act. PDCA was developed by Walter Shewhart at Bell Labs in the 1930s, and popularized by his student, W. Edwards Deming. Sometimes PDCA is referred to as the Deming Cycle.

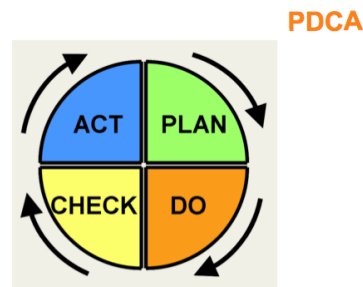


Figure 3: PDCA

PDCA is a rough and ready method of formulating and testing hypotheses, and is the tool most commonly used to test the effectiveness of countermeasures identified through 5 Whys analysis of plan failures. Suppose a commitment, made to remove a constraint on a scheduled task in the project’s lookahead plan, was not successful, and the task had to be delayed and rescheduled. 5 Whys analysis identified the root cause as assuming that soil conditions would be the same as on a nearby project. We might propose that people ought not to make assumptions, but that’s hardly an effective countermeasure. For the sake of this illustration, suppose that the countermeasure proposed was to incorporate into design reviews a checklist that called for listing all relevant assumptions and their bases. The hypothesis to be tested is: If <checklist>, then fewer unfounded assumptions, and so fewer plan failures in design. Developing the hypothesis is the PLAN in PDCA. The DO in Plan-Do-Check-Act is to perform one or more experiments to see if the hypothesis is supported. CHECK is checking to see if using the checklist reduces plan failures, and ACT is declaring the checklist a standard requirement and implementing that standard.

Detect-Correct-Analyze-Prevent

A connected problem solving cycle is Detect-Correct-Analyze-Prevent (DCAP). This was formulated primarily with quality defects in mind, but applies also to plan

failures and accidents/near misses. The idea is to DETECT breakdowns (variations from target) as close as possible to their origin, to take CORRECTive action so production can continue, to ANALYZE the breakdown to root causes (perhaps using 5 Whys), then develop and test countermeasures in order to PREVENT reoccurrence. An example: Suppose an error on a drawing is discovered after the drawing has been issued for fabrication, but before fabrication starts. The corrective action is to stop the use of that drawing, collect all previously issued drawings, correct and distribute the corrected drawing. That enables fabrication to resume, but does nothing to prevent similar errors from happening in the future, so an analysis of the breakdown is needed in order to discover why it happened. Analysis reveals that the drawings were issued late, and the urgency for speed contributed to the error. Countermeasures could be developed for such situations, but further analysis is needed to determine why the drawings were late. Eventually it is discovered that key vendor data was delayed, and a countermeasure was developed to incorporate vendors into LPS and engage them in the practice of reliable promising.

A construction example: A construction worker was injured when struck by a wrench dropped from a higher elevation. In this case, correction consists in providing medical treatment to the worker and alerting the work area from which the wrench came that there had been an injury. Further specifics depend on the situation, but one likely possibility is to stop work in areas below higher work until steps are taken to prevent repetition of the incident.

The relationship between PDCA and DCAP is shown in the following diagram:

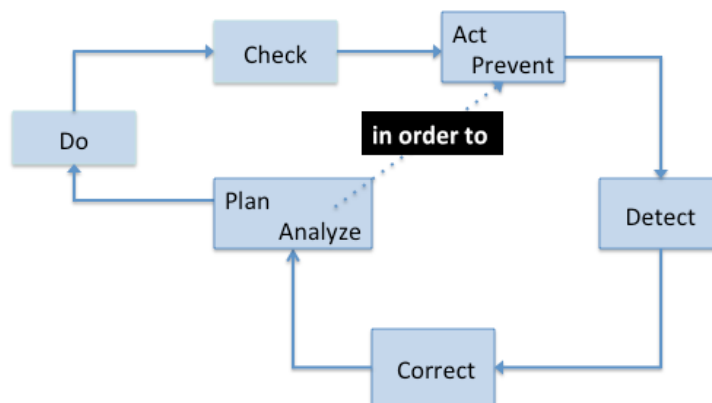


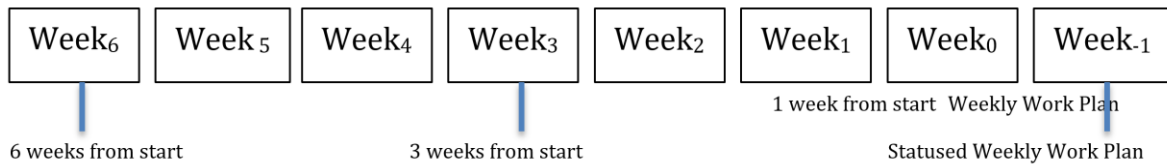
Figure 4: DCAP/PDCA combined cycles

Metrics

Currently, there are four established metrics to measure the effectiveness of LPS implementation:

- PPC
- TA
- TMR
- Frequency of Plan Failures

The first three of these metrics involve comparison of task sets in different weeks of the lookahead window. In the figure below, a six week lookahead window is assumed, beginning 6 weeks ahead of scheduled start.



Percent Plan Complete (PPC) - PPC measures workflow reliability; i.e., the predictable release of work between work groups. is generally tracked on a weekly basis. PPC compares the tasks that were completed (Week₋₁ in figure above) against the tasks in the weekly work plan for that week (Week₀). At the end of the plan period (day, week, shift, etc.), PPC is calculated as the percentage of completed tasks relative to those that were planned at the beginning of the week. PPC compares the stated weekly work plan (Week₋₁) against the weekly work plan (Week₀).

Tasks Made Ready (TMR) - TMR is the same measurement as PPC, only done earlier in the lookahead process, comparing the weekly work plan (Week₀) against an earlier week in the lookahead window (Week₋₁). TMR measures the ability of the team to identify and remove constraints ahead of the scheduled start of specific work tasks.

Tasks Anticipated (TA) - TA measures the percentage of tasks for a target week that were anticipated in an earlier plan for that target week. The objective of this indicator is to provide a relative measure of how well the team is able to cause what is actually going to happen on the project within the next few weeks. This planning ability is critical because without it, the right work cannot be made ready.

Measurement of TA and TMR starts by comparing task sets at Week₋₁ (the last week in the lookahead window prior to scheduled start) against the task sets at Week₀ (the weekly work plan). Suppose the task set at Week₋₁ is ABCDE and the task set in the weekly work plan (Week₀) is ACEFG. Only A, C and E appear in both, so $TMR = ACE / ACEFG = 60\%$. F and G are in the weekly work plan, but were not in Week₋₁, so $TA = FG / ACEFG = 40\%$.

As TMR and TA approach 100%, measurement shifts to comparison of Week₀ against Week₂. How far to extend TMR and TA is an empirical question at this point, as we are not aware that anyone has ever measured beyond Week₋₁. Note also that there can be good reason for changing committed tasks; for example, when external conditions change, making it imperative or beneficial to change course; or when constraints reappear that we thought had been removed. Of course, we want to learn how to prevent negative changes, but learning how to accommodate necessary changes or opportunities is equally important.

Frequency of Plan Failures - As discussed above (see Percent Plan Complete - PPC), during execution tasks are annotated as to whether or not each was completed when planned. Those not completed when planned are assigned to a category which describes in general the cause of the plan failure or variance. For example, some usual categories during construction are "Owner Decision," "Engineering/Design," "Weather." These categories are generally established prior to the start of the project and reflect the broad categories of plan failure that might be expected during execution of this type of project. However, as the project evolves the categories can be refined to bring added insight to the causes of plan failure. As plan failures occur, a frequency chart is updated to visually

indicate the relative frequency of each category of plan failure. When frequency of specific categories of plan failures are tracked over time, it reveals the extent to which root causes have been identified and countermeasures taken to prevent reoccurrence.

These categories, often called “Reasons for Variance”, are useful to identify weaknesses in specific support systems or flows. For example, recurrent problems with materials may signal a failure in the materials management information system or in supplier/site coordination. The actual source of plan failures has to be discovered by analysis. Identification of a category is like giving bloodhounds the socks of a lost child in order to put the hounds on the scent. Categorization without analysis does not prevent reoccurrence of plan failures.

H. Implementation

This section has two parts. First, the design of a project production planning and control system is described, then the deployment of a project production planning and control system is described.

Design

Due to the inherent complexity of project production (multiple stakeholders, different locations, alternate sourcing options, etc.), the means through which production is planned, executed, controlled and improved must be tailored to the type of work and workers that perform it¹⁵. Therefore, a cookie-cutter approach or replicating another project’s control system should be avoided. The allowable amount of *variability* in the production system and the corresponding allocation of buffers should determine which control protocols the production control system should enable including the level of detail and frequency of planning, control and feedback. In this regard, the production control system can use one or a combination of physical control, software (control solutions including sensors) and human control. As is done to prevent accidents, where possible, they are engineered out of the system. When that is not possible, to prevent human error, software is used to control actions. Finally, where dependence on human judgment is necessary, the production system is structured and managed to facilitate judgments that advance the system towards its goals. When errors are made, that triggers a search for countermeasures to prevent reoccurrence.

LPS enables control of work execution by providing the functions, principles and processes each individual last planner involved in the delivery of a project must follow in order to optimally achieve the desired project objectives. However, this is not done in isolation. The conventional scheduling system sets the baseline schedule and measures progress. This baseline schedule and associated milestones serve as objectives for project production. If they are flawed, that cripples production control. When this happens, teams either tend to give up on LPS and return to traditional behaviors, or recreate the project schedule themselves using pull planning.

The role of the last planner is to align the actions of individuals (craft workers and knowledge workers) involved in the project to deliver the objectives. Seen from a value stream perspective, the relationship of craft workers and knowledge workers are typically

¹⁵ “Contrasting Project Production Control With Project Controls”, Project Production Institute 2015

intertwined, therefore, the design of LPS for a given project must incorporate both types of work.

In addition, depending on the type of project, the amount of inherent variability is vastly different. For example, a greenfield residential project typically experiences less variability than a turnaround project in a refinery, where the scope is expected to constantly change based on what's discovered when equipment is dismantled. The penalties of not managing the sources and associated implications of variability also differ tremendously. For example, a week delay in turning a refinery back on will have direct implications on revenue and valuation of that company. The same amount of delay typically has less implications for the owner of residences. Therefore, the frequency of control and adjustment due to variability (re-planning) must be aligned with the type of work.

Since the purpose of the phase schedule is to specify the handoffs and conditions of satisfaction between processes within a given project phase, planning needs to be performed sufficiently ahead of the phase to allow lookahead planning to be effectively performed and when there is change in scope or allocation of scope. During the course of executing the phase plan, when replanning is needed, the team tries to recover to the original phase schedule as soon as possible, but may need to replan the remaining work to complete within the phase milestone. If that is not possible, the team planning the next phase will have less time within which to execute their phase of work. Everyone does what they can to hold the completion date.

Critical Notes on planning windows: lookahead and commitment planning

The lookahead is the main mechanism used to determine how and what work should be done when by whom. To reiterate, the work here is not limited to craft or knowledge work, but the lookahead should allow enough time to identify and manage engineering, fabrication and/or delivery of any long lead-items that the project team needs to coordinate. Therefore, if the strategy is to do just-in-time fabrication of certain material, the optimal scenario is that the lead time associated with fabrication and delivery should be less than the lookahead of the installation. If the strategy is to build inventory of the material on site ahead of the installation based on forecasted usage, the lookahead window associated with that work can be shortened to cover the delivery of the material to the installation area.

The window of commitment planning also must vary based on the type of work. Typically for knowledge work (such as design), where cycle times for generating outputs are more than a few days, the commitment planning process should be performed weekly or bi-weekly. For craft work, where work content is generated on a daily or shift basis, the commitment planning process should be performed at the same pace, daily or by shift.

Deployment

The deployment of LPS should incorporate the means to assess if project teams are performing its functions, and adopting and using its principles and processes effectively. If the deployment approach selected for a given project is knowledge transfer, users of LPS can be assessed based on a developmental framework that incorporates development



stages such as aware, understand, capable and master. By doing this, the effective development of technical competence can be monitored. In addition to technical competence, the level of commitment to the effort should also be assessed and monitored. At the end, commitment is needed to develop technical competence. To do this effectively, a whole approach including frequency of assessments and assessment tools must be developed and implemented.

In order to configure LPS for a specific project, the following questions must be answered:

Relationship of the Last Planner System to other Project Management Components

- Is the Last Planner System defined and understood as something distinctively different than Project Controls?
- What is its interaction with Project Control, especially with higher level schedules?
- What is the scope (all phases or just construction) of LPS implementation?
- What role will physical controls, sensors and automated equipment play in controlling work, resolving constraints and ensuring quality of work?

Configuration of the Last Planner System

- Who has what roles and responsibilities?
- How will the Phases be defined?
- How many weeks ahead of scheduled start will each phase be planned?
- How long will the lookahead schedule be? Note: This may vary by phase, depending on the lead time required to remove constraints.
- How far in advance of commitment planning will the tasks be broken down to appropriate level? e.g., 3 weeks ahead of scheduled start, 2 weeks ahead of scheduled start.
- How long is the planning horizon for commitment planning; one shift, ½ day, 1 day, 1 week, etc. ?
- What will be the weekly, monthly cycle of LPS events?
- What are the standard agendas and participants for phase planning, lookahead planning and commitment planning meetings?
- What plan failures will be analyzed in search of countermeasures? Who/how will the decision to analyze be made? How will analyzes be carried out?

Implementation

- How will the work of project team members offsite be incorporated into the Last Planner system?
- Will the implementation be done top down or bottom up?
- How will education & training be done?
- How will the effectiveness of implementation be assessed and improved?

I. Future Research

We do not believe that the current benchmark is the best that can be achieved, especially as regards methods. Indeed, given the lean principle of continuous improvement, better practice is always possible. Based on research to date, we offer the following tasks to be performed and hypotheses to be explored and experimentally tested:

1. Develop and test potential high leverage drivers of LPS performance. The critical question to be answered is “What are the few actions or behaviors of the project team, while working in the process, that are highly correlated with desired project outcomes?” The next step then would be to develop metrics to measure these desired actions and behaviors. Some preliminary thoughts in this area, which are based on field experience with successful and unsuccessful LPS implementations, are centered on the team’s ability to make the right tasks sound in the right sequence and rate. It appears that the key factors involved are to adequately identify and remove constraints in advance of scheduled work and to learn from plan failures. Teams that do well with this tend to have high PPC and are meeting or exceeding schedule and budget targets. The crucial underlying abilities seem to be (1) having stable lookahead schedules, (2) requesting and obtaining reliable commitments to remove constraints, and (3) developing and implementing countermeasures to prevent repeated plan failures. The hypothesis to be tested would be that focusing on the improvement of these three abilities will result in improved PPC and better attainment of intermediate schedule and budget targets. To help focus teams on improving these fundamental abilities, indicators are needed. The existing Tasks Anticipated metric (TA) measuring the changes in each week of the lookahead window may serve as an adequate indicator in regards to (1). For (2), perhaps measuring each week “Percent Promises Made” (number of reliable commitments to remove unresolved constraints/total number of unresolved constraints), “Percent Promises Kept” (Number of constraints resolved in the week as promised/Total number of constraints promised to be resolved in the week) will focus the team on the desired behaviors. For (3), a potential metric might be a measure of the number of countermeasures implemented relative to the number of plan failures over some past time window. *Courtesy of John Draper, Lean Project Consulting*
2. Develop means to assess the qualities of phase plans. When a team engages in phase planning, participants explore options for how work can be structured and they define hand-offs between their so-defined chunks of work. That planning process all too often ends when one feasible plan has been identified. If the team finds one plan that is feasible, might they be able to find additional ones that are feasible as well? If so, might some of these plans be better than others? We need metrics to assess the qualities of phase plans so we can discriminate between them and choose the one most suitable to deliver the project at hand. Metrics may pertain to the degree of flow that has been achieved, for example by gauging the extent to which trade crews will be able to work without interruptions (e.g., don’t have to leave the site and due to lack of work return only several days later). In our ongoing research on takt time planning we are developing other metrics so that we can gauge how well a plan meets the following objectives: Have trades work in a way they prefer

- a. Aim for constant crew sizes and continuous work flow
 - b. Avoid trade stacking
 - c. Use timely on Takt handoffs
 - d. Balance the whole while pushing for speed
3. Develop more standard work
 - a. Work that rolls over (it passes the screening process) from the phase plan into the lookahead schedule, will then be made ready over the course of the duration of the lookahead time window. Work chunks (“boulders”) get broken down to smaller ones in the process (to “dust”) until they are of a size a Last Planner can commit to when making their weekly work plan. At present, we are not aware of their being a standard methodology for conducting this breakdown nor of a standard work description that results from it. Some standardization is being done, for example, a work standard gets established after a First Run Study. Developing more such standards, and doing so consistently, will help with learning on how work can be done within and across projects.
 4. How do current policies and practices, including commercial contracts, obstruct successful LPS implementation?
 5. Extend reliable promising to direct workers. This has previously been recommended for design, where more work is done by individual specialists than in construction, so the ability to assess capacity when responding to requests calls for individual work plans at the commitment level. A process for soliciting and getting commitments from individual construction workers is now in use by Veidekke and Skanska in Norway. The research could start by examining current practices, assessing their impact, and experimenting with refinements as needed. How to overcome obstacles to extending reliable promising to direct workers, such as frequent change in direct workers on projects, could be included in the research.
 6. Resource load commitment plans; i.e., plans to complete and release work next week, next day, next shift. Commitments should be made within available capacity and all capacity should be committed, mindful of underloading to assure reliable workflow. [This is being done already, but is not a universal practice.]
 7. Increase use of visuals to communicate information. For example, leading indicators that provide information what needs to be done now to move the project toward its objectives.
 8. Benefits and challenges of LPS software solutions. This research would begin by specifying the criteria for evaluation; generally, do they help promote the practices advocated in this LPS Benchmark, and in what conditions are they most effective or needed.
 9. Relationships between LPS and safety, quality, cost and time performance. “Does LPS, properly implemented, reduce illness and injury on construction sites? Does it reduce defects, reduce cost, and reduce time?” There is some evidence regarding impact on safety (MTH, a Danish contractor, reported a 75% reduction in lost time accidents on projects using LPS), quality (on the Temecula Valley Hospital Project, 1 of 1300 inspections failed first time), and cost (Liu et al.’s 2009 paper reporting a positive correlation between LPS and labor productivity; Gonzalez et al.’s 2008

- paper), and project durations (Boldt Construction's world record on a Stora Enso project). But more data is needed. With the broader take up of LPS, statistical analysis should now be possible with larger data sets.
10. LPS is designed to be an engine for continuous improvement, the mechanism of which is shrinking buffers by reducing variation. To what extent is that potential being exploited in the industry?
 - a. Has anyone reduced capacity buffers in response to consistently achieving near-100% PPC?
 - b. Has anyone reduced their schedule (time) buffers in response to consistently hitting phase milestones?
 11. Conversations for action (reliable promising) play a central role in LPS as currently designed, but language action also includes conversations for possibility. How might conversations for possibility be incorporated into LPS? What benefits are realized from that incorporation?
 12. Given the increasing use of relational contracts that involve designers and constructors in the early stages of projects, collaborative generation of project master schedules is an appropriate research topic--how to do it, whom to involve, critical preconditions, etc. And on projects where the participants share risk and reward, the search for better phase plans, plans that optimize work flow, is clearly appropriate--beyond simply squeezing the work within the available time.
 13. Extension of managerial responsibility to front line supervisors was one of the motivations for the creation of LPS. However, that does not mean there is no role for other levels of supervision. More explicit specification of those roles and responsibilities could be helpful in getting LPS to function properly, and to facilitate its use in continuous improvement through systematically 'lowering the river to reveal the rocks'.
 14. Planning and control is focused on delivery of what's needed by clients to accomplish their purposes, and their conditions of satisfaction (for cost time, etc.). In the construction phase, it may be assumed that delivery of value to customers is accomplished by building to the design documents. Consequently, deciding what work is to be done in what sequence is achieved in the construction phase by consideration of project cost and schedule objectives--what's the best way to move toward those objectives from where we are now and with what we now have in hand. When designing the asset, that obviously cannot be assumed. What is done now, with various degrees of success, is synchronizing drawing delivery dates with construction's execution times, but that's done late in the design process. How are sequencing decisions best made in early design before production of construction documents?
 15. Several methods from software development are now being used in planning and controlling design work in the construction industry; e.g., Scrum and David Anderson's Kanban. A description and evaluation of these methods should be done to decide if to incorporate into future LPS Benchmarks.
 16. When a committed task cannot be completed, ask the direct workers involved to explain what happened; to take the first steps in a 5 Whys analysis. Prearrange who has responsibility for continuing the analysis depending on the category of reason for plan failure.

17. Explore how to better produce proactive project execution strategies and milestone plans, that make use of established knowledge about planning under uncertainty on where and when to develop flexibility and buffers, and the proper relationship of those strategies and project control schedules. Courtesy of Hajnalka Vaagen, NTNU
18. How does Last Planner work to enable resilience in projects, what are the social-behavioral prerequisites for successful Last Planner implementations, and does/how does Last Planner strengthen social networks and thus increase resilience? Courtesy of Hajnalka Vaagen, NTNU
19. Everyday improvement: what can be done to improve the way project teams and trade teams learn and improve on a daily and weekly basis with the Last Planner System? *Courtesy of Alan Mossman, The Change Business*
20. LPS can influence a variety of social dynamics within a construction organization
Social dynamics refers to the resulting behavior of groups from the interactions of its individual members and the analysis of the connections between individual interactions and group level behaviors (Durlauf and Young, 2001). At this point, trust has been one of the more relevant social dynamic variables studied to date. But the LPS can endanger synergies and feedback loops with other social dynamics variables such as Power Distance and Goal Setting. This research could start applying a variety of social science techniques to explore the following questions: what specific social dynamics variables and mechanisms are endangered by LPS in a construction organization? and how do they interact (synergies and feedback loops)? The questions established in an exploratory phased can be further studied by using computer modelling techniques such as Agent-Based Modelling or System Dynamics. Empirical data and experimental settings can demonstrate that LPS social research go beyond that traditional focus on language-action-perspective, people development, culture and transformation, and integral theory, and pay attention to specific social dynamics variables (other than trust) that can promote a more effective adoption of lean-based tools such as LPS in a construction organization.
 - a. Durlauf, S. and Young, H. P., 2001. *The new social economics*, Cambridge, MA, USA: MIT.
 - b. González, V. A., Sacks, R., Pavez, I., Poshdar, M., Priven, V. and Ben Alon, L. (2015). *Interplay of Lean Thinking and Social Dynamics in Construction*. Proceedings 23rd International Conference for Lean Construction, Perth, Western Australia, 28th - 31st July. Courtesy of Vicente Gonzalez, Univ. of Auckland

J. Frequently Asked Questions

1. Why should LPS be considered a lean method? Answer: Lean is a philosophy of management dedicated to increasing value delivered to customers and stakeholders, and to decreasing waste. Value is increased when projects deliver what customers need to accomplish their purposes, within customer constraints (of time, cost, location, codes, etc.), and when what's delivered enables expansion of customer purpose. LPS is a method for deciding how to achieve these objectives, and for steering projects toward them. In the Toyota Production



System, three types of waste are identified: muri, mura and muda. Muri is overloading, mura is unevenness, and muda is what is unnecessary. All are to be avoided to the extent possible at a specific time and place. LPS addresses all three. Overloading is avoided when tasks are designed to the capabilities of the resources assigned to their execution. Unevenness is avoided when the release of work is made more predictable. What is unnecessary is avoided when tasks are executed in a sequence that reduces/eliminates rework, and also when resource utilization is increased.

2. What is the right target for PPC? Answer: 100%. The goal is reliable release of work, so anything less than a PPC of 100% is a failure to fully achieve that goal. Some people think that a 100% goal encourages sandbagging, but that's true of any goal, and the only effective countermeasure is persuading project team members that PPC measures the effectiveness of the planning system; though supervisory oversight can also help. Don't confuse a 100% PPC goal with overloading resources; i.e., not allowing any capacity buffer for variation in process durations. We always want to underload when making assignments, but with the goal of perfect workflow reliability. As countermeasures are developed for plan failures, actual capacity will increase. As PPC approaches 100%, increase the load placed on capacity and reduce the time slots in planning; i.e., plan to the ½ day rather than the day.
3. How much should capacity be underloaded? Answer: Given the importance of workflow reliability, where feasible, we should underload so that there is a 99% chance that the assigned capacity will be sufficient to complete the task as scheduled. But to do that precisely requires information concerning the standard deviation for the relevant operations. 2 standard deviations corresponds to a 95% confidence level. 3 standard deviations corresponds to a 99% confidence level-- meaning that the underloading (capacity buffer) will be sufficient 99 times in 100 in achieving target completion dates. This shows how valuable it is to reduce the standard deviation! In practice, the standard deviation may not be known, in which case, we learn from our experience and make adjustments accordingly.
4. Another relevant point here is that we tend to waste something on the order of 30% or more of labor capacity when workflow reliability is low. That can be considered a built-in buffer for underloading. Underloading implies some loss of labor capacity, but that loss will be less than what has happened historically because underloading helps improve workflow reliability.
5. How many weeks should we look ahead when doing constraints analysis? Answer: That number of weeks required to remove the constraint with the longest lead time. Example: A construction task first enters the lookahead window. If the needed design information is behind schedule, a 6 week lookahead provides 6 weeks to expedite production and delivery of that information. If the design resources are not dedicated or otherwise have uncertain capacity, more weeks may be needed. Note that constraints such as design information and materials have already been synchronized with the construction schedule because they have lead times far exceeding 6 weeks. The relevant lead time here is for solving problems with design information, materials and such. Items with lead times for

production and delivery exceeding the lookahead window are to be embedded in higher level schedules.

6. How to select which plan failures to analyze in search of countermeasures?
Answer: As many as you have capacity to analyze. Assuming limited capacity, select those with the biggest impact on project performance.
7. How is PPC measured? Answer: At the end of the commitment plan period (1 shift, 1 week, 1 day, etc.) , the team notes which commitments have been met and which have not. A commitment is understood to have been met when it was done as planned e.g., started and/or finished as planned. This is usually done by asking the question “Did we do what we said we were going to do?” i.e. “Did we start the task as planned?” “Did we finish it as planned?” The appropriate response is either “Yes” or “No.” There is no partial credit. It is important to realize that PPC is a measure of a team’s ability to reliably plan and execute work and is NOT a measurement of completed work. Nor is PPC a measure of productivity. It is possible to have 100% PPC and poor productivity if capacity exceeds ready work. The recommended planning precision is to plan to the day or shift (although after achieving near 100% PPC, that can change to the ½ day, etc.). Counting tasks finished by the end of a week involves committing only to tasks that are fully sound at the beginning of the week. The larger the batch size of commitments, the longer the project will take to complete.
8. Should early finishes be counted as completions? Answer: Yes, if tasks are completed within the committed time frame, they should be counted as completions. To increase the probability that committed tasks will be completed on time, we advise underloading; i.e., assigning more capacity (labor hours) than might be needed, allowing for variation in processing durations. Completing early is expected and desired. What we want to focus attention on is excessively early completions. That can be done by tagging tasks completed early and discussing in the daily or weekly planning meetings if there is an opportunity for adjusting future task durations or capacity allocation. That is the job of the manager of the planning meetings and the last planner’s immediate supervisor. To avoid loss of capacity, it is advised to include in commitment plans both priority tasks and others available as follow-on or fallback. Take care not to use capacity to perform tasks that are otherwise ready, but doing now causes more pain later in the project--for example, using temporary hangers (#9 wire) to put pipe spools into their final position in order to claim more progress and hence payment. When the pipe supports arrive, they will be more difficult to install than was expected in budgeting. Another possible use for excess capacity is to have workers participate in problem solving; e.g., 5 whys analysis of plan failures or revisions of operation designs that have been shown to need improvement.
9. Is LPS a scheduling system? Does it replace project controls? Answer: No, LPS is a production control system with elements of planning, scheduling and execution. A distinction should be made between planning and scheduling - planning is the upfront activity of determining what should be done, in what sequence, how it should be done, and lining up the resources to do the work. The plan becomes a schedule when commitments are made to accomplish certain work on certain days. LPS functions in the dimensions of planning, scheduling, execution of work,

and learning from planning/execution variances. LPS does not replace project controls, the function of which is the establishment of cost, time and other performance targets (See “Why Last Planner?” at the beginning of this document). LPS is then used to steer project performance towards the objectives set by the project controls.

10. How many more meetings and employees will we need if we do LPS? Answer: None. In fact, you may be able to reduce indirects as workflow reliability increases, reducing the amount of firefighting.
11. Should we have crews do more work if they complete committed tasks sooner than anticipated? Answer: Yes, but only if that work does not cause more harm downstream than the benefit provided by using otherwise lost capacity. What’s needed is to specify on commitment plans Plan B tasks available for each work group should they complete committed tasks early or should they be unable to perform committed tasks.
12. Why the name “Last Planner”? Answer: The name designates the front line supervisors whose plans initiate production as opposed to feeding lower levels of planning. “Last Planner” was used because the position that functions as front line supervisor can vary from place to place, and the names for those positions also vary. For example, “capataz” in South America corresponds roughly to “foreman” in North America, but in many South American projects, engineers actually function as last planners. The front line supervisors of all companies involved in design and construction are included as last planners, both those employed by the company leading design (e.g., an architectural firm in a building project) and construction (a general contractor), and the front line supervisors of engineering consultants and of specialty contractors. The expression “Last Planner” was also chosen to emphasize that front line supervisors have managerial responsibilities and are not simply cogs in a machine.
13. Does implementation of LPS transfer power over project progress to subcontractors? Answer: No. In a traditional contracting structure, general (main) contractors have financial interest in delivery of projects on or ahead of schedule, while the financial interest of subcontractors is to use their crews productively. When LPS is used on construction projects with such traditional contracting structures, the parties retain their different interests, but act together to achieve both. General contractors control progress by assuring that tasks are made ready in the needed sequence and rate in lookahead planning, and by releasing tasks into workable backlog. They have more control over flows of design information, materials and equipment than subcontractors. Subcontractors control productivity by participating in lookahead planning, which gives them foresight of future workload so they can make better decisions about bringing labor to site, by designing operations and by including on commitment plans only tasks that are well defined, sound, sequenced and sized to the capabilities of performers. If the project schedule is well formed, and lookahead planning and commitment planning do their jobs, both progress and productivity will be better. Courtesy of Carina Schlabach, Zublin Construction
14. Who leads lookahead planning? Answer: In design, lookahead planning is usually led by the design project manager. In construction, lookahead planning is usually

led by the project general superintendent. On larger projects, lookahead planning may be divided between areas or systems, in which case the design manager or superintendent over the area or system provides leadership.

15. Who leads commitment planning? Answer: Same leaders as for lookahead planning. When LPS is working well, the last week of the lookahead is the default commitment plan for the following week, and commitment planning meetings are devoted to making any needed changes, and to deciding about Plan B (fallback/follow-on tasks ‘below the line’).

K. Acknowledgements

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L. Glossary

Activity Definition Model (ADM): An input-process-output representation of work to be done in design or construction. The model depicts the specification of directives (entering the process rectangle from above), prerequisites (including materials and information to be transformed into the desired output, entering the process rectangle from the left), and resources (entering the process rectangle from below). It also shows an inspection process resulting either in redo or release to the customer process. The model is used as a guide to exploding scheduled tasks into a level of detail at which their readiness for execution can be assessed and advanced.

Breakdown: Deviation from target outcome(s). Plan failures, errors and defects, and occupational illnesses and injuries are common breakdowns in construction.

Buffer: A mechanism for deadening the force of a concussion; e.g., a capacity buffer is created by scheduling less than all the time available (aka. **underloading**). If production falls behind schedule, there is **capacity** available for catching up. Capacity buffers may be preferred over inventory buffers. In addition to capacity and inventory buffers, other types of buffers are time buffers, monetary buffers (contingency), and spatial buffers (tolerances). Arguably, monetary buffers can be converted into, e.g., capacity buffers or inventory buffers.

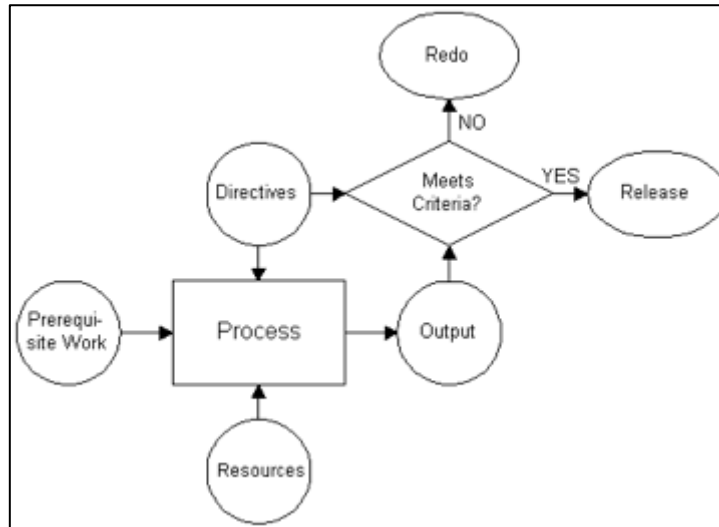


Figure 5: Activity Definition Model

Commitment Planning: Near term (day, shift, week) plans that consist of tasks that have been screened for definition, sequence, soundness and size, and have been negotiated between immediate requester and performer using reliable promising.

Conditions of Satisfaction: Conditions that a requestor places on performance of a promise; e.g., when it is to be completed, how much the requestor will be asked to pay, etc.

Commitment: A promise made between a ‘supplier’ and a ‘customer’ to perform an agreed task by a certain date. Commitments are made to the day or shift, depending on the nature of the project. As we learn how to be reliable planning to the day, we can begin learning how to be reliable planning to the half day, and so on.

Constraint: Something that stands in the way of a task being executable or sound. Typical constraints on design tasks are inputs from others, clarity of requirements criteria for what is to be produced or provided, approvals or releases, and labor or equipment resources. Typical constraints on construction tasks are the completion of design or prerequisite work; availability of materials, information, and directives. Screening tasks for readiness is assessing the status of their constraints. Removing constraints is making a task sound.

Daily huddles: Brief, typically stand-up, meetings each day by groups of interdependent players, at which each, in turn, shares what commitments they have completed, what commitments they need help with or cannot deliver. This can be done within a design squad or construction crew, and between front line supervisors of design squads or construction crews.

DCAP (Detect-Correct-Analyze-Prevent): A process for reacting to and learning from breakdowns. Detect breakdowns as close to the source as possible. Take corrective action so the operation can be restarted. For example, correct errors on drawings and replace previous drawings with corrected. Analyze the breakdown to find countermeasures. Implement the countermeasures to Prevent reoccurrence of the breakdown.

First run studies (FRS): First trial execution of an **operation** as a test of capability to meet safety, quality, time and cost targets. The FRS begins several (e.g., 2 or 3) weeks

ahead of the first run with a planning session in which the team that will do that work is involved in developing a detailed work plan at the ‘step’ level of task breakdown, so each person on the team knows what they are to do. First run studies follow the **plan-do-check-act** cycle. The plan is developed, the first run is carried out, the results are checked against the targets. If the results are inadequate, the operation design is replanned and the test performed again. This continues until the operation is considered capable, then that way of doing that type of work is declared the standard to meet or beat. First-run studies are done ahead of the scheduled first start of the operation, while there is time to acquire different or additional prerequisites and resources. First run studies are one of three ways in which operations can be designed: the other two are virtual prototyping (virtual first run studies or VFRS) and physical prototyping (mock ups).

Five Whys: Asking *why* repeatedly to help uncover countermeasures to reoccurrence of a problem. Usually the ‘root cause’ is identified within 5 “whys”.

Frequency of plan failures: The percentage of total plan failures from each primary category; e.g., lack of prerequisite work, lack of design information (none or defective), lack of materials, changed priorities, or failure in execution.

Lookahead planning: The level of planning between phase schedules and daily/weekly work plans, dedicated to making scheduled tasks eligible for commitment. That is done through constraints analysis and removal, breaking down tasks into operations, and collaboratively designing those operations. When constraints cannot be removed on critical tasks, replanning is initiated.

Master schedule: Schedule covering an entire project start-to-finish, then further detailed and validated in phase scheduling, the activities in which are then exploded when creating the make-ready schedule.

Milestone: Completion point of project phases such as substructure, superstructure, utility rough-ins, and finishes on a building project.

PDCA (Plan-Do-Check-Act): Process for learning from experiments. Experiments start with a hypothesis about the consequences of an action, formulated in a Plan. For example, it might be hypothesized that improving workflow reliability increases productivity. Do is performing the experiment; i.e., taking the action. Check is assessing the consequences of the action, in this case measuring if productivity increases with better workflow reliability. After appropriate revisions and retests, Act consists in standardizing practice. The Analyze step in DCAP is the PDCA process, in which the hypothesis to be tested is the countermeasure proposed to prevent the breakdown being analyzed.

Percent Plan Complete: Metric used in the LPS to gauge plan reliability. The percentage of actual completions to planned completions in a daily or weekly work plan.

Phase Scheduling (also called Reverse Phase Scheduling): One level in LPS, where a phase gets broken out from the master plan, in which milestones define phases, and people responsible for the work in that phase jointly develop the plan. People in a “design phase” may include engineers, architects, owners, designers; perhaps also constructors and permitting agents. People in a “construction phase” may include designers, the general contractor and specialty contractors, perhaps also owners, inspectors and commissioning agents. Pull planning is used to identify, define and sequence tasks, creating a logic network. The phase schedule is produced by assigning durations to tasks and arranging them on a calendar.

Physical prototyping: Testing a product or process design using mock-ups.

Production control: Steering toward project safety, quality, time and cost targets

Project controls: Setting project time and cost targets and tracking progress toward them.

Pull planning: A method of planning collaboratively with those who are to do the work being planned. Features include first doing a backward pass from the target completion date or time of the work being planned and creating a schedule buffer that is allocated to critical and risky tasks in the plan. The initial output is a logic network showing the temporal dependence of tasks to be performed in the phase, process, or operation being planned. A schedule can be produced by estimating task durations.

Reliable promising: Promise reached by sticking to the steps of the Language-Action cycle (aka, Workflow Loop): (1) Making a request, (2) Negotiating (clarifications, conditions of satisfaction, and counteroffers), (3) Committing, (4) Executing, (5) Declaring Complete, and (6) Declaring Satisfaction.

Resources: Labor or instruments of labor, including tools, equipment, and space. Resources have production capacities as well as costs. Consequently, materials and information are not resources, but rather what resources act on or process.

Task breakdown: The tasks involved in executing a project can be usefully described at different levels of detail, but there is no generally accepted standard. We propose the following: projects are composed of phases, phases are composed of processes, processes are composed of operations, operations are composed of steps, and steps are composed of elemental motions. An example: Calhoun 101 Project consists of phases, including the Substructure phase. The Substructure phase consists of processes, including Place Drilled Caissons. The process for Place Drilled Caissons includes the operation Fabricate Cage. Fabricate Cage consists of steps including Fit and Tack Lifting Bands, which could be (but rarely is) further analyzed into elemental motions such as grasp, lift, rotate, etc.—how a robot would be programmed to do that task.

Task definition: A requirement for inclusion on daily or weekly work plans is that tasks are defined so that performers understand what is to be done, where, when, by whom; can determine what is needed by way of materials, information, tools, and equipment to perform the task; and task completion can be easily assessed.

Task sequence: The order in time of a set of tasks. A requirement for inclusion on daily or weekly work plans is that tasks can be performed now without incurring a penalty later.

Task size: A requirement for inclusion on daily or weekly work plans is that tasks are sized to the capability of those who are to perform them within the time constraints of the plan. This improves workflow reliability. As performers increase their capability, more work is assigned to them.

Task soundness: A requirement for inclusion on daily or weekly work plans is that in general tasks have had all constraints removed prior to start of execution. Note however by exception reasonable bets can be made; for example, regarding the reliability of suppliers delivering materials needed in time to perform the task.

Tasks anticipated (TA): A metric in the LPS that measures the percentage of tasks for a target week in the lookahead that were anticipated in an earlier plan for that target

week. The objective of this indicator is to provide a relative measure of how well the team is able to predict for the lookahead time horizon what is actually going to happen on the project. This planning ability is critical because without it, some of the tasks that need to be done cannot be made ready. In other words, TA measures the instances when tasks drop into the WWP that were not anticipated at the beginning of our lookahead planning window.

Tasks made ready (TMR): TMR is a metric in LPS that gauges the ability of the plan(ner) to forecast (predict) accurately in week i what tasks will take place $j-i$ weeks into the future (TMR_{ij}). It gauges the percentage of tasks in an earlier plan for a target week that are included in a later plan for the target week. Together with TA it characterizes the ability of the planning team to make work ready.

TA measures how well we are anticipating what tasks need to be executed within the lookahead window, and consequently is driven by task breakdown. TMR measures how well we remove constraints from those tasks so they can be executed, and consequently is driven by constraints analysis and removal.

Underloading resources: To allow for variation that cannot be reduced at a moment in time, resources are asked to produce less than what they could produce if there were no variation in arrival times of inputs or in processing durations. These capacity buffers are to be reduced as variation is reduced; e.g., by analyzing breakdowns and implementing countermeasures.

Variation: Occurrence of non-uniformity. For example, processes can vary in their durations, deliveries can vary in their arrival relative to due date, products can vary in their defects, workload can vary from one day or week to the next, resources can vary in their relation to available workload, etc. Reducing variation is usually possible, but there will always be some residual variation in production systems. As a result, buffers of time, cost, or capacity are needed in order to absorb that variation and allow the system to function.

Variability: The spread in a set of data points; measured by extent above and below a mean, by variance (the average of the squared differences from the mean), and by standard deviation (the square root of the variance).

Virtual prototyping: Testing a product or process design using computer modeling.

Visual controls & Visual displays¹⁶: Visual controls are used to manage input resources; e.g., color coded hats, zone plans, lines sprayed on the floor. Visual displays are used to communicate process status; publically placed and easy-to-interpret information regarding the state of a project relative to target (e.g., 71% complete, 5% below budget, only 1 lost time accident in the last 500,000 labor hours worked), the need for help with a problem (e.g., a light in the project office that flashes when workers need bricks delivered to the 7th floor), the status of a problem-solving effort—in short, anything that gives people on the project team information they need.

Workable backlog: This term has been used in two ways in LPS; 1) to name tasks that have been released for commitment in daily and weekly commitment plans (see Figure 2 in Section F: Processes), and 2) tasks that are available as fallback or follow-on options should specialists be unable to complete tasks on commitment plans, or can do

¹⁶ Distinction courtesy of Steve Ward, 6ix Consulting.

more tasks than planned, respectively. We recommend using “workable backlog” in the first sense, to refer to tasks that have been released for commitment, and “Plan B” for tasks included on commitment plans to serve as fallback or follow-on work.

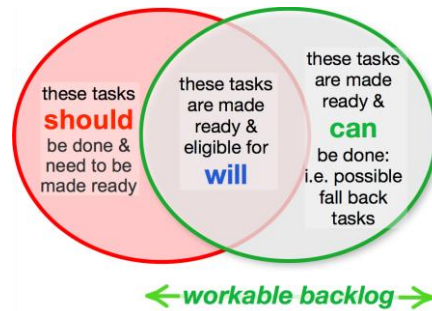


Figure 6: Forming Commitment Plans (courtesy of Alan Mossman)

All tasks on commitment plans are to be selected from workable backlog, and tasks are placed into workable backlog only if they satisfy criteria for definition, soundness, sequence and size. Tasks that are not critical, and hence are not included in SHOULD on the left hand side of Fig. 6 above, may be placed into workable backlog if they can be executed now without incurring a penalty later¹⁷.

Commitment plans may consist of a Plan A and a Plan B. Plan A tasks are those which are truly speaking commitments; others are depending on them being completed within the plan period. Plan B consists of fallback/follow-on tasks in case Plan A tasks cannot be completed, or as follow-on work in case Plan A tasks are completed earlier than expected. It is important for all interdependent players to understand both Plan A and Plan B, to avoid conflicts over space or other shared resources and to mitigate safety hazards from working in nearby spaces.

When forming commitment plans, Plan A tasks are selected first from tasks that SHOULD be done (as shown in the middle of Fig. 6 above). If there is additional

capacity, non-critical tasks that can be executed in the plan period without incurring a later penalty (as shown in the right hand side of Fig. 6 above) can also be included in Plan A.

Workflow reliability: A metric in LPS measured by Percent Plan Complete (PPC). It measures the extent to which a current commitment plan accurately predicts the state of the project at the start of the next plan period, and hence what workload will be available at that point in time for the various specialists working on the project. On different types of projects, different choices may be made about the timing of commitments. On most construction projects, the recommendation is to plan to the day, though once daily plans approach 100%, the target should change to planning to the half day. On very detailed operations, planning may be to the hour or even to the minute.

¹⁷ An example of ‘a later penalty’: In pursuit of more reportable progress and hence payments, when pipe supports are late arriving, pipe spools might be erected with #9 wire. This usually increases the difficulty of installing the pipe supports when they finally arrive and must be threaded through a maze of pipe, cable tray, conduit, and structures.

M. Last Planner System Publications

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