2020 CURRENT PROCESS BENCHMARK FOR THE LAST PLANNER® SYSTEM OF PROJECT PLANNING AND CONTROL

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ABOUT THE PROJECT PRODUCTION SYSTEMS LABORATORY (P2SL) AT UC BERKELEY

The Project Production Systems Laboratory (P2SL) at UC Berkeley is a research institute dedicated to developing and deploying knowledge and tools for the management of projects, which we understand as temporary production systems—hence the term "project production system." The Laboratory is housed under the umbrella of the Center for Information Technology Research in the Interest of Society (CITRIS).

P2SL is dedicated to developing and deploying knowledge and tools for the management of project production systems and the management of organizations that produce and deliver goods and services through such systems. Project production systems include for example construction, product development, software engineering, air and sea ship building, work order systems, job shops, performing arts productions, oil field development, and health care delivery.

Companies worldwide, and especially those involved in the Northern California construction industry, are invited to team up with P2SL staff and students, and use our resources to advance the theory as well as the implementation of the Lean construction philosophy, principles, and methods in the industry, its companies, and its projects. Our goal is to advance and deepen understanding of how to deliver Lean projects. All members of the industry are invited to become contributors and to participate in the Laboratory: owners, regulators, architects, engineers, contractors, unions, suppliers, insurers, financiers, etc.

Please join us in conducting research and by participating in P2SL events. We welcome your support, financially and in-kind.

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PREFACE

The Last Planner® System (LPS)[1] was initially designed as a system for planning and controlling production on projects, that is, to do what is necessary to achieve set targets (Ballard 2000). It was understood to differ from project controls, which sets targets (objectives and constraints on their delivery) and monitors progress toward them.

Initially, LPS consisted only of lookahead planning (Ballard 1997), weekly work planning, and learning from breakdowns. In the early 2000s, planning and scheduling project phases (which provide inputs to lookahead planning) were added to its scope, as described in the 2016 Benchmark (Ballard and Tommelein 2016). This 2020 Current Process Benchmark further extends LPS in principle to both production[2] (i.e., striving for targets) and project planning and control (i.e., setting targets).

That does not mean there is no longer a role for technical specialists such as schedulers, estimators, inspectors, etc. It means that a single system is needed rather than two systems; a system for the project chain of command to both manage the project and continuously improve the project's planning and control system. Technical specialists are still needed to collect and analyze information that managers at different levels need in order to make good decisions.

Project management functions other than project planning and control include human resource management, project financing, project contracting, and incorporation of technologies. The Lean Construction Triangle shown in Figure 1 provides a way to understand the scope of project planning and control: the LPS has its pride of place in the project operating system.

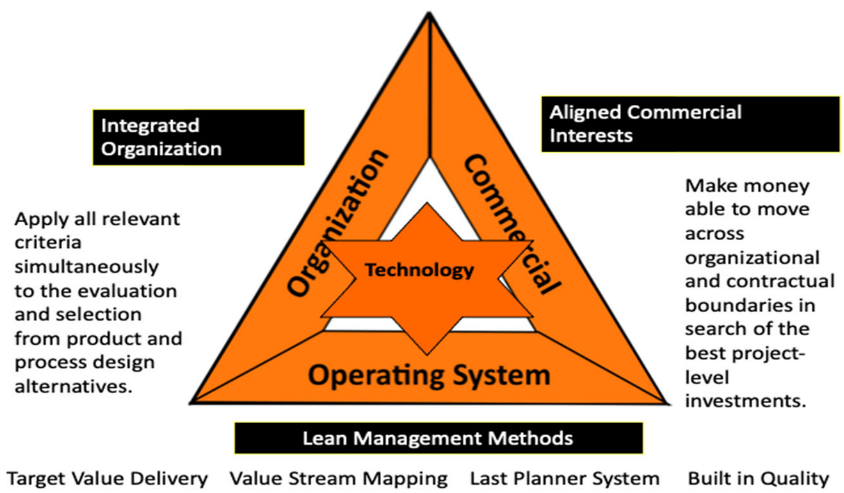

Figure 1: Lean Construction Triangle
(after triangle figure by Darrington et al. in Chapter 1 of Thomsen et al. 2010)

1 Last Planner®, Last Planner System®, LP®, and LPS® are registered trademarks of the Lean Construction Institute (LCI) (www.leanconstruction.org).
2 Production spans designing as well as making, i.e., design and construction.

In addition to extending the functions of LPS, a number of other changes will be found in this 2020 Benchmark document. Many of these changes were developed by five task teams working together since 2017. Team 1 was tasked with extending the LPS to planning and control of the entire project. To support that extension, Team 2 was tasked with developing and improving metrics. Team 3 was tasked with recommending location-based work structures for all appropriate project phases. Team 4 was tasked with reducing the barriers to take up of the LPS in design. Team 5 was tasked with developing a better description of means for learning from breakdowns. These five teams each published research reports (respectively Ballard et al. 2020, Christian and Pereira 2020, Nutt et al. 2020, Chiu and Cousins 2020, and Wilkinson et al. 2020) that are available at www.leanconstructionjournal.org and p2sl.berkeley.edu. The reports were used as input to this 2020 Benchmark.

Other changes were informed by research opportunities identified in the 2016 Benchmark that have since been addressed to various degrees by researchers around the world.

Appendices of this 2020 Benchmark illustrate methods and tools developed and generously shared by practitioners who have adopted the LPS and adapted the System to their project needs. These illustrations are not to be replicated exactly as they are but, rather, we suggest that you view them as a source of ideas and adapt them to your planning needs, language, and practices of your project team.

The authors of the 2020 Benchmark decided what changes to include and additions to make, and are solely responsible for any errors and omissions.

ACKNOWLEDGMENTS

For Help with the 2020 Current Process Benchmark

Thanks are due to the Lean Construction Institute for a research grant, to the authors and members of the five task teams that produced research reports on the topics listed below, and to everyone who shared examples of their Last Planner implementation, illustrated in the Appendices.

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For Help with the 2016 Current Process Benchmark

Although errors and omissions in this document are the P2SL authors' responsibility alone, this LPS Benchmark was produced through the combined efforts of many people. Jason Klous and John Draper [both of Lean Project Consulting], James Choo [Strategic Project Solutions], and Mike Williams [Project Production Institute] labored mightily on the draft of the document that was sent for comment to external reviewers. Valuable input was received from external reviewers Tariq Abdelhamid [Michigan State University], Dick Bayer [the Realignment Group], Samir Emdanat [vPlanner], Vicente González [University of Auckland], Ole Jonny Klakegg [Norwegian University of Science and Technology (NTNU)], Lauri Koskela [University of Huddersfield], Alan Mossman [The Change Business], Carina Schlabach [Zublin Construction], Bill Seed [Transformation Achiever Coach], Steve Ward [6ix Consulting], David Umstot [the Realignment Group], and Hajnalka Vaagen [Norwegian University of Science and Technology (NTNU)].

TABLE OF CONTENTS

LIST OF FIGURES

1 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 document reports on the current benchmark for the Last Planner® System (LPS)[3] for project planning and control.

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 and conventions, principles (or rules), and processes, to be a specification for project planning and control—not a specific way to plan and control 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 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 select or invent methods and tools (including metrics) 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.

Many of the presuppositions underlying LPS contradict paradigms characteristic of traditional, non-Lean construction, e.g., "Trust is for suckers," "Planners plan and doers do," and "The job of the supervisor is to tell their people what to do, not to ask if what SHOULD be done also CAN be done." For those who understand their world through such paradigms, the benefits of following Lean principles are simply impossible. Those considering adoption of LPS or other Lean methods

[3] Last Planner®, Last Planner System®, LP®, and LPS® are registered trademarks of the Lean Construction Institute (LCI) (www.leanconstruction.org/).

should review LPS presuppositions and see how they might conflict with their own presuppositions.

Recognizing that a standard practice must extend to the level of methods and tools, and that each organization needs to have standards for project planning and control, we list the elements to be specified in developing a standard (see standard in the Glossary).

Readers of this document may approach this Benchmark from different angles. The structure was established for readers who want to have a sufficient understanding regarding the WHAT and WHY of the LPS 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 Section 7 Processes, 8 Methods, 9 Implementation, and 10 Frequently Asked Questions, and then return to the remaining sections.

We understand that the LPS can and is being used to plan and control other instances of humans working together, but in this document we assume that it is applied in a construction project, both in designing and constructing.

A glossary of terms is located at the end of this document in Section 12. Terms in the Glossary are *italicized* on first use.

2 WHY LAST PLANNER?

A distinction is commonly made between "planning," in the sense of designing ways to achieve objectives, and "controlling," 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* (Ballard 1994). 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. In contrast, 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 (Ballard 1994, 2000, Ballard and Howell 2003, Ballard and Tommelein 2016). 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) were still set outside the LPS. That changes with this 2020 Benchmark, which extends LPS to planning and control of the entire project. This change impacts LPS functions, methods, and associated metrics.

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 capabilities (e.g., Ballard and Howell 1994a, 1994b, 1998) (see *task definition*, *task soundness task sequence*, and *task size* in the Glossary).

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 rate[4], a *lookahead planning* process was added to LPS so what SHOULD be done CAN be done when needed[5].

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* (aka. master plan), phase by phase (*phase scheduling* aka. reverse phase scheduling). Soon collaborative pull planning came to be used at every level of task breakdown: project (master schedules), phase, process, operation, and step. Now the functions of project controls are absorbed into the LPS.

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[4] Whether or not the rate of progress is adequate is a function of the amount of capacity relative to demand. See Section 5 Presuppositions and Conventions.

[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!

In contrast, the lookahead function within LPS is proactive. It involves making scheduled tasks ready, and replanning when some scheduled tasks cannot be made ready. As will be seen later in Section 8 Methods, "make ready" is done by identifying and removing any remaining constraints on scheduled tasks in the lookahead period, then breaking scheduled tasks down into operations, and designing those operations. If constraints cannot be removed, the task is rescheduled for a later date when constraints will have been removed.

3 LAST PLANNER SYSTEM INSIGHTS

Through the years, reflection on LPS implementation experiences has produced important insights. Here are a few; many of which, like the first one listed, 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 express concern or participate in the search for causes and countermeasures (Deming 1986, Dekker 2006).
- There is always a trade-off between time and cost, but the level at which the trade-off is made changes with workflow reliability, and LPS, properly implemented, improves workflow reliability[6].
- 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[7].
- *Five 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 LPS production control, which previous to this Benchmark did not presuppose any specific work structure[8]. This 2020 Benchmark includes a recommendation that location-based work structures be created for each phase of the project for which they are appropriate (see methods specifications Section 8.2.6).

6 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. (2014). Simply stated, as capacity utilization approaches 100%, wait time increases without end. Howell et al. (2001) applied this insight to LPS.

7 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).

8 Location-based work structures, including flow lines (Location Based Management System) and takt zones (takt planning), have been successfully used with LPS. To the extent that reliable release of locations 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, and synchronizing flows of materials, information and resources with the location plan (Seppänen et al. 2010, 2015, Frandson and Tommelein 2016).

- Currently, the three least-implemented components of LPS are design of operations (Section 8.2.8), measurement of lookahead planning performance (Section 8.2.14), and learning from breakdowns (Section 8.2.12). Many people who say they use the LPS do only weekly work planning. Some do only collaborative phase planning or pull planning. LPS is a system of interconnected parts. Omission of a part destroys the system's ability to accomplish its functions.

4 WHAT ARE THE FUNCTIONS OF THE LAST PLANNER SYSTEM?

Functions are the proper work of the system; its jobs. By extending the range of application of LPS from production planning and control to also include project planning and control with this 2020 Benchmark the functionality of LPS expanded. The set of functions that support the LPS fall in three categories: (1) Project Definition[9] functions, (2) Functions for setting and steering toward time and cost targets for the project, and (3) Project production planning and control functions.

- Project Definition functions:
  - Defining what's wanted from the project (its objectives and targets) and the *constraints* on its delivery.
  - Assessing the risk of achieving project objectives within constraints (incl. using *risk management*).
  - Deciding if to fund, revise, or abandon the project.
- Functions for setting and steering toward time and cost targets for the project:
  - Scheduling.
  - Cost budgeting.
  - Making visible the current and future state of the project.
  - *Planning to complete.*
- Project production planning and control functions:
  - Specifying what tasks should be done when and by whom to achieve project objectives, from milestones to phases between milestones, to processes within phases, to operations within processes, to steps within operations (see task breakdown in the Glossary).
  - Making scheduled tasks ready to be performed.
  - Selecting tasks for daily and weekly work plans—deciding what work to do next.
  - Making release of work between specialists reliable.
  - Assessing and improving the performance of the planning and control system; e.g., learning from plan failures[10].

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 functions are perhaps (almost) unprecedented; e.g., the explicit focus on making work ready, on workflow reliability, and on specification of selection criteria (beyond criticality) for tasks to be placed on near-term work plans.

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[9] Project Definition refers to the first triad in the *Lean Project Delivery System* (Ballard 2008).

[10] 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.

5 PRESUPPOSITIONS AND CONVENTIONS

Presuppositions[11] are what is assumed to be true about the world in which the project and production planning and control functions are to be performed. Since projects are production systems that are both social and technical, the relevant presuppositions concern the social, the technical, or their combination.

A. Production systems are both social and technical.

B. All plans are forecasts and all forecasts are wrong. Forecast error varies with forecast length and level of detail.

C. Planning is dynamic and does not end until the project is completed.

D. Involving those who will directly supervise or perform the work being planned results in better plans and greater ability to adapt plans when needed.

E. Operational performance (quality, safety, time, and cost) varies with the degree of planning and preparation.

F. 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. 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.

   Note: the proper goal for PPC is 100%; see D in Section 10 Frequently Asked Questions.

G. Making *commitments* publicly 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.

H. 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.

I. 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).

J. Actors within a project production system can make choices that help or hinder achieving project objectives; i.e., actors have discretion.

[11] Presuppositions are not the same as beliefs: the latter imply that their truth is taken for granted. Evidence and arguments exist for these presuppositions, but their truth remains open for discussion.

K. Understanding project objectives and the current and future state of the project helps actors make better choices.

L. Perfect planning may not be possible, but it is possible to never make the same mistake twice.

M. *Variation* in production systems can be reduced but never eliminated. Variation that is statistically predictable can be mitigated through *buffers* that absorb that variation and protect targets. Variation that is not statistically predictable must be handled by building flexibility into plans and project teams.

N. Workflow reliability, as measured by PPC, rises when commitments are made only to tasks that are properly defined, sound, sequenced, and sized (Principle 8 in Section 6 Principles and Rules).

O. Labor productivity is the ratio of input to output; e.g., 10 labor hours per ton of steel erected. That ratio is the product of the percentage of paid labor time used productively (labor utilization) and the output per unit of productive labor time (labor fruitfulness). Labor productivity rises and falls with PPC, but only in certain conditions. 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.

P. Progress rises and falls with PPC to the extent that tasks are made ready and executed 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.

- An activity or task[12] can be broken down and detailed at many different levels. 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 motions[13].

[12] We use both "activity" and "task" in this Benchmark to allow for discussion of previous work in its own terms.

[13] Motion analysis, the method of analyzing worker movements in terms of 18 elemental motions (described using so-called therbligs) was developed by Frank and Lillian Gilbreth in the early 1900s. Therbligs is inverse of the letters in their last name but keeping "th." Elemental motions are what robots are programmed to do, e.g., grasp, lift, and rotate. Motion analysis is not yet visible in construction, but may appear as robotics are introduced in fabrication shops and virtual reality simulations are developed.

6 PRINCIPLES (OR RULES)

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

1. Keep all plans, at every level of detail, updated and in public view at all times.
2. At project start, keep master schedules at milestone level of detail, except for tasks to be performed at a given time in order to initiate flows of information, materials or *resources* needed in later project phases, *long-lead items*, and *options*.
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, both positive and negative).
11. Underload resources to increase reliability of work release.
12. Allocate capacity first to *critical tasks* that have been released for commitment.
13. Maintain *workable backlog*; a backlog of ready work (tasks ready to be executed) to buffer against capacity loss and time loss.

7 PROCESSES THAT DEFINE THE LAST PLANNER SYSTEM

In this section, we describe the LPS using two diagrams (Figure 2 and 3) to show the relationship between levels of planning and the various functions fulfilled at each level. These functions are performed using methods that describe processes and steps.

A note on terminology: Recognizing that the terms system, process, operation, and method are used in a variety of ways in common speech and are sometimes substituted one for the other, we want to be clear how we are using the terms in this Benchmark document.

- The Last Planner is called a "system" because it is structured to perform specific functions in order to accomplish the purpose of planning and control.
- A process is a series of events and steps that produce an outcome; i.e., are used to perform a function such as determining which scheduled tasks are released for commitment in weekly work plans.
- An operation is the name we give to steps within processes with those steps being assigned to a single trade or discipline (or to an integrated team); e.g., installing pipe hangers in the process of erecting pipe.
- A method is a way of performing the operations within processes; e.g., preinstall pipe hanger weldments in structural steel fabrication, or install them on site after receipt of the steel, or install them after steel is erected.

When we say that methods are used to perform functions in accordance with principles, we are compressing the intermediate distinctions between functions and methods. Otherwise, we would have to say: 'Methods are used to perform operations within processes, which are used to perform functions within the Last Planner System, all of which is done in conformance with principles.' We trust that this compression, which occurs frequently in common speech, is understandable to our readers.

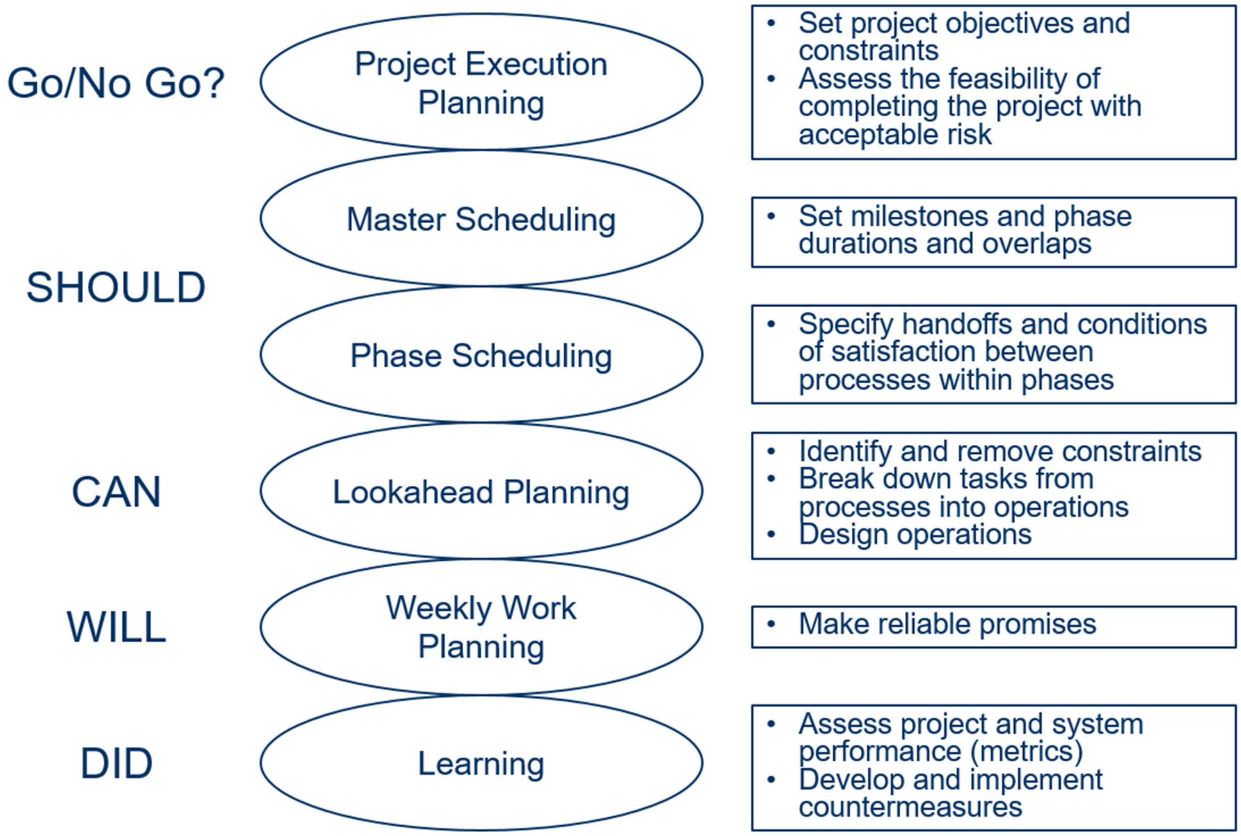

Figure 2: Last Planner System of Planning and Control -
Go/No Go?-SHOULD-CAN-WILL-DID

The structure of the diagram in Figure 2 is based on first deciding if to initiate a given project. Project execution plans are created to assess the feasibility of successfully completing a given project. Master and phase schedules specify what SHOULD be done when and by whom in order to achieve project objectives. 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 (e.g., broken promises or notable successes) are identified by comparing DID to WILL. Then, in case of a negative deviance, the failure is analyzed in search of countermeasures to prevent reoccurrence; in case of a positive deviance, it is analyzed in search of repeat opportunities and possible incorporation of the practice into a new standard that raises the bar.

Figure 3 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 consists of operations. Operations designs (specification of how work is to be performed in order to meet set expectations) are expressed in steps to be carried out by individuals or teams.

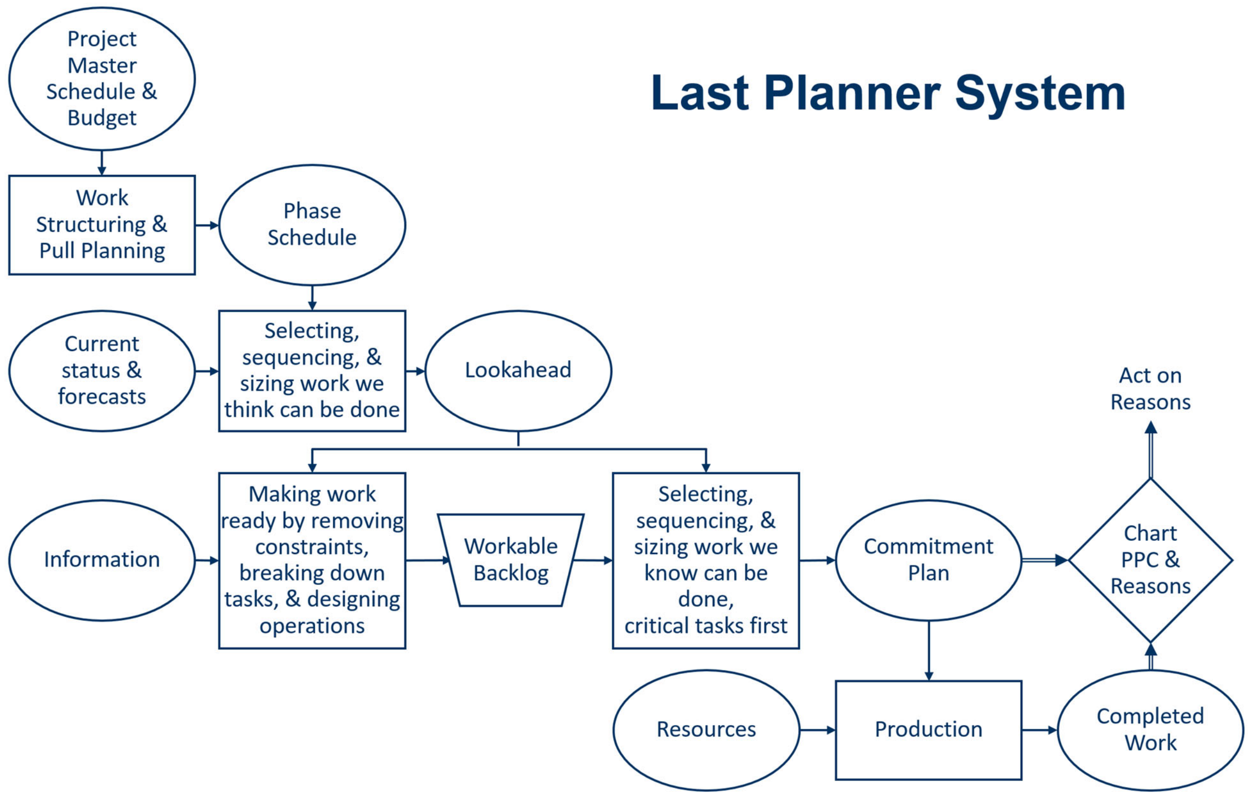

Figure 3: Relationships between planning levels in the Last Planner System

Note that the work plan that immediately drives production is the product of selection from eligible tasks in workable backlog. Commitment can be made only to workable backlog tasks, namely tasks that have been screened for constraints, have been made constraint-free, and are tagged as critical or non-critical. Last Planners should be involved in lookahead planning so they can see what will become available for them to choose from, they will recognize critical tasks and allocate their capacity first to those, and they can help make decisions how to allocate scarce capacity (see workable backlog in the Glossary).

The tasks in commitment plans are tied to operations. Execution of operations in accordance with their design is controlled by the front-line supervisor (Last Planner) and those executing the work.

Also note that the workable backlog may include tasks not directly related to production, but aimed at improving performance of the individuals, the task, the project, or the organization(s) involved.

8 WHAT METHODS ARE USED TO ACCOMPLISH THE LAST PLANNER SYSTEM FUNCTIONS?

Methods and tools are products of invention and are judged by their consistency with principles and utility in performing functions within specific circumstances. We offer three examples of methods: Walter Shewhart invented a form of Plan-Do-Check-Act in the 1930s; more recently, pull planning was adapted from earlier collaborative planning approaches and understanding that complex, adaptive systems must have mechanisms to allow for real-time feedback; and the taxonomy offered in this Benchmark 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.

Note that some of the methods listed are broader in their application than others; we do not intend to limit their range of application. For example, methods for learning, problem solving, coordination, goal setting, etc. apply to the LPS but also well beyond it.

In the subsections that follow, we first list the methods according to the LPS functions they accomplish and then describe each one. We hope to have identified those methods that are both capable and have been proven in practice and theory. It is likely that other methods are in use and likewise suitable, however we may not be aware of them or they may not yet have been tested against the criteria presented in this benchmark. If you are confused about whether or not a method is appropriate for the LPS, here are the criteria: Is the method fit for purpose in performing a LPS function? Is it consistent with LPS presuppositions and principles? Recommendations for future research in Section 10 are intended to identify and test new methods and tools for adoption. If the need for a method in which you are interested is not included, feel free to add it in.

8.1 Methods Categorized by LPS Function

Section 4 introduced 3 categories of functions: (1) Project Definition functions, (2) Functions for setting and steering toward time and cost targets for the project, and (3) Project production planning and control functions. Here we expand on methods to accomplish those functions.

A. Methods for performing the following Project Definition functions:
    1. Define what's wanted from the project (objectives) and the constraints on its delivery.
        i. What's wanted refers to the purpose for which the project is being done; e.g., to provide specific services to customers in a region. Traditional methods for defining what's wanted from a project are satisfactory so long as the objectives do not specify only means as opposed to ends, and so long as there is a systematic way to identify and include the concerns of internal and external stakeholders (Ballard 2020).
        ii. As regards constraints on project delivery, Target Value Delivery methods are recommended; i.e., taking a whole life view of benefits and costs, agreeing an allowable

cost for what's wanted, estimating the expected cost for what's wanted, assessment of the gap between allowable and expected and exploration of ways to eliminate or reduce the gap (Tommelein and Ballard 2016, Ballard 2020). Project cost and duration are typical constraints, but goals and objectives function as constraints on successful delivery and goals can be economic, social or environmental.

2. Assess the risk of achieving project objectives within constraints.
   i. The best method of which we are aware is to develop a project execution plan and assess its level of risk after mitigation of risks and exploitation of opportunities are incorporated into the plan. A future research task is to assess the use of CPM plus *stochastic planning* methods to develop the schedule within the project execution plan (Ballard et al. 2020, Grau et al. 2019).
3. Decide if to fund, revise or abandon the project.
   i. These decisions are made by the project client (paying customer); but on projects where risk and reward are shared, the companies who will share the risk also have the power to accept or reject taking on project risk.

B. Methods for setting time and cost targets for the project[14]

1. *Scheduling*
   i. Mindful that the project execution plan developed in Project Definition is almost certainly not how the project will actually be delivered, simplify to a major milestone schedule with long lead items embedded. Note that long lead items include options as well as purchases. Once the project begins, decide how to structure the work in each project phase and use pull planning to plan how to do the work in each phase collaboratively with those responsible for doing the work.
2. Cost (*Budgeting*)
   i. Allocate the total project cost target developed in Project Definition to cross functional teams responsible for the systems and components to be designed. In Target Value Delivery, project cost targets are set prior to Design[15]. As a result, allocation of that total cost target to systems and components to be designed are necessarily provisional, allowing for increases in the cost of one system to be offset by decreases in the cost of other systems. Allocation is to systems and components because it is the cost of these that are affected by design alternatives. (Likewise, other design targets, such as weight, may be set prior to design and managed in a similar fashion.)
   ii. Allocate the total project cost target developed in Project Definition to the high-level work packages that are to be constructed. Allocating cost in Construction[15] should also be by system and component, but if the key design and construction firms do not share

[14] The project needs to be steered toward targets set for other constraints; e.g., quality including safety, social, or environmental outcomes. The scorecard shown in Appendix A was developed for a large Sutter Health project; it illustrates how such targets can be framed and tracked.

[15] Design and Construction are capitalized as they refer to triads in the Lean Project Delivery System (Ballard 2008).

risk and reward, cost allocation should also be expressed in terms of contracts, reflecting the various contracted work scopes.

3. Planning to complete
   i. Assessing and improving the state of the project relative to its targets; i.e., planning to complete: from each point in time, planning how to achieve project objectives, or to achieve revised project objectives.
   ii. Making visible the current and future state of the project so everyone can better exercise their discretion—see *visual controls* in the Glossary.

C. Methods for project production planning and control

1. Methods for specifying Should
   i. Work structuring
   ii. Scheduling
   iii. Logic networks
   iv. Pull planning
   v. Location-based planning

2. Methods for lookahead planning/make ready
   i. Constraints analysis and removal
   ii. 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.
   iii. Collaborative design of operations—what steps in what sequence performed by whom using what:
      (1) Virtual prototyping
      (2) *Physical prototyping* (construction operations)
      (3) First Run Studies

3. Methods for increasing workflow reliability
   i. Reliable promising: Disciplined approach to commitment making in which both the requester and the 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).
   ii. Criteria for committing to tasks in short-term (e.g., daily/weekly) work plans
      (1) Task sequence
      (2) Task soundness
      (3) Task size
      (4) Task definition
   iii. Visual controls
   iv. Underloading resources
   v. Daily huddles

4. Methods for learning from plan failures
   i. Analysis of breakdowns to understand why they occurred and to identify the level of cause at which countermeasures can be effective in preventing reoccurrence.
      (1) *PDCA*: Plan-Do-Check-Act
      (2) *DCAP*: Detect-Correct-Analyze-Prevent

5. Methods for assessing the state of the project relative to its targets
   i. *Milestone Variance* (MV)
   ii. *Percent Required Complete* (PRC)

6. Methods for assessing the "health" of the planning system
   i. Commitment Level (CL)
   ii. Percent Plan Complete (PPC)
   iii. *Tasks Made Ready* (TMR)
   iv. *Tasks Anticipated* (TA)
   v. Frequency of Plan Failures

8.2 Description of Methods that Accomplish LPS Functions

8.2.1 Risk Assessment and Mitigation

Risk is generally understood as something negative, but is grounded in uncertainty, and uncertainty can offer opportunities for gain as well as possibility of loss. Uncertainty is of various kinds, one of which involves *variability*, which may either be completely indeterminate or statistically predictable. Only the latter can be buffered. Indeterminate variation can only be mitigated by increasing flexibility in plans and in teams.

8.2.2 Stochastic Planning

Stochastic planning refers to methods for planning in conditions of uncertainty. Since there is always uncertainty in projects, there are often needs for stochastic methods such as *postponement* and *hedging*.

8.2.3 Pull Planning

Pull planning is a method for planning and scheduling. It is so-called because the first pass is done backwards from target completion to start. That is done in order to promote reliable promising among the participants who are working together in the project, phase, process, operation, or step being planned. Pull planning can be used to plan work in any time horizon, or to sequence activities as part of a production plan, such as a phase of a project.

Pull planning should be done sufficiently in advance of planned start to allow time for "making ready." For example, pull planning 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 G in Section 10 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., specialists in safety, quality, logistics, and auditory engineering. A key to successful pull planning is to have those experts collaboratively working together to develop the sequence of activities that produces an acceptable workflow.

Pull planning involves the identification and definition of the milestone, or key event that the team will be pulling to; e.g., a point in time that releases subsequent work activities. This event may be shown as a milestone on the master schedule, or it could be a point in time the team chooses to target.

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.

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, see examples in Appendix E) 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. 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 (e.g., we ask for an entire submittal package when we need only the answer to one question). 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, multiple detailed pull plans may be developed for different areas, systems, or time periods all in the same phase of work.

A planning process that starts with pull planning, during which those who have a stake in doing the work (generally referred to as "trades" or "disciplines") engage in (re)structuring the network (rearranging tasks relative to one another, as well as adjusting their duration and repositioning them on a timeline), will get the benefit of reliable promising (described in Section 8.2.10). Through conversation, trades involved in pull planning will make clear what handoffs they expect to get from others, and what handoffs they can guarantee to others. 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 (Ballard et al. 2020). Pull planning produces a plan that is viewed as a logic network in order to determine the amount of time in the phase or project being planned relative to the available time. When the project master schedule is being pulled, the available time is between scheduled start and completion of the project (but a schedule at any other planning level can be pulled in a similar fashion). If an attempt at pulling is too long to fit within scheduled start and completion, replanning is launched to try to make it fit by identifying activities or scopes of work that are not needed, can be reduced in duration, or can be divided into parts that overlap, increasing concurrency. This second attempt typically produces more intense conversations as participants try to better understand what their immediate customers really need, and what they themselves really need in order to serve their customers. To prepare them, participants are introduced to the reliable promising process in their orientation to pull planning.

The criterion for "fitting within available time" is the longest path through the network plus a time buffer sized by the participants after identifying elements that are both critical and highly variable. Figure 4 shows a network that does not fit within the available time even before adding the time buffer.

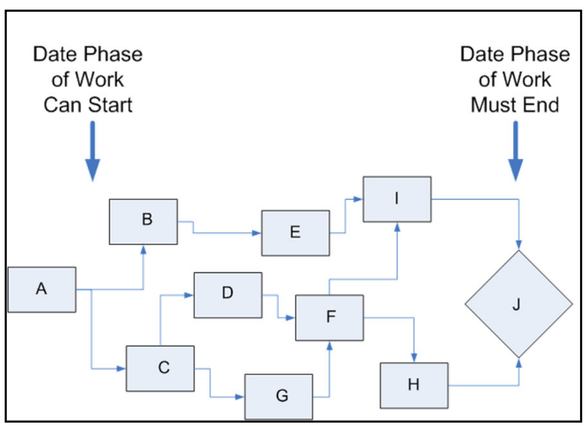

Figure 4: Logic network does not fit within available time

Figure 5 shows the network produced after replanning, including provision for a schedule buffer. In this example the buffer is approximately 10% of the scheduled duration of the network without buffer, but note that this percentage is to be calculated by the team to suit each plan. The buffer is shown at the front of the network as it was obtained by starting to pull from the end milestone J, defining prerequisite handoffs, and gradually working to the front of the network.

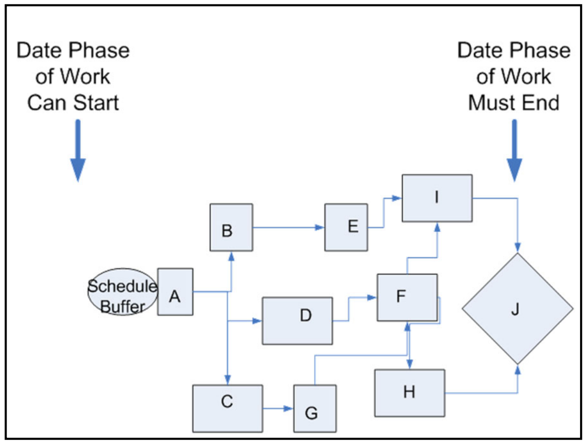

Figure 5: Logic network with schedule buffer

The next step is to assess if that schedule buffer will be sufficient to make the schedule as resilient as desired. It may be possible to divide the buffer into smaller ones to be positioned judiciously at key locations in the network. If not, another attempt at replanning is in order.

On projects where the participants are paid collectively for performance, as in Integrated Project Delivery projects, a part of the schedule buffer may be placed at the end of the project or phase and drawn down as needed. This approach is advocated for, e.g., in Goldratt's (1989) Theory of Constraints; its implementation requires that participants invest in having resources at-the-ready to start as soon as their predecessors finish. However, being at-the-ready may be particularly challenging for participants who are balancing resource requirements over multiple projects and when activity durations are hard to predict.

On projects where participants have separate commercial interests, the schedule buffer should be allocated to activities that are both critical and uncertain (Figure 6), in order to absorb that variation in time, should it occur, and thereby avoid changing the start dates of successor activities.

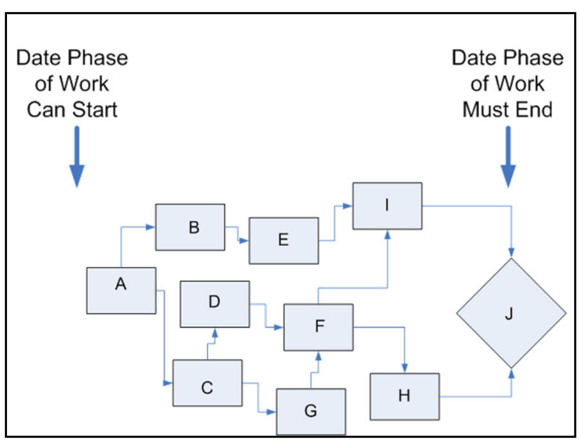

Figure 6: Logic network after buffer has been distributed

Some project phases may need to be completed on specific dates. Consequently, once a master schedule has been drafted that fits within the available time and is buffered, it must be checked for meeting all project milestones. Displaying master schedules as logic networks helps identify if a milestone is achievable, and also helps Last Planners be better able to determine task criticality in execution. If the draft master schedule indicates that all activities necessary to complete a milestone will not be completed before the date of that milestone, then the appropriate Last Planners need to identify alternative workflows that can meet the milestone. An advantage to having the scheduler involved in creating the master schedule during the pull planning session is that they have the opportunity to check that the resulting master schedule meets project milestones. If it does not meet them, the Last Planners can make the necessary adjustments to the pull plan and schedule to meet project milestones during the pull planning session.

When phases are head-to-tail, without overlaps in time, the critical path[16] is easy to see. Head-to-tail sequencing of tasks means that resources to perform those tasks will be used consecutively. However, if phases overlap, which often happens, it is more challenging to ascertain that all phase milestones can be hit. It is more difficult to spot which tasks are critical because a task in one phase may compete for resources needed by a task in a parallel phase, and such resource constraints may not be shown in the schedule. In situations of resource contention, prioritization in resource allocation will affect which path can or cannot proceed.

8.2.4 Work Structuring

Work structuring is the process of breaking work into pieces, where pieces will likely be different from one production unit to the next, so as to promote flow and throughput. Work structuring answers the following questions (Ballard 1999, Tsao et al. 2004):

1. In what units will work be assigned to production units (groups of workers)?
2. How will work be sequenced?
3. How will work be released from one group to the next?
4. Will consecutive groups execute work in a continuous flow process or will their work be decoupled?
5. Where will decoupling buffers be needed and how should they be sized?
6. When will different units of work be done?

Work structuring is a dynamic process to be re-evaluated in the course of a project. At the project onset, work structuring deals with designing the overall system. As the project progresses, work structuring becomes more focused to guide the design and execution of interacting pieces of impending work. Accordingly, the products of work structuring are (1) global sequencing, (2) project organizational and contractual structure, (3) supply chain configurations (how the project hooks to external production systems), (4) master schedule and phase schedules, and

[16] The critical path as computed using the Critical Path Method (CPM) is the sequence of activities with no float.

processes within them, (5) rough-cut operations designs (e.g., decision to cast-in-place vs precast, or use a tower crane vs rolling stock), and (6) detailed operations designs (e.g., how to form-rebar-pour basement walls).

The work to be done on a project can be structured in different ways. The simplest might be sequence, e.g., the cladding of a building is to start at the southwest face and proceed clockwise. When work can be divided spatially, some form of location-based structuring is recommended, e.g., using flow lines or takt planning. Some design work can be organized by location, e.g., production of room data sheets and detailed engineering.

8.2.5 Scheduling

Scheduling is the process of assigning dates and times to planned tasks arranged in a logic network (e.g., depicted as an activity-on-node precedence diagram) in order to produce a schedule, which includes milestones and the start and end time of activities (activity durations). This process typically is supported using Critical Path Method (CPM) calculations to determine the overall duration of the project, identify float (aka. slack) in the schedule, perform time-cost trade-off analysis, and decide on resource allocation and leveling. Such calculations are also done in other scheduling methods (see for example the following section 8.2.6 on Location-based Planning).

The CPM is widely used in project management but its traditional use has been critiqued for failing to address the needs of production management[17]. High-level CPM schedules tend to abstract away resource allocations and loading to available capacity, and fail to acknowledge variability in the activity network and how to buffer for it. In contrast, LPS is structured to recognize the frailties of planning:

- Plans are forecasts and forecasts are always wrong.
- The further out into the future you plan, the more wrong you are.
- The greater detail you plan, the more wrong you are.

8.2.6 Location-based Planning

Participants in pull planning, as described in Section 8.2.3, will likely take into account where tasks are to be done and how much space will be needed to perform them, considering space needs to a lesser or greater degree. The process of pull planning can thus be used with location-based planning methods to determine "trade" sequence through locations, and to reveal locations where A performs operation a, B performs operation b, and A performs operation c, thus necessitating that A's work in such locations be interrupted until B provides a prerequisite condition.

Location-based planning methods make the use of space explicit and thereby make it possible to further streamline the workflow by structuring the work based on space availability and

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[17] Reference works on project management such as the PMBoK (PMI 2017) state that they are not concerned with production or day-to-day operations planning.

recognizing there is always contention for space (e.g., space where work is to take place, where materials are stored, where access is needed, etc.). Several location-based planning methods exist, such as the line-of-balance method (LoB), short-interval planning (SIPS), block scheduling, even-flow production, and takt planning. These all aim at creating flow but they do so in different ways.

8.2.6.1 Line-of-Balance Method (LoB)

The line-of-balance (LoB) method represents the schedule by showing activities over time vs. by units of space displayed one-dimensionally. Each activity is assumed to be governed by a resource that sets its pace of progress (e.g., production rate). The LoB method is typically applied on projects with repetitive units where crews progress from one unit to the next. For horizontal projects (e.g., highways), the horizontal axis will display space (e.g., a road section of a certain length between stations) and the vertical axis time. For vertical projects (e.g., tall buildings), the opposite is the case: the horizontal axis displays time and the vertical axis space (e.g., a floor) (Figures 7 and 8).

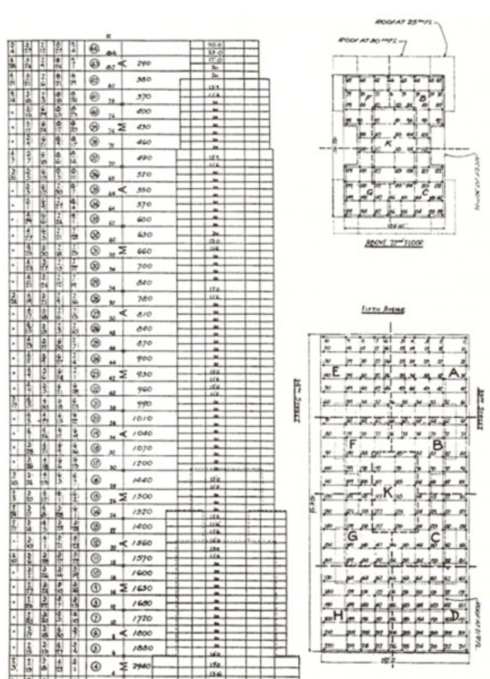

Figure 7: Schedule for structural steel for the Empire State Building, with dates of information and drawings required from the architects, mill orders, shop drawings, steel delivery, and steel erection. From *Architectural Forum*, 52 (1930): 772 (Figure 1 in Willis 1998)

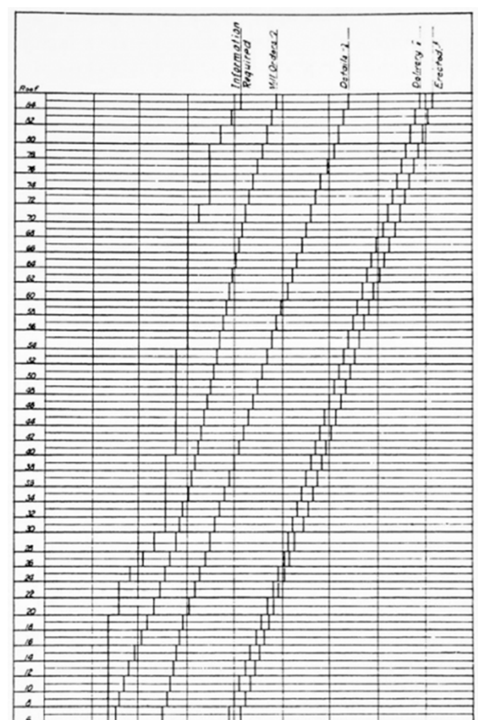

Figure 8: Detailed program for manufacture and erection of structural steel, Empire State Building, New York City. From "The Economic Design of Office Buildings" by R.H. Shreve, in *Architectural Record*, 67 (1930): 346 (Figure 2 in Willis 1998)

The LoB depicts the speed at which work progresses and thus makes it clear if those speeds are balanced across activities and trades. Balancing is done by selecting a pacemaker and then syncing other work up with it. For example, the builders of the Empire State Building used 4 pacemakers related to structural steel and then aligned the speed of on-site work as well as the project's supply chains with them (Willis 1998). Planning goals include ensuring continuity in resource use and completing the project expediently, and prioritizing one over the other in case of conflict (Harris and Ioannou 1998). Time and space buffers are added to the LoB schedule to counteract the manifestation of variability in activity durations that can result in interruptions of subsequent work and cause reverberations of delays through the schedule.

Kenley and Seppänen (2010) described how the LoB method can be made integral to a location-based management system (LBMS) for managing and controlling projects. In turn, they integrated LPS concepts into their system to take advantage of the LPS functions to adaptively steer and control the work flow (Seppänen et al. 2010, 2015).

Frandson et al. (2015) summarized the history of location-based planning methods, and compared specifically the LBMS with takt planning (TP). They concluded that "Construction planners can use four types of buffers: (1) time, (2) capacity, (3) space, and (4) plan buffers (workable backlog). LBMS buffers with (1), (3), and (4). Time is the preferred buffer, but space is also used when work is scheduled in areas larger than a crew requires to complete their task productively. In contrast, TP buffers with (2), (3), and (4). Capacity is the preferred buffer, accomplished through underloading. Space (zones) unoccupied by any trade during a given takt can also serve as a buffer." It is this selection of buffers, and how buffers are sized and positioned in the schedule, that differentiates location-based planning methods. Before saying more about takt planning, we first address a set of methods in-between, known as short-interval planning system (SIPS), block scheduling, and even-flow production.

8.2.6.2 Short-interval Production Scheduling (SIPS), Block Scheduling, and Even-Flow Production

Several planning methods address the desire to balance the speed of all activities in a process sequence—an objective also in the LoB method—in a different way. Methods such as short-interval production scheduling (SIPS) (Burkhart 1989), block scheduling, and even-flow production (Bashford et al. 2003, Wardell 2003), start at a high level (e.g., the master or phase schedule) to plan the work top-down by setting the pace of progress to match the project's or phase's start- and end milestones, while simultaneously carving out work areas. Each specialty contractor involved then identifies their scope by location and adjusts their production rate to match the pace. Their input can also lead to adjustments in the schedule and work areas.[18]

[18] Details are lacking; the principles and technical details of these methods are not well documented in the literature.

Wardell (2003) describes a builder who adjusts the sales price of their homes in order to maintain a steady production throughput rate (i.e., an application of Little's Law[19]). Even-flow production can be improved by increasing work flow reliability, and developing multi-skilled, multi-craft teams so that activities can be reduced in duration (e.g., through first run studies and operations analysis) and can be overlapped within their phase of the work (Ballard 2001).

A week-beat schedule paces the work by choosing one week as the time unit for the short interval. For example, Court (2009) planned 4 days of work and reserved the 5th day as buffer time. This buffer gives crews time to catch up on any delays and thus helps to increase the likelihood that the next week's work will be able to start as planned.

Horman et al. (2003) illustrated the SIPS approach taking to renovate the Pentagon. Figure 9 gives a birds-eye view of the overall construction sequence. Figure 10 illustrates one part of the location breakdown structure; not shown are the other major spaces namely the "chevrons" in the corners of the wedge. Figure 11 shows the SIPS schedule (aka. block schedule) based on a 5-day work structure.

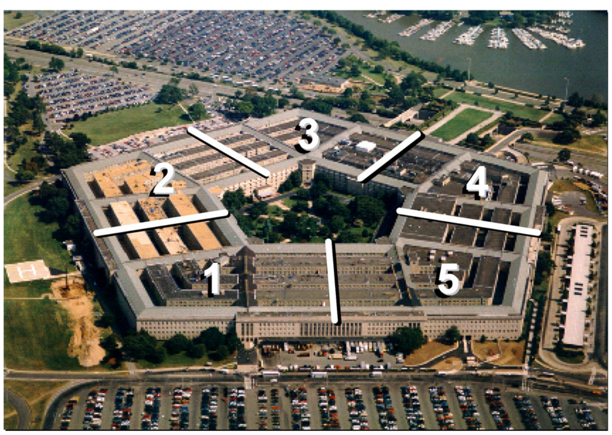

Figure 9: Overall construction sequence for Pentagon renovation (Figure 1 in Horman et al. 2003)

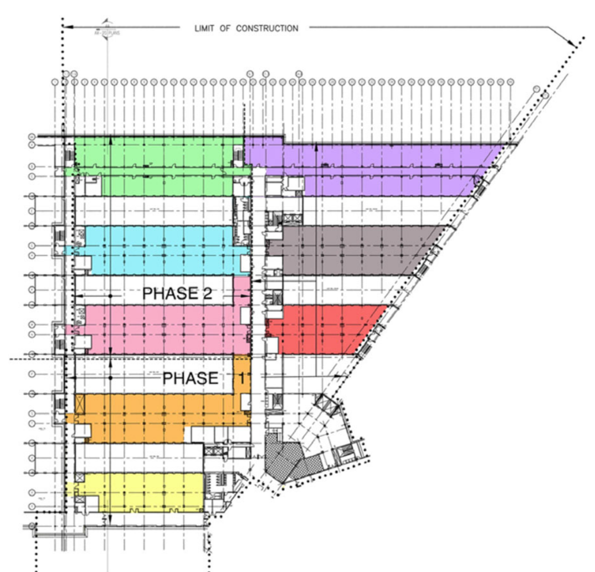

Figure 10: Location breakdown structure showing the "main bars" for Pentagon renovation (Figure 3 in Horman et al. 2003)

As shown, SIPS schedules tend to have long activity "trains." Such trains need to include time (sometimes entire weeks) to allow for any catch-up and rework, inspections, punch list work, etc. In order to stick to the week-beat (or other short-interval beat) yet also make work progress fast, train wagons may include not one but several specialty contractors who in turn then need to coordinate the use of the work space and other resources they share.

[19] Throughput = Work-in-Progress/Cycle Time (Pound et al. 2014)

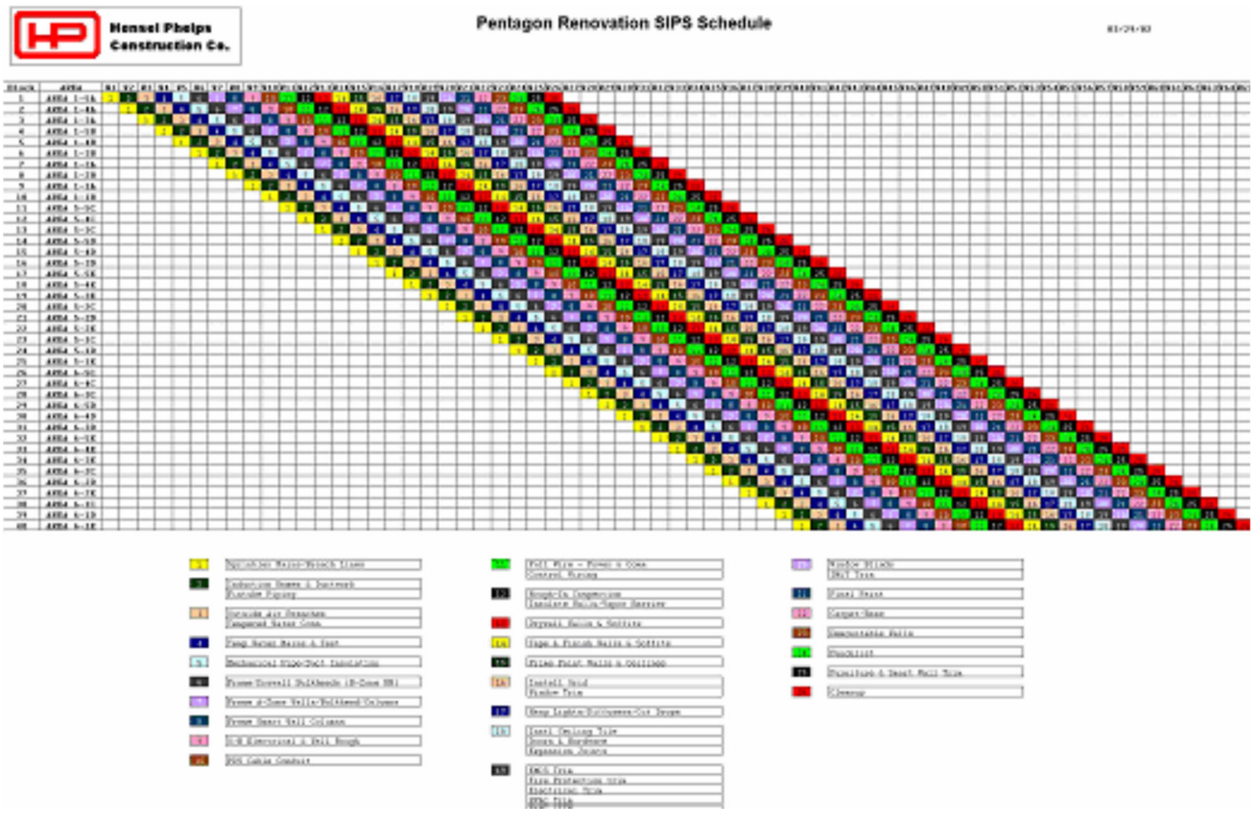

Figure 11: SIPS train for Pentagon renovation Wedge 2 (Figure 4 in Horman et al. 2003)

8.2.6.3 Takt Planning

Like the methods mentioned in the previous section, takt planning starts by identifying the milestones with the desired start and end date of a phase of work. These should be set by the demand of internal and external customers.

Taking these top-level considerations into account, takt planning then iterates using a top-down and bottom-up approach to planning. Engaging the trade specialists involved in a phase of work and leveraging their expertise and potential means and methods to find the best way to optimize the delivery of the phase, takt planning involves recognizing what work will take place where, identifying steps needed to complete work in the phase, lining up these steps in one or several processes, and then for each process deciding on the exact sequencing of the steps included in it and the maximum time (aka. takt) in which they are to be completed. This iterative process may involve investing in certain steps to balance them better with others in a process, so that the takt for the process can be lowered. Steps may also be split or combined, and moved to other processes. In addition, the planning team must allocate capacity, inventory, and time buffers where appropriate, as well as decide how missed takt will be tracked, made up for (e.g., work overtime or on weekends), and paid for.

Figures 12 and 13 illustrate a work space zoning and the associated takt plan for the overhead rough-in phase of a multi-story healthcare project. After considering alternative settings for throttles in the system (e.g., ranges in crew sizes, possibility of off-site fabrication), the planning team divided the work space (one floor) into three zones. Based on logical sequencing, several sequences of steps were combined into processes (e.g., one process includes Fire Sprinkler, Layout, Posts, and Cores). Each process was then takted, and linked by hand-offs (using finish-to-start relationships). Figure 13 illustrates the takt plan for this phase of work spanning 4 floors.

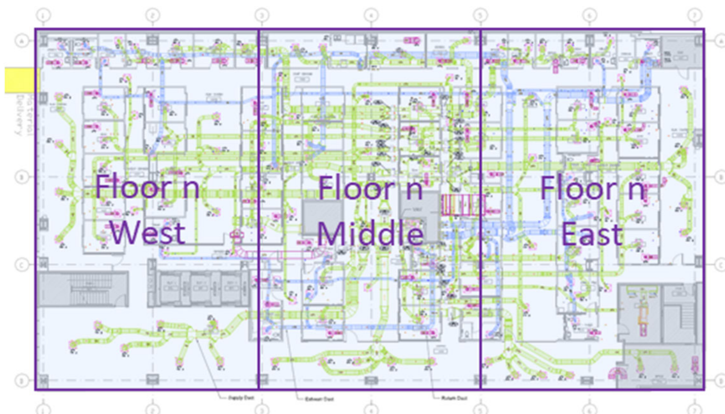

Figure 12: Zoning for takt planning of healthcare project
(Courtesy of Samir Emdanat [vPlanner])

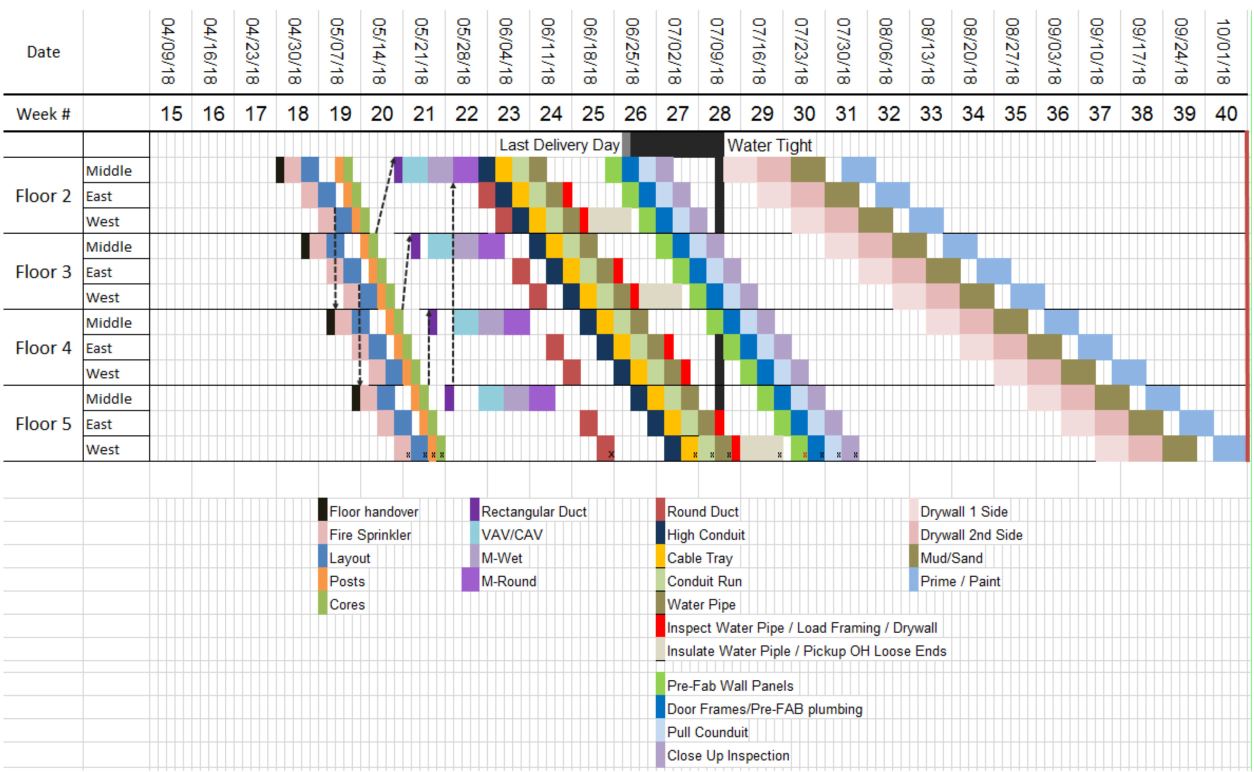

Figure 13: Takt plan (Courtesy of Samir Emdanat [vPlanner])

Planners can use any one of several methods to develop their takt plan; the development of new methods and assessing their effectiveness is an area of ongoing research. For example, Binninger et al. (2017) describe Technical Takt Planning developed for building projects with clearly-identifiable replicable elements (e.g., hotels). This method is based on dividing the project by type of functional area, in each of which the same process will be performed. After determining area priorities, the smallest repetitive part of the project is determined ("Standard Space Unit"), and the team then plans the sequence of steps for each of these. Based on take-off quantities and production rates, durations are established, activities with very uneven durations may be grouped, and the takt plan is created.

Where architectural features do not appear to have a regular pattern (e.g., interior overhead work in healthcare projects does not have the same kind of replicable elements as patient rooms may have), the Work Density Method (Tommelein 2017, Jabbari et al. 2020, Singh et al. 2020) offers a means to create regularity. This method is based on identifying location by location what operations are to be performed and how much time each trade needs in order to complete their work, then defining processes, and for each process then zoning the work space so that workloads are leveled and a takt can be established for the process. Constraints Analysis and 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 information (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. The *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 and construction managers are responsible for having labor appropriately skilled and in the quantities required when needed. Design squad bosses may be responsible for removing constraints on execution of design tasks. Construction engineers may be responsible for removing design information constraints on construction tasks, materials managers for material constraints, etc. It is important to identify the departments and individuals who will be the go-to people for each type of constraint in each project phase. They are responsible for learning from breakdowns in their processes. If they do not implement countermeasures for failures to make scheduled tasks ready when needed, those failures will reoccur time after time (Appendix I offers two examples of processes used to learn from breakdowns).

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 designed to improve).

Figure 14 depicts a timing guide for lookahead and weekly work planning. Assuming a 6-week lookahead window, constraint analysis starts 6 weeks ahead of scheduled task starts. Typically, information and material constraints are the most difficult to remove in a short period of time, so they come first. Other constraints can usually be removed within 2-3 weeks, so operations to be released for commitment can be provisionally selected by the end of $Week_4$. Those operations can be designed in $Week_3$ and resource and permitting constraints analyzed in $Week_2$. The weekly work plan is committed by Last Planners in $Week_1$, executed in $Week_0$, and statused at the end of that week.

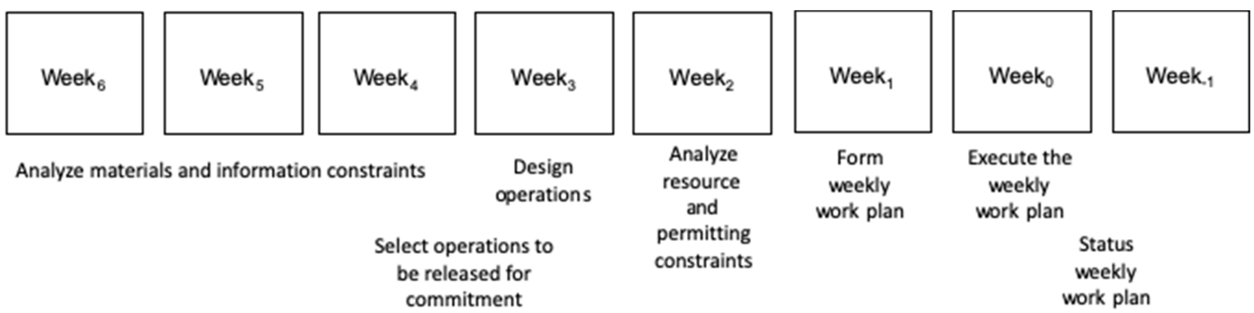

Figure 14: Timing guide for lookahead and weekly work planning

Learning from breakdowns runs throughout—when constraints are found not to have been removed and when commitments are not kept—and may continue into and beyond $Week_1$ (safety incidents and quality defects, failures to execute as committed). Projects distant from suppliers and in otherwise less forgiving conditions should adjust lookahead window length and timing accordingly. Constraints for which Last Planners are responsible (arranging for access and egress from work locations, reservation of equipment shared with others, assignment of workers with needed skills, etc.) are handled as soon as operations have been provisionally selected, but also reviewed just prior to task execution to make sure that actual conditions match the conditions assumed in planning.

8.2.7 Task Breakdown

The task breakdown taxonomy used in LPS understands projects as composed of phases, phases of processes, processes of operations, and operations of steps. Processes consist of operations performed to achieve a single objective; e.g., detail-fabricate-preassemble-deliver-install, and may involve a single company that does all operations or multiple companies, as when detailing, fabrication and preassembly are done by one firm, delivery by a second, and installation by a third. Phase schedules may consist of processes or operations, but only operations are to be committed in daily/weekly work planning. That's why tasks in phase schedules should be broken down into operations in the lookahead planning process. Again assuming a 6-week lookahead window, identification and removal of constraints begins on tasks scheduled to be executed 6 weeks before scheduled starts. 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.

Figure 15 shows an example of task breakdown. A building project 101 Calhoun consists of multiple phases, including Substructure, Superstructure, and MEP Rough-in. Any such phase can be divided into processes. For example, Substructure can be divided into Excavate, Shore, and Place Drilled Caissons. Any such process can be divided into operations. For example, Place Drilled Caissons can be divided into Fabricate Cage, Drill Hole, Place Cage in Hole. Any such operation can be divided into its steps. For example, Fabricate Cage consists of $Step_n$, $Step_{n+1}$, $Step_{n+2}$. Steps can further be divided into elemental motions such as grasp-rotate-carry-position-release.

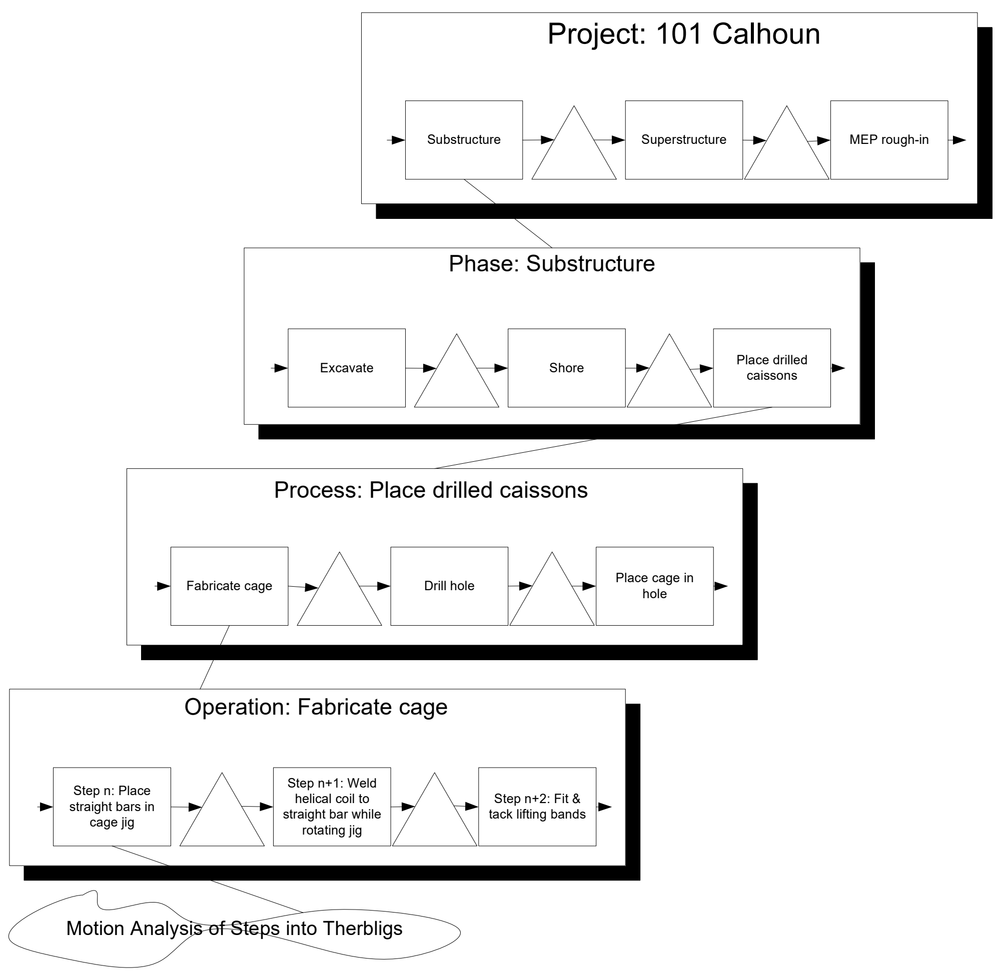

Figure 15: Task breakdown taxonomy used in LPS

8.2.8 Collaborative Design of Operations

A 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 (and their 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.

Operations consist of steps to be performed by one or several workers, consequently the design of an operation specifies those steps, their durations, their sequence, who performs each step, and pathways for workers, equipment and materials. The traditional means for representing operations designs are bar charts (Figure 16), crew balance charts (Figure 17) and plot plans showing dimensioned pathways (Figure 18). These are simplified examples used for training, so please note that steps (label, pull, reel & cut) typically overlap in time, and also that several people may perform a step, sometimes with machines such as cranes and welding machines. Also note that the Site Plan can and should not only show where the work area is within the project, but also the egress and exit paths for workers, equipment and materials. These three basic parts of an operation design can be supplemented with guides to executing steps, including key points to avoid injury and to assure quality.

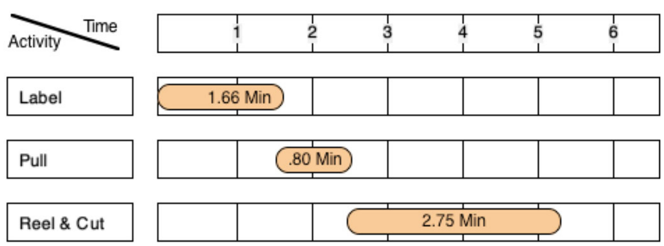

Figure 16: Operation bar chart (based on Howell et al. 1993)

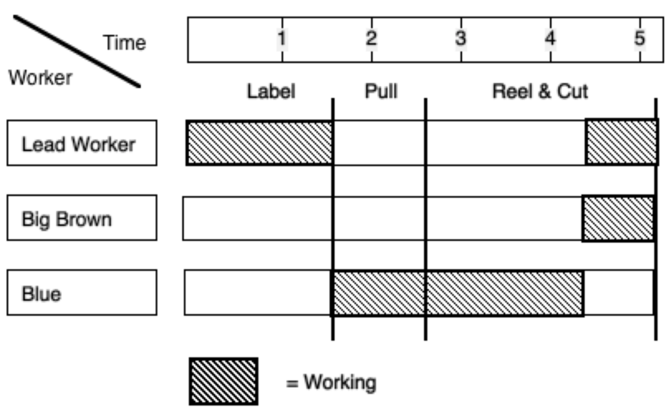

Figure 17: Crew balance chart (based on Howell et al. 1993)

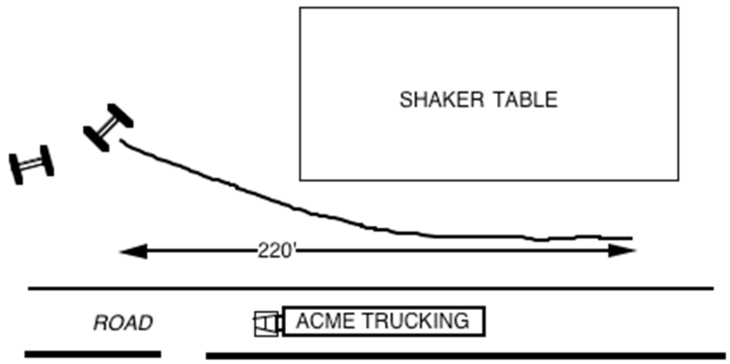

Figure 18: Site plan (based on Howell et al. 1993)

8.2.9 Reliable Promising

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.

Clarification: Before making the promise, the performer first makes sure that their understanding of the request is the same as that of the 'customer'. That can be done by saying back what you understood, and by asking why the request is being made. In some cases, this clarification process can cause the customer to change their request to something better able to deliver what they want.

Negotiation: Once like-mindedness is achieved regarding the request, the performer makes a reasoned assessment of their ability to act on the request within the requested timeframe. Apart from concerns regarding whether the request should be done (it could be against the law, a violation of project requirements, or simply not the best way for the customer to get what they want), there are acceptable two responses: (1) "Yes, I can do what you request." and (2) "Yes, I can do what you request if (I get the materials/soils report in time), (Bill can wait one more day for me to deliver on a promise I made to him), etc." Saying "Yes, if…" informs the requestor of constraints that have to be removed. If constraints cannot be removed, the performer may offer alternatives; e.g., "How about I do what you ask on Wednesday rather than Monday?" or "How about I do XYZ part of what you ask. Would that be useful to you?"

Commitment or Agreement to stop trying: There may be no acceptable solution. If a solution is agreed, the commitments are made and documented on the commitment plan.

Performance, Declaration of Completion, Declaration of Acceptance: What is requested and committed is performed, and a declaration of completion made to the customer. In some cases, testing or inspection by specialists is needed to assess conformance to the request. Once that information is made available to the customer, they either declare acceptance or explain in what way the commitment was not kept. Analysis of such failures can help improve reliable promising practice.

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.

Weekly work plans consist of commitments to perform operations. Commitments are made to the day; meaning that what operations each work group is to execute each day are shown on the weekly work plan. To reduce the waste of work waiting on workers, when appropriate, commitment can be made to complete a task at more precise times; e.g., morning or afternoon, before 10 am, etc. The Last Planner is responsible for controlling execution to the plan.

8.2.10 Visual Controls

The purpose of a visual control for a production system is to provide clear easy-to-see 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, (2) up-to-date information (not a print-out of last week's information), or (3) what's really possible (not an out-of-date schedule posted on the wall). Simple graphs and charts posted in public places can be very effective.

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

8.2.11 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. Appendix H provides examples.

8.2.12 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 Five Whys technique.

Timely generation and implementation of countermeasures reduces accidents, rework, and plan failures. The return on investment makes this something everyone with appropriate authority should do. 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.

8.2.12.1 Plan-Do-Check-Act (PDCA)

Countermeasures developed through analysis of breakdowns are tested using Plan-Do-Check-Act (Figure 19).

Figure 19: Plan-Do-Check-Act (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 Five 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. Five 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 verifying to see if using the checklist reduces plan failures, and ACT is declaring the checklist a standard requirement and implementing that standard. This process may have to be repeated a number of times before a standard is agreed to.

8.2.12.2 Detect-Correct-Analyze-Prevent (DCAP)

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 Five 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.

Figure 20 shows the relationship between PDCA and DCAP.

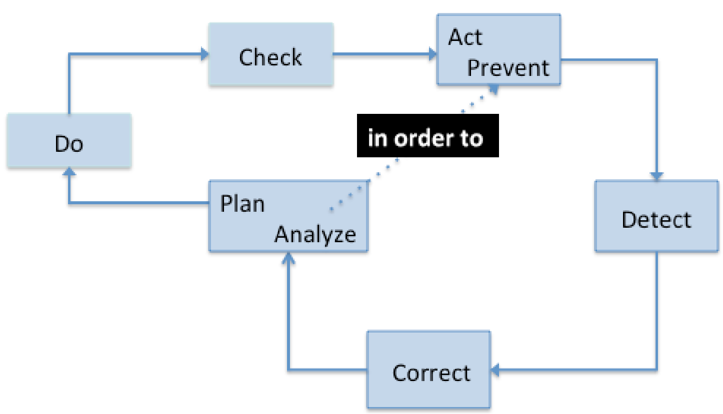

Figure 20: Detect-Correct-Analyze-Prevent and Plan-Do-Check-Act (DCAP/PDCA) combined cycles

8.2.13 Methods for Assessing and Improving the State of the Project Relative to its Targets

1. Milestone Variance (MV)
2. Percent Required Complete (PRC)

The state of the project relative to its schedule target is assessed using the metric milestone variance defined as the number of days early or late a milestone is expected to be reached.

The metric percent required complete provides the information needed to calculate the days early or late; namely, what *required tasks* were not completed in the previous week.

Progress toward other targets is assessed with metrics specific to the target; e.g., cost, noxious gas emissions, local employment, etc.

8.2.14 Metrics for Assessing and Improving the "Health" of the Planning and Control System

There are now five established metrics to measure the effectiveness of LPS implementation with the objective of promoting continuous improvement:

1. Commitment Level (CL): Is capacity being allocated first to required tasks?
2. Percent Plan Complete (PPC): Are commitments being kept?
3. Tasks Anticipated (TA): Are operations being defined in time to identify and remove local constraints?
4. Tasks Made Ready (TMR): Are constraints being removed early enough?
5. Frequency of Plan Failures: Are we learning from plan failures how to prevent reoccurrence?

Commitment Level (CL): Research has found that capacity is not always allocated first to critical/required tasks. This could have several causes. Last Planners (front line supervisors) might not know which tasks are critical, and their supervisors are not reviewing preliminary weekly work plans for adherence to this rule. Last Planners may know what is critical but choose to do easier work in order to make their productivity look good; and again, supervisors are not doing their jobs. Likewise, Last Planners may choose work that will count in earned-value metrics, but this can run counter to maintaining workflow reliability (Kim and Ballard 2000, 2010). It is also possible that supervisors above the design squad boss or construction foreman do not know what scheduled tasks are critical. Following recommendations from one of the LPS improvement task forces (Christian and Pereira 2020), LPS projects are required to track what scheduled tasks are critical and the tasks released for commitment from the lookahead process are tagged as critical and non-critical. This enables the Last Planners to follow the rule to first allocate capacity to critical tasks. Making sure that supervisors at every level have the information needed to do their jobs is essential; as is reviewing commitments for conformance to the rule: Allocating capacity first to required (critical) tasks is a supervisory responsibility.

The next three of these metrics involve comparison of task sets in different weeks of the lookahead window. These are explained by referring to Figure 21, where a 6-week lookahead window is assumed, beginning 6 weeks ahead of the scheduled start of the work week (Week$_0$).

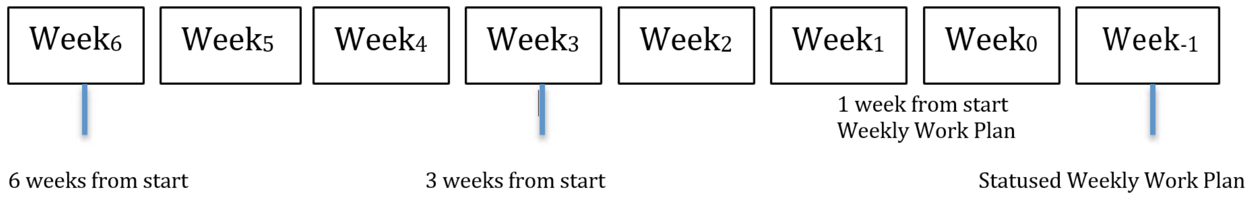

Figure 21: 6-week lookahead window

Percent Plan Complete (PPC): PPC measures workflow reliability; i.e., the predictable release of work between work groups and is generally tracked on a weekly basis, but can be tracked at any time interval appropriate to the work being performed. For example, plant shutdowns plan and track commitments at every shift. PPC compares the tasks that were completed (Week$_{-1}$ in Figure 21) against the tasks in the weekly work plan for that week (Week$_0$). 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 statused weekly work plan (Week$_{-1}$) against the weekly work plan (Week$_0$).

Tasks Made Ready (TMR): TMR is the same measurement as PPC, only done earlier in the lookahead process, comparing the weekly work plan (Week$_0$) against an earlier week in the lookahead window (Week$_n$). 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 Week$_0$ (the weekly work plan). Suppose the task set at Week$_1$ is ABCDE and the task set in the weekly work plan (Week$_0$) is ABEF (Figure 22), and suppose that tasks W and X are workable backlog for Week$_0$ (not shown in this Figure because they have not yet been committed to).

Only A, B, and E appear in both Week$_1$ and Week$_0$; these were the tasks that were made ready the week prior to execution and that were selected for execution so TMR = ABE/ABDCE = 60%.

F is in the weekly work plan Week$_0$, but was not in Week$_1$, so TA = ABE/ABEF = 75%.

It may be that F relates to work that should have been completed the week prior but was not, and represents remaining work to be done now in $Week_0$. It could also be that it reflects a newly recognized priority (e.g., it was in the lookahead but at $Week_2$, $Week_3$, or even further out) or that it is unanticipated work (not appearing anywhere in the lookahead schedule).

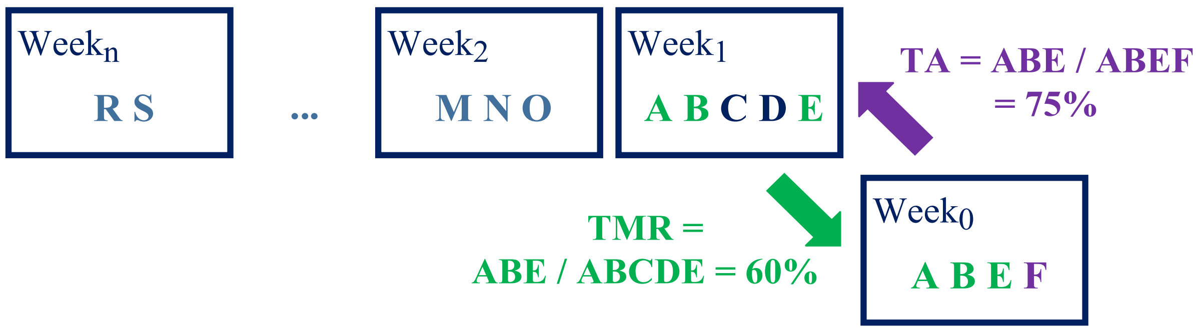

Figure 22: TA and TMR metrics

As TMR and TA approach 100%, measurement shifts to comparison of $Week_0$ against $Week_2$. 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 (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.

9 LAST PLANNER SYSTEM IMPLEMENTATION

This section has two parts. The first part describes the design of a project planning and control system, and the second one describes deployment of a project planning and control system.

9.1 Design of the Planning and Control System

With this 2020 Benchmark's extension of LPS to planning and control of the entire project, design is required for planning and control of the project as well as for planning and control of project production.

9.1.1 Design of the Project Planning and Control System

- Project Definition: objectives, constraints, feasibility assessment and funding decision
  - For setting targets (i.e., articulating objectives and constraints), we recommend using the Target Value Delivery process (Tommelein and Ballard 2016). Appendix A shows a scorecard that the delivery team used on a large Sutter Health project; it illustrates frequent and public measurement of progress toward targets.
  - For assessing feasibility and deciding on funding, we recommend developing a project execution plan in which risks and opportunities are identified and strategies are incorporated for mitigation and exploitation, respectively.
- Project Delivery Strategy
  - Process for evaluating and selecting suppliers of goods and services.
    - We recommend using some form of best value procurement (Dimitri 2013, Bade and Haas 2015, Tran et al. 2016).
  - Choice of contract structure (design-bid-build, design-build, collaborative design-build, agency construction management, construction management at risk, integrated project delivery). Note: "collaborative design-build" applies integrated project delivery's Lean project management, shared risk and reward, and organizational integration to the design-build entity, but excludes the client and subcontractors whose work can be decoupled from the project mainstream.
    - We do not recommend design-bid-build except for projects on the "simple and certain" end of the spectrum.[20]
    - We recommend the use of Lean management methods for all contract structures.

[20] Projects can be located on a spectrum ranging from simple and certain on one end to complex and uncertain on the other. Experience has shown that LPS and the Lean philosophy in general are more needed for projects that are more complex and uncertain. There is still opportunity for improving simple and certain projects, but the risk of failing to achieve objectives is lower.

  - For contract structures other than collaborative design-build and integrated project delivery, commercial terms must be selected.
    - For projects on the "complex and uncertain" end of the spectrum, we recommend shared risk and reward commercial terms.

- Processes for steering to project targets
  We recommend using Target Value Delivery (Tommelein and Ballard 2016) to both set and steer to project targets for what's wanted and the constraints on their delivery. Frequent and public measurements are needed for all targets. These lagging indicators should be supplemented by leading indicators such as project team flexibility and problem solving capability.
  - Value
    - Value is delivered when what is constructed is fit for purpose and delivered within economic, social, and environmental constraints.
  - Quality
    - The quality of the constructed asset and its parts are specified in terms of the so-called "-ilities"; e.g., reliability, availability, serviceability, usability, and installability. Different project stakeholders are likely to have different preferences among these 'ilities'. Reconciliation of these conflicting preferences is recommended prior to final design. Choosing By Advantages (CBA) (Suhr 1999) is recommended for achieving consensus to the extent possible.
  - Safety
    - Physical and mental safety of construction project participants is a function of the design of operations (designing out hazards) and of psychological safety (willingness to look out for one another and warn one another about potential hazards and help each other get out of hazardous situations without harm).
  - Duration
    - We recommend collaborative work structuring and scheduling in order to produce better schedules and to increase flexibility to change. Planning to complete is the epitome of steering to targets.
  - Cost
    - An acceptable project cost (budget) exists in relation to the benefits that cost is to purchase. If expected benefits change, that may change the allowable cost—the most a client is willing and able to pay to get what they want. Target value delivery includes steering toward cost in design and in construction; and beyond the capital project, also includes steering costs to maintain and use constructed assets.
  - Social objectives
    - Social objectives for projects include, for example, providing local employment, and improving or maintaining the architectural harmony of the built environment.

- Environmental objectives
  - Environmental objectives for projects include both those required by law and those that are adopted voluntarily; e.g., reducing the release of noxious gases or the consumption of energy, both during construction and afterwards in use.

9.1.2 Design of the Project Production Planning and Control System

Due to the inherent complexity of project production (multiple stakeholders, different locations, alternate sourcing options, etc.)—though also noting that some complexity is self-inflicted—the means through which production is planned, executed, controlled, and improved must be tailored to the type of work and workers that perform it (Arbulu et al. 2016). 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, unwanted variations 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. LPS also 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 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 severe implications for the owner of residences.

Therefore, the frequency of control and adjustment due to variability (replanning) 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.

Some basic decisions must be made regarding deployment. In order to configure LPS for a specific project, questions in several categories must be answered:

1. **Relationship of the LPS to other Project Management Components**
    - With this 2020 Process Benchmark, the LPS is extended to include the functions performed by Project Controls, namely setting project targets, then assessing the state of the project relative to its targets. That does not mean that schedulers, estimators, and such will no longer be needed. Technical specialists may still produce the means for line managers to assess and improve performance.
    - 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?

2. **Configuration of the LPS**
    - Who has what roles and responsibilities?
    - How will the work of project team members offsite be incorporated into the LPS (i.e., how far beyond the project site does the system extend)?
    - 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; e.g., one shift, ½ day, 1 day, 1 week, ...?

- What will be the weekly, monthly, or other time cycle of LPS events? Appendix E provides examples.
- What are the standard agendas and participants for phase planning, lookahead planning, commitment planning meetings, and daily huddles? Appendix F provides examples.
- 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?

9.1.3 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. 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. That enables pulling to occur within the lookahead window. 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.

9.2 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.

Some basic decisions must be made regarding deployment:

- Will the implementation be done top down or bottom up?
  - Our recommendation is to start top down to make sure that those with organizational authority over others provide the needed leadership; e.g., by promoting psychological

safety and continuous improvement. Ideally, have managers taught the why and how of the LPS and basics of the Lean management philosophy by internal or external consultants, then have those managers teach their direct reports, and so on down through front line supervisors.

- How will education and training be done?
  - There are multiple components in an effective education and training program: site induction, coaching by supervisors at every level of the project organization, and classroom training that includes games that teach key concepts and methods through simulations. Coaching by supervisors is a continuation of the basic training they each deliver to their direct reports, but now in periodic job walks to develop the ability to see waste and value, and opportunity for its reduction or increase respectively.
  - Ensure that everyone in the organization masters the methods of operations design (work that the direct worker performs, individually), reliable promising, learning from breakdowns, and process mapping and improvement (work that involves handoffs to others).
- How will the effectiveness of implementation be assessed and improved?
  - Periodically conduct confidential surveys to assess morale and how project team members view efforts to make the project a learning organization and achieve any other objectives.

10 FREQUENTLY ASKED QUESTIONS

A. 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 used to decide 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.

B. 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/progress. 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 shorten 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.

C. 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.

Such tasks should also include observation, assessment, learning, and improvement, but we note that the pressure for project speed stands in the way of developing improvements aimed at increasing reliability (Tommelein 2020). Use excess capacity is to have workers participate in problem solving; e.g., Five Whys analysis of plan failures or revisions of operation designs that have been shown to need improvement, so that they will increase their *process capability*.

Take care not to use capacity to perform tasks that are otherwise ready, except for some predecessor activities. Doing these tasks now may cause more pain later in the project (e.g., 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.[21]

D. 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.

E. How much should resources (capacity) be underloaded?

Answer: Given the importance of workflow reliability, where feasible, we should underload so that there is a very high chance that the assigned capacity will be sufficient to complete the task as scheduled and allow for other valuable uses of capacity, i.e., training, planning, learning from breakdowns (see *underloading resources* in the Glossary). But to do that precisely requires

[21] Granting partial credit is done to improve the precision of progress measurement, but it encourages doing work out of sequence. In fact, what happens is the opposite to what is intended: measurements of project progress in systems which reward working out of sequence will look better than they are in reality. We could say that the problem with earned value measurements is that they don't value sequence (Kim and Ballard 2000, 2010). An additional negative consequence is an increase in the waste of work waiting for workers, which extends project durations.

information concerning the standard deviation for the relevant operations. 2 standard deviations correspond to a 95% confidence level. 3 standard deviations correspond 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.

F. How much capacity is used now, possibly wasted, when workflow reliability is low?

Answer: 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. However, when underloading is practiced judiciously, it can be used to benefit the system more. Underloading implies some loss of labor capacity used in direct production, but that loss will be less than what has happened historically because underloading helps improve workflow reliability. In addition, time not used or needed for direction production can be planned for use to observe and improve operations, or to develop people and company capabilities.

G. 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.

H. 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.

I. 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.

J. Should we have crews do more work if they complete committed tasks sooner than anticipated?

Answer: Yes, if there are no compelling needs for using labor capacity in training, planning, or learning from breakdowns at the time. Otherwise use available capacity to do more direct work, 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 (see *Plan A and Plan B* in the Glossary) tasks available for each work group should they complete committed tasks early or should they be unable to perform committed tasks. Plan B tasks are screened in the same way as Plan A tasks, so can be assured to be ready to be performed and will be known to all interdependent Last Planners.

K. 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.

L. 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])

M. 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.

N. Who leads commitment planning?

Answer: The 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").

Note: The metric Tasks Made Ready (TMR) measures the extent to which the last week of the lookahead matches the commitment plan for the following week.

O. How does LPS differ in design?

Answer: In early design, it is often difficult to accurately predict how long a specific task will take, which makes it challenging to make reliable promises. A countermeasure for this problem: Assign such tasks to teams that are to work closely together, with frequent check-ins, and focus on the next *Last Responsible Moment* to determine and hence better manage the available time. A typical process in early design involves researching to understand what's needed and what's possible, generating alternatives, evaluating those alternatives, and selecting from alternatives. The time available is from the date you start to the date required for selecting from alternatives. Use provisional allocations of the time, adjusting as you move toward the LRM. For example, you may have 10 weeks total and decide to spend 2 weeks on research, 4 weeks on initial generation, and 4 weeks on evaluation, regeneration, coordination with connected tasks, and selection. If you finish the research in 1.5 weeks, decide where that .5 week will be most beneficial.

11 FUTURE RESEARCH

We do not believe that this 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 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:

- Aim for constant crew sizes and continuous workflow
- Avoid trade stacking
- Use timely on-takt handoffs
- Balance the whole while pushing for speed

2. Develop more *standard work*.

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. The standard process follows the nomenclature for task breakdown, following the rule that tasks committed on daily/weekly work plans are operations. Some standardization is being done, for example, a work standard gets established after a First Run Study of a construction operation. Developing more such standards, and doing so consistently, will help with learning on how work can be done within and across projects.

3. Extend reliable promising to direct workers.

This has previously been recommended for design, where more work is done by individual specialists than in construction, which requires that individuals be able to assess capacity when responding to requests for commitment. 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.

4. Resource-load commitment plans.

In LPS, the role of lookahead and daily/weekly commitment plans is to ensure (a) the work is sound and made ready before it starts, (b) the workers pull from a workable backlog that has been made ready and (c) workers track commitments to ensure the work is done according to the plan and also record the reasons of non-completion for continuous improvement. There are many different ways the teams carry out the lookahead and weekly/commitment planning process. Sticky notes, spreadsheets, and other digital planning tools are used to plan and track commitments. While some teams may explicitly address the aspect of resource loading of commitment plans, others may treat this implicitly. The role of LPS has been to bring out such implicit issues to the fore (often in the form of constraints) and addressing them at the time of lookahead and weekly planning. Thus, it becomes very important that teams tackle the aspect of resource loading in order to ensure the available capacity is used across the teams. Two major stages are identified in this process:

- Allocating resources at the lookahead level. Each team leader/trade foreman will identify the resources required to complete each activity and allocate them to the tasks at the lookahead planning stage and agree to make them available before the work starts. The Last Planners will ensure that all available capacity is utilised and reasonable buffers are allocated to ensure reliable workflow.
- Confirmation of resource availability at the weekly/commitment planning stage. The Last Planners will confirm the availability of planned resources at the commitment planning stage. In case of non-availability reasons will be recorded and tasks rescheduled.
- Tracking of resource availability. Every day the Last Planners will report back on the resources utilised against planned to ensure the commitments will be completed as planned. The managers can proactively address resource unavailability problems and try to ensure tasks are completed on time.

These starting thoughts are offered to encourage the practice of loading work plans and to encourage researchers to document and evaluate alternative methods. (Courtesy of Bargav Dave [VisiLean])

5. **Increase use of visuals to communicate information.**

For example, leading indicators that provide information about what needs to be done now to move the project toward its objectives.

6. **Assess benefits and challenges of LPS software solutions.**

In the last decade several software solutions have been designed and are being offered commercially to support the LPS process. To assess LPS software is to answer at least these primary questions: (1) Which LPS functions are supported? (2) How well are the functions supported? (3) Can reports be generated automatically without negatively impacting process or culture? (4) Does the software support virtual collaboration? and (5) Is it able to integrate with other systems? Researchers may add additional relevant questions.

7. **Measure relationships between use of LPS and quality, safety, 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 quality (on the Temecula Valley Hospital Project, 1 of 1,300 inspections failed first time), safety (MTH, a Danish contractor, reported a 75% reduction in lost time accidents on projects using LPS), cost (Liu et al. (2011) reported a positive correlation between LPS and labor productivity; also see González et al. (2008)), and project durations (Reiser's 2005 report on Boldt Construction's world record on a Stora Enso shutdown) but more data is needed. With the broader take up of LPS, statistical analysis should now be possible with larger data sets.

8. **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?

9. **Refine existing and invent new methods, possibly with mathematical algorithms, that support the exploration of plan and schedule alternatives and selection of those best fit-for-purpose, e.g., when using takt planning.**

10. **Study how using the Last Planner might 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])

11. What specific social dynamics variables and mechanisms are endangered by LPS in a construction organization? How do they interact (synergies and feedback loops)?

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 2004). 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 by applying social science techniques or 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 systems thinking, e.g., using the LPS in a construction organization. (Courtesy of Vicente González [University of Auckland])

12. How to go "beyond" reliable promising?

There has been some research on reliable promising, a process (structured conversation) for making promises that both should and can be kept. That is important and valuable, but more research is needed to explore and document structured conversations. Reliable promising is grounded in Fernando Flores' work on language action, which includes both conversations for action and conversations for possibility (Flores 1982, 2013). Many Lean practitioners think about these as a separate set of conversations. In practice, we are engaging in conversations for possibility and action as we move through the world. In everyday life, we share our assessments about what is possible with our friends, family, co-workers, and others in our lives. We share our assessments about what is possible on a sunny day, what will happen in the stock market next week, what a client might build next, or the advantage of adding more workers to a crew. These everyday conversations explore our assessments about what is possible, or not possible, in the future. Some of those conversations lead us to create action by making requests and offers, Conversations for Action, of others to bring about some new possibility.

The mood of the team members and the team's mood has a significant influence on Conversations for Possibilities. A team in an expansive mood like curiosity or wonder will produce a broader range of possibilities than a team in a restrictive mood like resignation or cynicism. A team should take care to cultivate an expansive mood, not least by promoting psychological safety of team members.

Master and Phase Planning: In the domain of Master Planning, we are sharing our assessments about how we might do something in the future– design a system or sequence construction activities, for example. These are not planning conversations, but rather conversations focused on creating new possibilities for working together. Planning typically starts with a set of criteria that we have already agreed upon but creating and inventing starts from declaring new possibilities for the project.

In the Phase Planning portion of the LPS, we enter into a more focused conversation about how we will perform work during a specific project phase. We often have an established completion date in a phase planning exercise, and our partners are already selected and under contract. As a result, the Phase Planning conversations' domain of possibilities can be more restrictive than in a Master Planning conversation. Regardless, we strive to produce a conversation amongst the Last Planners in which we share assessments about what we think we know, what is possible, and what is needed from others. In this conversation, the Last Planners can make declarations about what is possible for them.

These are but a few of the occasions in which conversations for possibility and action can and should occur. What those are and how those conversations might be structured is a worthy objective for future research. (Courtesy of Jason Klous [Lean Project Consulting])

13. What are the roles and responsibilities of supervisors and managers "above" the front line supervisor?

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 would 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'. A sample research question: Do managers of material, information and resource flows act on feedback received from constraints analysis in lookahead planning to improve those flows?

14. How to structure design work?

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?

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16. Can "agile" methods augment the LPS?

Several methods from software development are now being used in planning and controlling design work in the construction industry; e.g., Scrum (Schwaber 1997, Sutherland and Schwaber 2007) and Kanban (Anderson 2010). A rigorous description and evaluation of these methods should be done to decide if to incorporate into future LPS Benchmarks.

17. How to better produce proactive project execution strategies and milestone plans?

Explore alternatives 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. Some work has been published in the years since 2016, but more research is needed. (Courtesy of Hajnalka Vaagen [NTNU])

18. Assess the use of CPM plus stochastic planning methods to develop the schedule within the project execution plan.

CPM proposes to produce the sequence and timing of events that the project will follow. As explained elsewhere in this document, that is not possible. However, CPM might be useful in testing alternative ways a project could evolve in response to different possible sets of risks and opportunities. That may be the best way to answer the question if a project can be delivered with acceptable risk.

19. Promote 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 LPS? (Courtesy of Alan Mossman, The Change Business)

20. Study what improvements, if any, can be made in the LPS through application of operations science.

Pound et al. (2014) in their book "Factory Physics for Managers" use "three equations and four performance graphs" plus buffer and demand-stock-production concepts to advise managers how to manage their manufacturing operations. Construction projects are arguably more similar to product development (e.g., Toyota's Product Development System rather than the Toyota Production System) but obviously include fabrication and assembly, so these equations, graphs, and concepts should have some relevance for managing construction, especially the planning and control functions performed using LPS. The question is: what relevance, offering what benefits?

12 GLOSSARY

Activity Definition Model (ADM): An input-process-output representation of work to be done in design or construction. As shown in Figure 23, 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.

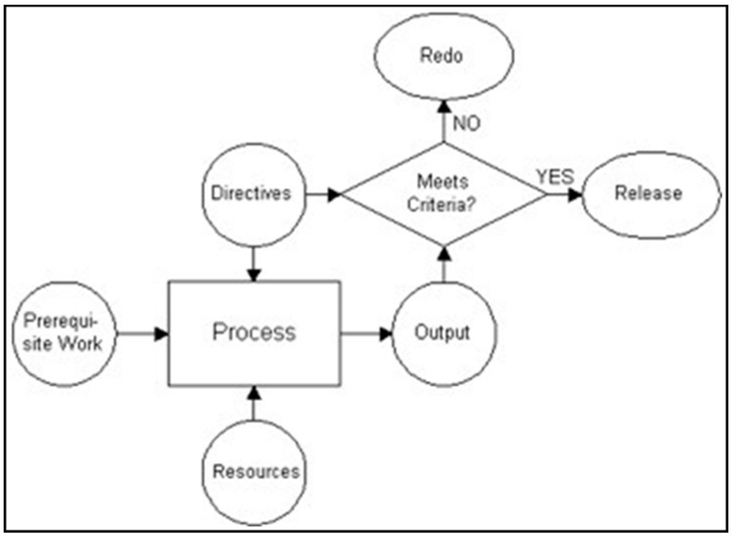


Figure 23: Activity Definition Model

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

Buffer: A mechanism for deadening the force of a concussion; e.g., a capacity buffer is created by scheduling less than all the time a resource has 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 (e.g., geometrical tolerances or areas where work could take place). Arguably, monetary buffers can be converted into, e.g., capacity buffers or inventory buffers.

CBA → see **Choosing By Advantages**

Choosing By Advantages (CBA): A decisionmaking system that enables organizations, project teams, and individuals to make sound decisions (Suhr 1999). The system consists of definitions, models, principles, and methods that are suited to support decisions of any complexity. By focusing on advantages (beneficial differences between attributes of alternatives), CBA helps decisionmakers articulate what is of value to them (expressed in units of Importance of Advantages) and, separately, consider Importance of Advantages relative to cost (money).

Jim Suhr developed CBA while working at the US forest service. John Koga (2014) offers a detailed tutorial.

CL → see **Commitment Level**

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.

Commitment Level (CL): The percentage of required tasks that are committed to be performed on weekly work plans. Gauging the commitment level is a method to assess the "health" of the planning system.

Commitment Plan, 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 (CoS): 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.

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.

CoS → see **Conditions of Satisfaction**

Critical Task: task that, if not completed at the time it is scheduled to be, would delay the phase milestone or project completion time.

Daily Huddles: Brief, typically stand-up, meetings each day by groups of interdependent players but each with their own weekly work plan, at which each, in turn, shares what commitments they have completed, what commitments they need help with or cannot deliver. Daily huddles offer an adjustment mechanism to (re)align weekly work plans during their execution. This can be done within design squads or construction crews, 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. Once there is a standard, the operation can be further improved, either on the project where it was developed, or on subsequent projects when that same operation is scheduled to be performed. 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 countermeasures are identified within 5 "whys." If there are multiple answers to 'Why…?', then the search will branch out accordingly, and fishbone diagrams may be useful in keeping track of the analysis.

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 resources, lack of materials, changed priorities, or failure in execution.

FRS → see **First Run Studies**

Hedging: "Buying" options that preserve the possibility of beneficial action regardless what alternative events occur in the future. All options have costs, so calculation of cost versus benefit is necessary.

Labor Productivity: the ratio of input to output; e.g., 10 labor hours per ton of steel erected. That ratio is the product of the percentage of paid labor time used productively (labor utilization) and the output per unit of productive labor time (labor fruitfulness).

Last Responsible Moment (LRM): The LRM of an alternative is that point in time when that alternative becomes no longer available.

Lean Project Delivery System (LPDS): Representation of the delivery of a project from determining that which helps clients better achieve their business purposes through final use. Positive iteration is encouraged within each phase so as to prevent negative iteration between the phases. Production control, work structuring, and learning are continuing functions (Ballard 2008).

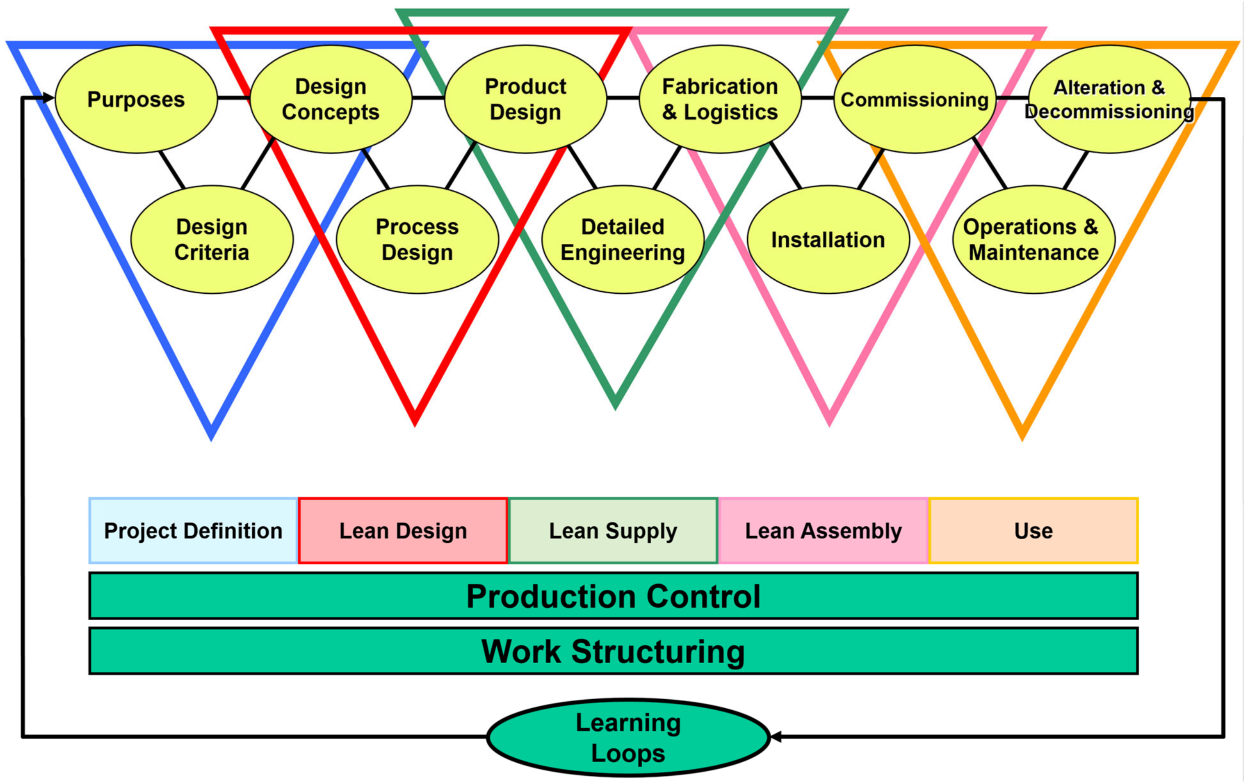


Figure 24: Lean Project Delivery System (Figure 3 in Ballard 2008)

Long-lead Items: So-called because the lead time for acquiring them is larger than the project's lookahead window, and hence acquisition must be initiated earlier.

Lookahead Plan, Lookahead Planning (aka. Make-ready 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.

LRM → see **Last Responsible Moment**

Make-ready Plan, Make-ready planning → see **Lookahead Plan, Lookahead Planning**

Master Plan, Master Schedule: Schedule covering an entire project start-to-finish, then further detailed and validated in phase scheduling, the activities in which are then broken down into operations in lookahead planning.

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

Milestone Variance (MV): A metric that measures the number of days early or late that a milestone is expected to be reached. Gauging MV is a method to assess the state of the project relative to its targets.

MV → see **Milestone Variance**

Options: Actions that can be incorporated into plans in order to accommodate uncertainties in a project's future. Example: Some equipment has not yet been selected. An option to explore is if design can be re-sequenced or changed to accommodate the possible future choices.

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 (PPC): Metric used in the LPS to gauge plan reliability, which is a method to assess the "health" of the planning system. The percentage of actual completions to planned completions in a daily or weekly work plan.

Percent Required Complete (PRC): is a method to assess the state of the project relative to its targets. It provides the information needed to calculate the days early or late; namely, what required tasks were not completed in the previous week.

Phase Scheduling (also called **Reverse Phase Scheduling):** One level in LPS, where a phase gets broken out from the master schedule, 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. In contrast to → **Virtual Prototyping**.

Plan A and Plan B → see **Workable Backlog**

Planning to Complete: Project schedules are intended to be one pathway from start to completion of a project. Traditional schedule control consists of identifying deviations from the pathway and developing and executing a recovery plan, which either returns the project to the initial pathway, creates a new pathway to targeted completion, or tries to complete the project with as little time loss as possible. Another way to think about schedule control is to determine from wherever you are if there is a way to get where you want to be at target completion date, whether or not prompted by deviation from the original pathway, i.e., always look forward. This planning to complete alternative assumes that uncertainties and changes (including opportunities) will arise despite best planning and it aims to achieve established or revised project objectives.

Postponement: Following the rule to act (make decisions or take other actions) at the last responsible moment, when more information is expected or can be made to be available.

PPC → see **Percent Plan Complete**

PRC → see **Percent Required Complete**

Process Capability: Probability distribution describing the variation in the geometry of the material output of a process under normal operating conditions. When that variation falls within the allowable range (e.g., allowable tolerance), the process is said to be "capable." This definition pertaining to geometry equally applies to any material or information, resource, or process property such as duration, temperature, impact strength, etc. For an in-depth characterization and assessment, consult the literature on statistical process control.

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

Productivity → see **Labor Productivity**

Project Controls: Setting project time and cost targets in alignment with project scope and tracking progress toward them.

Psychological Safety: "feeling able to show and employ one's self without fear of negative consequences of self-image, status, or career" (Kahn 1990 p. 708). A shared belief that the team is safe for interpersonal risk taking (Edmondson 1999). In psychologically safe teams, team members feel accepted and respected.

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.

Required Tasks: Scheduled tasks which, if not completed as scheduled, will result in a negative milestone variance, unless replanning can overcome the delay.

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

Risk, Risk Management: Identifying, evaluating, and mitigating risks, understood as events with a negative impact but, more broadly, it involves identifying, evaluating, and exploiting opportunities, understood as events with a positive impact. Risks and opportunities are identified from historical data, from remembered experiences of participants, and from thinking through project execution. Risks and opportunities are both uncertain events: both probability of occurrence and potential impact can be uncertain. Unknown unknowns (aka. "black swans") obviously cannot be fully mitigated or exploited, although increasing flexibility of plans and teams can help. Known unknowns are events that are identified as uncertain and consequently can be managed to some extent. Risks and opportunities are commonly evaluated by multiplying probability of occurrence times expected impact. The product is understood as a measure of relative importance and hence need for mitigation or exploitation of opportunities. Interventions range from preventing occurrence of the risk event to reducing its impact. Opportunities may be completely or only partly exploitable. Risks whose probability of occurrence can be calculated and cannot be further reduced can be buffered (buffer costs are necessary at the moment in order to deliver value). However, the probability of occurrence of some uncertain events cannot be determined; e.g., whether or not an owner will delay or change decisions. The strategy in such cases is to increase the flexibility of teams and plans to mitigate risk events or exploit opportunities. Incorporating options into project schedules is one way to increase plan flexibility.

Standard: A standard is an accepted way of doing or assessing something; a construction operation, childcare, contracting, shoeing a horse. It is an agreed-upon reference or baseline from which deviation is observed and measured. Any standard is implied to be a current-best standard that can be improved upon and replaced by a better standard.

Standard Work: The establishment of a standard is one of three steps in the creation of standard work. The other steps are to identify the best method (i.e., process steps) to achieve the standard, and to ensure people can consistently execute the method to meet the standard and are willing and able to suggest potential improvements. Spear and Bowen (1999 p. 97) address what may appear to be a paradox of the Toyota Production System, that "activities, connections, and production flows […] are rigidly scripted, yet at the same time Toyota's operations are enormously flexible and adaptable."

Standardization: Standardization results from three very different objectives: (1) to discourage innovation, have everyone do a given task in the same way, with no opportunity to change, (2) to reduce waste, and (3) to encourage innovation, by providing a starting point for continuous improvement. The Lean philosophy advocates the second and the third.

Regarding the second, waste reduction happens when making things that are at first different to be more alike or the same, does not reduce value delivered. For example, in designing a building, limiting the number of different sizes, types and shapes of windows can reduce costs. In procurement, limiting the number of suppliers can reduce costs and enable joint innovation in supply chain management. In operations, having capable methods reduces waste of time and money, and can reduce injuries and illnesses.

Regarding the third, unless an explicit way exists to do a task with measured outcomes, it is impossible to know when a different way of doing that task is an improvement. Even though what is standardized can vary greatly, the basic way to establish a standard is through the PDCA cycle: PLAN (develop a possible answer to the question "How best to do x?"), DO (trial run the answer), CHECK (if the answer works), and, once an acceptable answer is created, ACT (declare the answer/solution the standard, assure capabilities to apply, and ask everyone to be alert for opportunities to further improve the solution going forward.

Stochastic Planning: Planning in conditions of uncertainty. Methods include postponement, hedging, and simulation. Simulation yields insights into processes that can be modeled using probability distributions from which points are sampled randomly over many iterations.

TA → see **Tasks Anticipated**

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.) describing how a robot might be programmed to do that task. Distinct from → **Breakdown**

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 gauges the percentage of tasks for a target week in the lookahead that were shown (i.e., anticipated) in an earlier plan for that target week. Gauging TA is a method to assess the "health" of the planning system. 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 shown 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}). Gauging TMR is a method to assess the "health" of the planning system. TMR 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.

TMR → see **Tasks Made Ready**

Underloading Resources: To allow for variation that cannot be reduced at a moment in time, resources are asked to plan to produce less than what they could produce if there were no variation in arrival times of inputs or in processing durations.

Underloading creates capacity buffers. Over time, 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 ability to vary. The spread in a set of data points due to any number of causes, some known and some unknown. This may be described by the extent to which points fall above and below a mean, the set's variance (the average of the squared differences from the mean) or its standard deviation (the square root of the variance), and skew or other shape parameters.

Virtual Prototyping: Testing the design of a product, process, or operation (virtual first run studies or VFRS) using computer modeling. In contrast to → **Physical Prototyping**.

Visual Controls and Visual Displays[22]**:** Visual controls (Figure 25) are used to manage input resources; e.g., color coded hard hats, zone plans, lines sprayed on the floor. Visual displays (Figure 26) 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.

Figure 25: Visual control with color coding to show locations for sheet metal straps and pipe hangers in metal decking (Figure 2 in Tommelein 2008, source: John Mack, Southland Industries, Inc., presentation at 2007 Annual Conference of the Lean Construction Institute, San Francisco, CA)

22 Distinction courtesy of Steve Ward, 6ix Consulting.

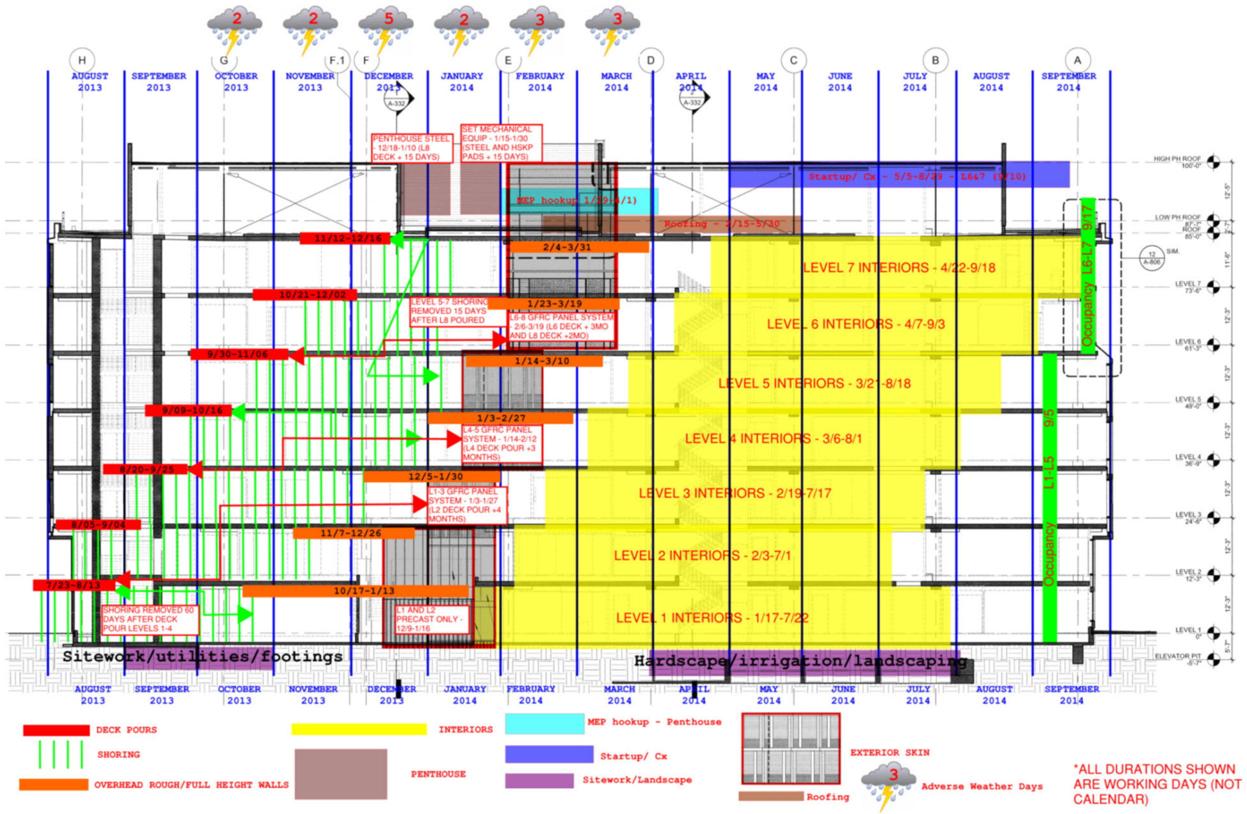


Figure 26: Schedule sequencing map and visual display of multi-story building UCSF Block 25 (Slide 46 in Nickerson 2014)

Work Structuring: The process of breaking work into pieces, where pieces will likely be different from one production unit to the next, so as to promote flow and throughput. See method specification in Section 8.2.4.

Workable Backlog: This term has been used in two ways in LPS, to name (1) tasks that have been released for commitment in (e.g., daily or weekly) commitment plans 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 more tasks than planned, respectively. Some or all of the workable backlog tasks will be selected by the Last Planner for execution and shown on their weekly work plan, so-called Plan A and the remainder may be selected as Plan B. 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.

All tasks on commitment plans are to be selected from workable backlog (one advantage of LPS software is that it can be programmed to make it impossible to select a task that is not in workable backlog, barring appeal and explanation), and tasks are placed into workable backlog only if they satisfy criteria for definition, soundness, sequence, and size. Last Planners must select critical tasks first. If they are short on capacity to commit to all critical tasks, then replanning at a higher level is in order (see "planning to complete") so that the work can stay on target to hit its phase milestone.

Figure 27 illustrates how to decide on including tasks in Plan A or Plan B. It shows a lookahead plan spanning Week$_1$ to Week$_n$ with tasks that satisfy all criteria for definition, soundness, sequence, and size shown in green (A*, B, E*, and N*). Furthermore, tasks marked with a star are critical: if they are not completed in the week indicated, then follow-tasks and the phase milestone may be in jeopardy. Tasks A*, D*, and E* in Week$_1$ are critical, but C and D* have not yet been made ready. Management is doing what they can to make them ready and in particular for D* is looking into schedule sequence implications.

The Last Planner who is creating their weekly work plan for Week$_0$ has one task to complete (F) that could not be completed the previous week. If completing F is not critical, the Last Planner must decide if completing it is the best use of the crew's capacity in Week$_0$; assuming this is the case, the crew adds it to their Plan A; otherwise it would have added F to Plan B. Gauging how much capacity the crew has, the Last Planner commits to also doing A*, B, and E* and adds those to their Plan A. Anticipating having extra capacity after completing all critical tasks and others now in Plan A, the Last Planner creates Plan B with tasks N* and T. N* can be done now and if done now it will not negatively impact tasks yet to follow, but it is not yet critical because the lookahead shows it in Week$_2$ (N* is critical in Week$_2$). Task T is a special training task that can be done at any time.

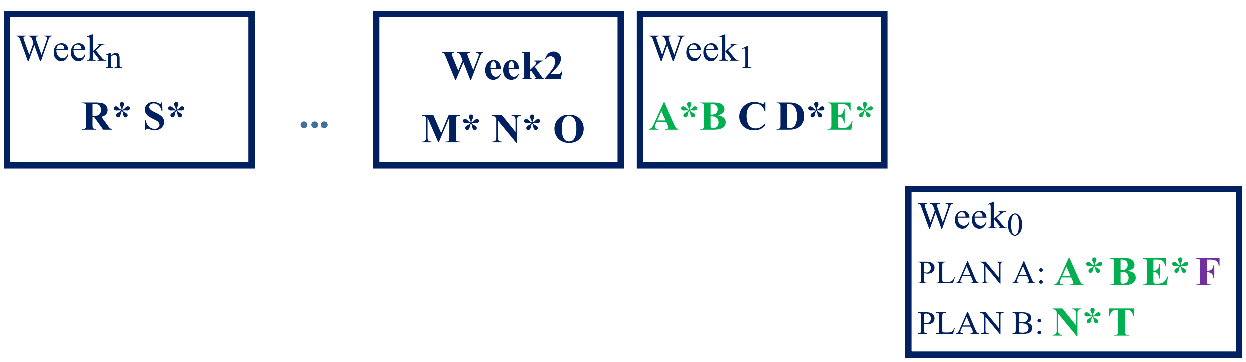


Figure 27: Forming commitment plans with a Plan A and a Plan B

Accordingly, commitment plans consist of a Plan A and a Plan B: Plan A tasks are truly speaking commitments; others are depending on them being completed within the plan period. Capacity is first allocated to critical tasks that must be completed in the coming plan period in order to stay on schedule. If there is more capacity than needed to perform critical tasks, selection can be made from non-critical tasks that have also been made ready. 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. The moment a Last Planner decides to not execute a Plan A task or to execute a Plan B task, coordination with interdependent crews must take place to ensure everyone has shared understanding of the state of the system at all time.

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% PPC, 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.

13 REFERENCES AND ADDITIONAL LPS PUBLICATIONS

The following list includes references cited in this Benchmark plus a selection from the many papers published on the LPS. Documents not cited in the text are marked with a *.

Papers presented at an Annual Conference of the International Group for Lean Construction are available on the IGLC website at iglc.net/Papers/.

*Abdelmegid, M.A., González, V.A., O'Sullivan, M., Walker, C.G., Poshdar, M., and Alarcón, L.F. 2019. "Establishing a Link Between the Last Planner System and Simulation: A Conceptual Framework." *Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC27),* Dublin, Ireland, 3-5 July, pp. 335-246.

Anderson, D.J. 2010. *Kanban: Successful Evolutionary Change for Your Technology Business.* Blue Hole Press, 278 pp.

Arbulu, R.J., Choo, H.J., and Williams, M. 2016. "Contrasting Project Production Control with Project Controls." Project Production Institute, San Francisco, CA, projectproduction.org/wp-content/uploads/2017/11/Contrasting-Project-Production-Control-With-Project-Controls.pdf

*Aslesen, S. and Tommelein, I.D. 2016. "What "Makes" the Last Planner? A Typology of Behavioral Patterns of Last Planners." *Proc. 24th Annual Conference of the International Group for Lean Construction (IGLC24)*, Boston, Mass., USA, 20-22 July.

Bade, M. and Haas, C. 2015. "Using Lean Design and Construction to Get More from Capital Projects." *Government Finance Review*, pp. 39-44.

Ballard, G. 1994. "The Last Planner." Northern California Construction Institute, Monterey, California, pp. 1-8.

Ballard, G. 1997. "Lookahead Planning." *Proc. 5th Annual Conference of the International Group for Lean Construction (IGLC5)*, Griffith University, Gold Coast, Australia, July.

Ballard, G. 1999. "Improving Work Flow Reliability." *Proc. 7th Annual Conference of the International Group for Lean Construction (IGLC7)*, Berkeley, California, July 26-28, pp. 275-286.

Ballard, G. 2000. *The Last Planner System of Production Control.* PhD Dissertation, Dept. of Civil Engineering, University of Birmingham, Birmingham, UK, June.

Ballard, G. 2001. "Cycle Time Reduction in Home Building." Proc. 9th *Annual Conference of the International Group for Lean Construction (IGLC9)*, Singapore.

*Ballard, G. 2002. "Managing work flow on design projects: a case study." *Engineering, Construction and Architectural Management*, 9/3, June, pp. 284-291.

Ballard, G. 2008. "The Lean Project Delivery System: An Update." *Lean Construction Journal*, pp. 1-19, www.leanconstruction.org/media/docs/lcj/2008/LCJ_08_001.pdf

Ballard, G. 2020. Target Value Delivery. Chapter 8 in Tzortzopoulos, P., Kagioglou, M. and Koskela, L.K. (eds.) *Lean Construction: Core Concepts and New Frontiers*. Routledge, 149-161.

*Ballard, G., Casten, M., and Howell, G. 1996. "PARC: A Case Study." *Proc. 4th Annual Conference of the International Group for Lean Construction (IGLC4)*, Birmingham, England, available at iglc.net

*Ballard, G., Hammond, J., and Nickerson, R. 2009. "Production Control Principles." *Proc. 17th Annual Conference of the International Group for Lean Construction (IGLC17)*, Taipei, Taiwan, July 13-15.

Ballard, G. and Howell, G. 1994a. "Implementing Lean Construction: Stabilizing Work Flow." *Proc. 2nd Annual Conference of the International Group for Lean Construction (IGLC2)*, Santiago, Chile, September, pp. 101-110 in Alarcon, L.F. (ed.) 1997. *Lean Construction.* A.A. Balkema, Rotterdam, The Netherlands, 497 pp.

Ballard, G. and Howell, G. 1994b. "Implementing Lean Construction: Improving Performance Behind the Shield." *Proc. 2nd Annual Conference of the International Group for Lean Construction (IGLC2)*, Santiago, Chile. Available in Alarcon, L.F. (ed.) 1997. Lean Construction, A.A. Balkema Publishers, Rotterdam, the Netherlands.

Ballard, G. and Howell, G. 1998. "Shielding Production: Essential Step in Production Control." *Journal of Construction Engineering and Management*, ASCE, 124 (1) 11-17.

Ballard, G. and Howell, G.A. 2003. "An Update on Last Planner." *Proc. 11th Annual Conference of the International Group for Lean Construction (IGLC11)*, Blacksburg, Virginia, August.

Ballard, G. and Tommelein, I.D. 2016. *Current Process Benchmark for the Last Planner System*. Online at p2sl.berkeley.edu and available in the *Lean Construction Journal*, pp. 57-89, www.leanconstruction.org/media/docs/lcj/2016/LCJ_16_011.pdf

*Ballard, G., Tommelein, I., Koskela, L. and Howell, G. 2002. Lean Construction Tools and Techniques. Chapter 15 in Best and de Valence (eds.). *Design and Construction: Building in Value*. Butterworth-Heinemann.

Ballard, G., Vaagen, H., Kay, W., Stevens, B., and Pereira, M. 2020. "Extending the Last Planner System to the entire project." *Lean Construction Journal*, pp. 42-77, www.leanconstruction.org/media/docs/lcj/2020/LCJ_19_019.pdf

Bashford, H.H., Sawhney, A., Walsh, K.D., and Kot, K. 2003. "Implications of Even Flow Production Methodology for US Housing Industry." ASCE, *Journal of Construction Engineering and Management*, 129 (3) 330-337, doi.org/10.1061/(ASCE)0733-9364(2003)129:3(330)

Binninger, M., Dlouhy, J., and Haghsheno, S. 2017. "Technical Takt Planning and Takt Control in Construction." *Proc. 25th Annual Conference of the International Group for Lean Construction*, Heraklion, Greece, 9-12 July, pp. 605-612.

Burkhart, A.F. 1989. "The use of SIPS as a productivity improvement tool." ASCE, *Proc. Construction Congress I*, March 5-8, San Francisco, CA, pp. 381-386.

*Canlong, L., González, V.A., Liu, J., Rybkowski, Z., Schöttle, A., Mourgues, C., and Pavez, I. 2020. "Accelerating the LPS Uptake Using Virtual Reality and Serious Games: A Socio-Technical Conceptual Framework." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28)*, Berkeley, California, US, 6-12 July.

Chiu, S. and Cousins, B. 2020. "Last Planner System® in Design." *Lean Construction Journal*, pp. 78-99, www.leanconstruction.org/media/docs/lcj/2020/LCJ_20_006.pdf

*Choo, H.J., Tommelein, I.D., Ballard, G., and Zabelle, T. 1999. "WorkPlan: Constraint-Based Database for Work Package Scheduling." *Journal of Construction Engineering and Management*, ASCE, 125 (3) 151-160.

Christian, D. and Pereira, M. 2020. "THE NEW LPS® 2.0 METRICS – What They Are, Why They Are Needed and Where They Are Used." *Lean Construction Journal*, pp. 119-140, www.leanconstruction.org/media/docs/lcj/2020/LCJ_20_008.pdf

Court, P.F. 2009. *Transforming traditional mechanical and electrical construction into a modern process of assembly*. Eng. D. Dissertation, Loughborough University, UK.

Darrington, J., Dunne, D., and Lichtig, W. 2010. "Organization, Operating System, and Commercial Terms." Chapter 1 (pp. 10-47) in Thomsen, C., Darrington, J., Dunne, D., and Lichtig, W. 2010. *Managing Integrated Project Delivery*. CMAA, McLean, VA, 105 pages.

Dekker, S. 2006. *The field guide to human error*. Bedford, UK: Cranfield University Press.

Deming, W.E. 1986. *Out of the crisis*. Massachusetts Institute of Technology, Center for Advanced Engineering Study, Cambridge, MA, 510.

Dimitri, N. 2013. "'Best value for money' in procurement." *Journal of Public Procurement*, 13 (2) 149-175.

Durlauf, S.N. and Young, H.P. 2004. *Social dynamics*. MIT Press.

*Ebbs, P. and Pasquire, C. 2019. *A facilitators' guide to the Last Planner® System: a repository of facilitation tips for practitioners*. Nottingham Trent University, UK.

*Ebbs, P.J., Pasquire, C.L., and Daniel, E.I. 2018. "The Last Planner® System Path Clearing Approach in Action: A Case Study." *Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC26),* Chennai, India, 18-20 July, pp. 724-733.

Edmondson, A. 1999. "Psychological Safety and Learning Behavior in Work Teams." *Administrative Science Quarterly*, 44 (2) 350-383.

*Etges, B.M., Reck, R.H., Fireman, M.T., Rodrigues, J.L., and Isatto, E.L. 2020. "Using BIM with the Last Planner® System to Improve Constraints Analysis." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28),* Berkeley, California, USA, 6-10 July, pp. 493-504.

*Ezzeddine, A., Shehab, L., Hamzeh, F., and Lucko, G. 2019. "Singularity Functions to Enhance Monitoring in the Last Planner System." *Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC27),* Dublin, Ireland, 3-5 July, pp. 287-298.

Flores, F. 1982. *Management and Communication in the Office of the Future*. PhD Dissertation, University of California, Berkeley, CA.

Flores, F. 2013. *Conversations for Action and Collected Essays: Instilling a Culture of Commitment in Working Relationships*. CreateSpace Independent Publishing Platform, 158 pp., conversationsforaction.com.

Frandson, A.G. and Tommelein, I.D. 2016. "Takt Time Planning of Interiors on a Pre-Cast Hospital Project." *Proc. 24th Annual Conference of the International Group for Lean Construction (IGLC24)*, Boston, Mass., USA, 143-152.

Frandson, A.G., Seppänen, O., and Tommelein, I.D. 2015. "Comparison between location based management and Takt Time Planning." *Proc. 23rd Annual Conference of the International Group for Lean Construction (IGLC23)*, 28-31 July, Perth, Australia, pp. 3-12.

Goldratt, E.M. 1989. *The general theory of constraints.* Abraham Goldratt Institute, New Haven, CT.

González, V., Alarcón, L.F., and Mundaca, F. 2008. "Investigating the relationship between planning reliability and project performance." *Production Planning and Control*, 19 (5) 461-474.

Grau, D., Cruz-Rios, F., and Sherman, R. 2019. *Project Validation: A Guide to Improving Owner Value and Team Performance*. Lean Construction Institute, Arlington, VA, www.leanconstruction.org/media/docs/Project-Validation-Guide_Version-1_May-2019.pdf

*Hamzeh, F., Ballard, G. and Tommelein, I.D. 2012. "Rethinking Lookahead planning to optimize construction workflow." *Lean Construction Journal*, 1 (1) 15-34, www.leanconstruction.org/media/docs/lcj/2012/LCJ_11_008.pdf

Harris, R.B. and Ioannou, P.G. 1998. "Scheduling Projects with Repeating Activities." *Journal of Construction Engineering and Management*, 124 (4) 269-278.

Horman, M.J., Messner, J.I., Riley, D.R., and Pulaski, M.H. 2003. "Using Buffers to Manage Production: A Case Study of the Pentagon Renovation Project." *Proc. 11th Annual Conference of the International Group for Lean Construction (IGLC11)*, Blacksburg, Virginia, USA.

*Howell, G. and Ballard, G. 1994a. "Lean Production Theory: Moving Beyond 'Can-Do'." *Proc. 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile, September, pp. 17-23 in Alarcon, L. (ed.) 1997. *Lean Construction.* A.A. Balkema, Rotterdam, The Netherlands, 497 pp.

*Howell, G. and Ballard, G. 1994b. "Implementing Lean Construction: Reducing Inflow Variation." *Proc. 2nd Annual Conference of the International Group for Lean Construction*, Santiago, Chile, September, pp. 17-23 in Alarcon, L. (ed.) 1997. *Lean Construction.* A.A. Balkema, Rotterdam, The Netherlands, 497 pp.

Howell, G.A., Ballard, G. and Hall, J. 2001. "Capacity Utilization and Wait Time: a Primer for Construction." *Proc. 9th Annual Conference of the International Group for Lean Construction*, Singapore, August, pp. 271-278.

Howell, G., Laufer, A. and Ballard, G. 1993. "Interaction Between Subcycles: One Key to Improved Methods." *Journal of Construction Engineering and Management*, 119 (4) 714-728.

Jabbari, A., Tommelein, I.D., and Kaminsky, P.M. 2020. "Workload Leveling based on Work Space Zoning for Takt Planning." *Automation in Construction*, doi.org/10.1016/j.autcon.2020.103223.

Kahn, W.A. 1990. "Psychological Conditions of Personal Engagement and Disengagement at Work." *Academy of Management Journal*, 33 (4): 692-724.

Kenley, R. and Seppänen, O. 2010. *Location-based Management System for Construction: Planning, Scheduling and Control*. London and New York: Spon Press.

Kim, Y.-W. and Ballard, G. 2000. "Is the Earned-Value Method an Enemy of Work Flow?" *Proc. 8th Annual Conference of the International Group for Lean Construction (IGLC8)*, Brighton, UK, 17-19 July, 10 pages.

Kim, Y.-W. and Ballard, G. 2010. "Management Thinking in the Earned Value Method System and the Last Planner System." ASCE, *Journal of Management in Engineering*, 26 (4) 223-228, doi.org/10.1061/(ASCE)ME.1943-5479.0000026

Koga, J. 2014. *Introducing the CBA Sound Decisionmaking System.* 16th Lean Construction Congress Training Programs, San Francisco, CA, 7-10 October, 144 pp., www.leanconstruction.org/media/docs/congress/2014/T1&2_LCI-AIA-Introducing%20CBA-10.2-slides-Koga-20141007.pdf visited 15 JAN 2021.

*Lagos, C.I., Herrera, R.F., and Alarcón, L.F. 2017. "Contributions of Information Technologies to Last Planner System Implementation." *Proc. 25th Annual Conference of the International Group for Lean Construction (IGLC25)*, Heraklion, Greece, 9-12 July, pp. 87-94.

Liu, M., Ballard, G., and Ibbs, W. 2011. "Work flow variation and labor productivity: Case study." *Journal of Management in Engineering*, 27 (4) 236-242.

*Liu, C., González, V.A., Liu, J., Rybkowski, Z., Schöttle, A., Mourgues Álvarez, C., and Pavez, I. 2020. "Accelerating the Last Planner System® (LPS) Uptake Using Virtual Reality and Serious Games: A Sociotechnical Conceptual Framework." *Proc. 28th Annual Conference of* *the International Group for Lean Construction (IGLC28),* Berkeley, CA, USA, 6-10 July, pp. 481-492.

*Lühr, G.J. and Bosch-Rekveldt, M.G. 2019. "Measuring Projects' Team Culture in Projects Using the Last Planner® System." *Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC27),* Dublin, Ireland, 3-5 July, pp. 963-974.

Nickerson, R.N.A. 2014. "Mistake-Proofing in Design: Leveraging BIM tools, standard process and parametric visualization to elevate the skills and knowledge level of design staff in place of legacy QA/QC efforts." Powerpoint slides presented at *LCI Congress*, San Francisco, CA.

*Novinsky, M., Nesensohn, C., Ihwas, N., and Haghsheno, S. 2018. "Combined Application of Earned Value Management and Last Planner System in Construction Projects." *Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC26),* Chennai, India, 18-20 July, pp. 775-785.

Nutt, H. III, Berghede, K., Odah, S. and Ballard, G. 2020. "LPS® 2.0: Location Based Planning Report." Lean Construction Journal, pp. 100-118, www.leanconstruction.org/media/docs/lcj/2020/LCJ_20_007.pdf

PMI 2017. *A Guide to the Project Management Body of Knowledge (PMBOK® Guide)*. 6th Edition, Project Management Institute, www.pmi.org, 756 pages.

Pound, E., Bell, J., and Spearman, M. 2014. *Factory Physics for Managers*. McGraw-Hill.

*Power, W., Sinnott, D., and Mullin, A. 2020. "Improving Commissioning and Qualification Delivery Using Last Planner® System." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28),* Berkeley, California, USA, 6-10 July, pp. 505-516.

*Priven, V. and Sacks, R. 2015. "Effects of the Last Planner System on social networks among construction trade crews." *Journal of Construction Engineering and Management*, 141(6) 04015006.

*Priven, V. and Sacks, R. 2016. "Impacts of the social subcontract and Last Planner System interventions on the trade-crew workflows of multistory residential construction projects." *Journal of Construction Engineering and Management*, 142 (7) 04016013.

Reiser, P. 2005. "Lessons Learned in Pull Scheduling on Paper Machine Rebuilds." Powerpoint presentation slides, *7th Annual Lean Construction Congress*, Lean Construction Institute, September.

*Salem, C., Lefèvre, C., Li, J., Waters, R., Tommelein, I. D., Jayamanne, E. and Shuler, P. 2018. "Managing the 'Receding Edge'" *Proc. 26th Annual Conference of the International Group for Lean Construction (IGLC26),* Chennai, India, 18-20 July, pp. 713-723.

*Saurin, T.A. and Rooke, J. 2020. "The Last Planner® System as an approach for coping with the complexity of construction projects." Chapter 16 in Tzortzopoulos, P., Kagioglou, M., and Koskela, L. 2020. *Lean Construction: Core Concepts and New Frontiers*. Routledge, pp. 325-340.

Schwaber, K. 1997. "Scrum development process." In: Sutherland J., Patel, D., Casanave, C., Hollowell, G., and Miller, J. (Eds). *Business Object Design and Implementation: OOPSLA'95 Workshop Proceedings*, Springer, London, pp. 117-134.

Seppänen, O., Ballard, G., and Pesonen, S. 2010. "The Combination of Last Planner System and Location-Based Management System." *Lean Construction Journal*, pp. 44-54, www.leanconstruction.org/media/docs/lcj/2010/LCJ_10_013.pdf

Seppanën, O., Modrich, R., and Ballard, G. 2015. "Integration of the Last Planner System and the Location-Based Management System." *Proc. 23rd Annual Conference of the International Group for Lean Construction (IGLC23)*, 123-132.

Singh, V.V., Tommelein, I.D., and Bardaweel, L. 2020. "Visual tool for workload leveling using the work density method for takt planning." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28)*, Berkeley, California, USA, doi.org/10.24928/2020/0061.

Spear, S. and Bowen, H.K. 1999. "Decoding the DNA of the Toyota production system." *Harvard Business Review*, 77:96-108.

Stedman, G. and Walter, R. 2017. "Creating Effective Communication & Empower the Craftsmen: LPS in the Field." KHS&S Contractors, presented at LCI Congress, October 18.

Suhr, J. 1999. *The Choosing By Advantages Decisionmaking System.* Westport, CT: Quorum Books, pp. 254.

Sutherland, J. and Schwaber, K. 2011. *The Scrum Papers. Nuts, Bolts and Origins of an Agile Process (Draft 29 Jan 2011, Paris)*, Scrum, Inc., Cambridge, MA, www.scruminc.com/scrumpapers.pdf

Thomsen, C., Darrington, J., Dunne, D., and Lichtig, W. 2010. *Managing Integrated Project Delivery*. CMAA, McLean, VA, 105 pages.

*Tommelein, I.D. 1998. "Pull-driven scheduling for pipe-spool installation: Simulation of lean construction technique." *Journal of Construction Engineering and Management*, 124 (4) 279-288.

*Tommelein, I.D. 2008. "'Poka Yoke' or Quality by Mistake Proofing Design and Construction Systems." *Proc. 16th Annual Conference of the International Group for Lean Construction (IGLC16)*, 16-18 July, Manchester, UK, pp. 195-205.

Tommelein, I.D. 2017. "Collaborative Takt Time Planning of Non-Repetitive Work." *Proc. Lean & Computing in Construction Congress (LC3), Vol. 1 (CIB W78), Proc. 25th Annual Conference of the International Group for Lean Construction (IGLC25)*, Heraklion, Greece, pp. 745-752, doi.org/10.24928/2017/0271 and conference presentation on YouTube at www.youtube.com/watch?v=500y23NrNms&t=604s

*Tommelein, I.D. 2019. "Principles of Mistakeproofing and Inventive Problem Solving (TRIZ)." *Proc. 27th Annual Conference of the International Group for Lean Construction (IGLC27)*, Dublin, Ireland, 3-5 July, pp. 1401-1412.

Tommelein, I.D. 2020. "Takting the Parade of Trades: Use of Capacity Buffers to Gain Work Flow Reliability." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28)*, Berkeley, California, USA, pp. 421-432, and conference presentation on YouTube at www.youtube.com/watch?v=KTMnbVL4zic&t=7s

*Tommelein, I.D. and Ballard, G. 1997. "Coordinating Specialists." *Technical Report No. 97-8*, Construction Engineering and Management Program, Department of Civil and Environmental Engineering, University of California at Berkeley. Also appeared in *Proc. Second Int'l. Seminar on Lean Construction*, 20-21 October, Sao Paulo, Brazil, organized by A.S.I. Conte, Logical Systems, Sao Paulo, Brazil.

Tommelein, I.D. and Ballard, G. 2016. *Target Value Design: Introduction Framework and Current Benchmark*. Lean Construction Institute, Arlington, VA.

*Tommelein, I.D. and Demirkesen, S. 2018. *Mistakeproofing the Design of Construction Processes Using Inventive Problem Solving*. CPWR, Silver Spring, MD, 60 pp., www.cpwr.com/sites/default/files/publications/Tommelein-mistakeproofing-construction-process.pdf

Tran, D., Molenaar, K.R., and Gransberg, D.D. 2016. "Implementing best-value procurement for design–bid–build highway projects." *Transportation Research Record*, 2573 (1) 26-33.

Tsao, C.C., Tommelein, I.D., Swanlund, E.S., and Howell, G.A. 2004. "Work structuring to achieve integrated product-process design." *Journal of Construction Engineering and Management*, 130 (6) 780-789.

*Tzortzopoulos, P., Kagioglou, M. and Koskela, L.K. (eds.) 2020. *Lean Construction: Core Concepts and New Frontiers*. Routledge.

Wardell, C. 2003. "Build by Numbers." *BUILDER Magazine,* January 1, http://www.builderonline.com/Industrynews.asp?channelID=59&sectionID=62&articletype=1&articleID=1000027886

*Wickramasekara, A.N., González, V.A., O'Sullivan, M., Walker, C.G., Poshdar, M., and Ying, F. 2020. "Exploring the Integration of Last Planner® System, BIM, and Construction Simulation." *Proc. 28th Annual Conference of the International Group for Lean Construction (IGLC28)*. Berkeley, California, USA, 6-10 July, pp. 1057-1068.

Wilkinson, B., Lowe, T., and Pereira, M. 2020. "Learning from Breakdowns in the Last Planner System®." *Lean Construction Journal*, pp. 141-153, www.leanconstruction.org/media/docs/lcj/2020/LCJ_20_009.pdf

Willis, C. 1998. *Building the Empire State*. New York, NY: W.W. Norton.

APPENDICES – ILLUSTRATIONS OF METHODS AND TOOLS

The illustrations of methods and tools provided in the appendices that follow are available thanks to the generosity of practitioners who have adopted the LPS and adapted the System to their project needs. These illustrations are just that: illustrations. It is not our intention to suggest that they are to be replicated exactly as they are but, rather, we suggest that you view them as a source of ideas and adapt them to your planning needs, language, and practices of everyone involved on your project team. We expect methods to vary and new methods to be invented and improved all the time. Be inspired and creative!

APPENDIX A - SCORECARD OF A HEALTHCARE PROJECT (Courtesy of Digby Christian [Sutter Health])

Metric	Goal	Project	Current	Trending
SAFETY				
LOST TIME INCIDENT RATE	< 0.3	0.2 (PROJECT TO DATE)	0 (NOV. INCIDENT COUNT)	–
TOTAL INCIDENT RATE	< 1.5	1.5 (PROJECT TO DATE)	1 (NOV. INCIDENT COUNT)	↑
RECORDABLE INCIDENT RATE	< 1.0	1.4 (PROJECT TO DATE)	1 (NOV. INCIDENT COUNT)	↑
CSI PARTICIPATION: FOREMAN	100%	83% (PROJECT AVERAGE)	97% (CURRENT MONTH)	↑
PREDICTIVE SOLUTIONS PARTICIPATION: SUPTs, APMs, PEs	100%	87% (PROJECT AVERAGE)	95% (CURRENT MONTH)	↑
PREDICTIVE SOLUTIONS PARTICIPATION: DIRECTORS, PMs, Sr. PMs	100%	90% (PROJECT AVERAGE)	89% (CURRENT MONTH)	↓
PREDICTIVE SOLUTIONS PARTICIPATION: SAFETY MGR, SAFETY ENGR	100%	100% (PROJECT AVERAGE)	100% (CURRENT MONTH)	–
PEOPLE				
LOCAL BUSINESS ENTERPRISE ON PROJECT	> 14%	14.3% (PROJECT AVERAGE)	15.0% (CURRENT MONTH'S AVG)	↓
LOCAL RESIDENT EMPLOYEE (JOURNEYMEN & APPRENTICES)	> 30%	28.9% (PROJECT AVERAGE)	23.1% (CURRENT MONTH'S AVG)	↓
PROJECT TEAM USE OF ALT. TRANSPORTATION	50%	50% (PROJECT AVERAGE)	65% (CURRENT MONTH)	↑
TEAM SURVEY: PULSE REPORT SCORE	≥ 5.0	5.6 (PROJECT AVERAGE)	5.7 (CURRENT MONTH)	↑
PULSE REPORT PARTICIPATION RATE	80%	45% (PROJECT AVERAGE)	71% (CURRENT MONTH)	↑
QUALITY				
INSPECTION PASS RATE	100%	99.7% (PROJECT AVERAGE)	99.7% (CURRENT MONTH)	↓
RE-INSPECTIONS OUTSTANDING FOR > 3 DAYS	0	32 (PROJECT TOTAL)	6 (CURRENT MONTH)	↑
DEFECTS FOUND (DELIVERED & INSTALLED)	0	7 (PROJECT TOTAL)	0 (CURRENT MONTH)	–
PRODUCTION / SCHEDULE				
INTERMEDIATE MILESTONE PERFORMANCE (ON TIME OR FASTER)	15/15	10/11 (PROJECT TO DATE)	0/0 (CURRENT MONTH)	–
TOTAL SCHEDULE SAVINGS	> 3%	0% (PROJECT TO DATE)	0% (CURRENT MONTH)	–
FIELD LABOR SAVINGS	> 10%	19.0% (LAST MONTH'S AVG)	20.0% (CURRENT MONTH'S AVG)	↑
COST				
WORK IN PLACE VARIANCE	-5%≤WIP≤5%	-5% (PROJECT AVG VARIANCE)	-14% (CURRENT MONTH)	↓
CONTINGENCY BALANCE	≥ $61,319,931	$50,131,526 (LAST MONTH)	$48,234,833 (CURRENT MONTH)	↓

Figure 28: Monthly scorecard used on large healthcare project (Courtesy of Digby Christian [Sutter Health])

APPENDIX B – ANNUAL INDIVIDUAL WEEKLY WORK PLAN REPORT FOR DESIGNERS
(Courtesy of Romano Nickerson [Boulder Associates])

Annual Individual WWP Report for Mia Design

2021

Welcome! This document is an Individual Weekly Work Planning Report prepared specifically for you, Mia Design. The content is generated based on the numbers you reported during the past year and is formatted to reflect areas of strength, as well as areas where you can improve. The report is further customized to identify specific strategies for improvement. Training and supplementary materials will be made available from the BA Lean Champions.

PROCESS & PARTICIPATION

	1	2	3	4	5	6	7	8	9	10	11	12	13	
Q1	S	S	S	S	S	S	S	S	S	S	S	S	S	100%
Q2	S	S	S	S	S	S	S	S	S	S	S	S	S	100%
Q3	S	S	S	S	S	S	S	S	S	S	S	S	S	100%
Q4	S	S	S	M	M	S	S	S	S	S	S	S	S	85%

S = Submitted M = Missing E = Excused P = Prior to Employment

PEER GROUP COMPARISON

Mia Design Average:	**96%**
Arch I Average:	98%
Sacramento Average:	87%
Architecture Average:	92%
Technical Employee Average:	95%

Thank you for participating in the 90|90 goal. We set the goal because it is important to be in touch with our process as professionals. The more fidelity we bring to the work planning process, the more we can leverage the numbers we track. A key part of that effort relies on feedback from the numbers and for that we need accurate reporting. You had a total of 9 weeks where you did not indicate the correct number of variances Remember that you must indicate a variance for each promised task that you did not complete. Another important contributor to successful work planning is reliable participation. Last year you submitted 50 total work plans, a participation rate of 96%.

REDUCING VARIANCE

Variance 1	*Incorrect estimate of time required to commit task*	**1**	1
Variance 2	*Need more information - internal*	**2**	0
Variance 3	*Need more information - external*	**3**	17
Variance 4	*Conditions of satisfaction not clearly defined*	**4**	3
Variance 5	*Superseded by other work on the project / fire fighting*	**5**	2
Variance 6	*Superseded by work on a different project / fire fighting*	**6**	1
Variance 7	*Commitment or promise was forgotten*	**7**	0
Variance 8	*Commitment or promise no longer required*	**8**	16
Variance 9	*Technical failure, sickness, or casus fortuitus, etc. prevented work completion*	**9**	1

PEER GROUP COMPARISON

	1st	2nd
Mia Design Most Frequent:	**3**	**8**
Arch I Most Frequent:	3	5
Sacramento Most Frequent:	1	6
Architecture Most Frequent:	6	1
Technical Employee Most Frequent:	1	6

By reviewing variances, we can focus our improvement efforts in the areas that will maximize the impact of your effort. Your most frequent variance for the past year was Variance 3. Your second most frequent variance was Variance 8. These two variances accounted for 80% of your total instances of variance for the past year. The following strategies will help you to reduce and even eliminate the instances of your two most frequent reasons for variance:

Variance 3 Need more information - external

Improving the negotiation between requester and promiser forms the basis for reducing and eliminating Variance 3. Remember to use the 10 Steps for Reliable Commitments to ensure that both parties are on the same page. Monitor this variance over time. If the same person, firm, or even client continues to hold up your work flow, then intervention may be in order. They may be unaware of the impact they are having or could be constrained in a way you are unaware of. All told, more communication is better! Remember that speaking with a client about commitments can be a touchy subject. Determine who is the main Boulder Associates point of contact with the client and coordinate with them before you read anyone the riot act.

Variance 8 Commitment or promise no longer required

When Variance 8 occurs, be sure to check that the decision to remove the commitment was mutual. Avoid inventing commitments simply to populate a work plan. Commitments should usually come from requests or from the pull of a milestone or handoff.

Figure 29: Annual weekly work plan (WWP) report for individual designer (Mia Design) – Process and participation data and variances (Part 1 of 2)
(Courtesy of Romano Nickerson [Boulder Associates])

IMPROVING RELIABILITY

PPC by Week

	Q1	Q2	Q3	Q4
1	100%	100%	82%	100%
2	79%	100%	100%	100%
3	100%	94%	100%	100%
4	92%	80%	100%	
5	96%	94%	100%	
6	100%	85%	64%	78%
7	94%	100%	53%	67%
8	59%	83%	70%	71%
9	86%	92%	100%	100%
10	100%	78%	47%	100%
11	100%	95%	100%	100%
12	100%	100%	100%	100%
13	100%	100%	100%	100%
	92%	**94%**	**84%**	**93%**

Understanding the Data

Your weekly PPC has been captured in the blue box immediately to the left. The darker colors indicate higher reliability. The numbers in **bold** are weeks where your PPC was especially high and the numbers in red indicate weeks where your PPC was especially low. Weeks with a "V" indicate vacation. The surface graph to the left is a plot of your weekly PPC.

PEER GROUP COMPARISON

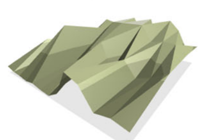
Mia Design Average:	**91%**
Arch I Average:	84%
Sacramento Average:	84%
Architecture Average:	82%
Technical Employee Average:	84%

Strategies for Improving Reliability

You completed 654 out of 718 promised tasks for a PPC for the year of 91%. This percentage is well above the average we would expect to see, so kudos and keep up the good work! You can excel even more by working to eliminate your most frequently reported variance. A strategy for increasing reliability first derives from looking at the types of variance you reported most frequently. Since your most frequently reported variance was Variance 3, it is likely that you may feel frustrated because the person constraining your work is outside the firm. However, this is certainly not an insurmountable challenge. The key for bringing outside team members into alignment is visibility and public accountability. This can be accomplished through commitment logs, meeting minutes, and open discussion at meetings, especially when the client is present. And if the delinquent promiser is the client, then a side conversation with the right deferential tone about setting the standard for the team can be the right catalyst for helping them back in line. Agencies can certainly be a tougher player, but it has certainly proven to be the case that they will fall all over themselves to help you if you build a relationship and then behave as an advocate for the system within which they work. Obviously, the efficacy of these approaches will vary from project to project and client to client, but it is certainly worth making the effort. Keep that in mind, as well as working the strategies outlined in the section on Reducing Variance.

BETTER WORK PLANNING

TA by Week



	Q1	Q2	Q3	Q4
1	15%	**57%**	11%	**54%**
2	9%	21%	35%	**88%**
3	8%	24%	**50%**	**82%**
4	4%	**100%**	**80%**	
5	9%	19%	**77%**	
6	5%	36%	**100%**	**100%**
7	3%	25%	**100%**	**63%**
8	19%	**80%**	**100%**	**100%**
9	**67%**	27%	**100%**	42%
10	**57%**	**57%**	**67%**	**100%**
11	24%	28%	**71%**	**78%**
12	31%	38%	**70%**	38%
13	26%	**55%**	54%	44%
	15%	**34%**	**66%**	**65%**

Understanding the Data

Your weekly TA has been captured in the green box immediately to the left. The darker colors indicate better planning ahead. The numbers in **bold** are weeks where your TA was especially high and the numbers in red indicate weeks where your TA was especially low. Weeks with a "V" indicate vacation. The surface graph to the left is a plot of your weekly TA.

PEER GROUP COMPARISON

Mia Design Average:	**39%**
Arch I Average:	65%
Sacramento Average:	30%
Architecture Average:	47%
Technical Employee Average:	38%

Strategies for Better Work Planning

Of the 654 tasks you completed last year, 253 of them were planned more than a week in advance, giving you a TA percentage of 39%. This percentage is a bit lower than we would like to see. You can use the following strategies to improve your planning, which will help your TA to rise. There are two sure-fire ways to increase TA: pulling from a strong team work plan and seeking and developing standard work. Both strategies will help pull your planning window further forward into the future. A solid team work plan should include milestones and handoffs. Work with your team weekly to plan and confirm the plan daily. Check frequently and consider how your individual work plan plugs into the team work plan, making adjustments as needed. Look for standardized work in any task or series of tasks that is repeated, either within the project or across many projects. Once repetitive work is identified, look for ways to optimize and tighten up the activity. This will save you time and intellectual energy, allowing you to accomplish more work with less effort.

Figure 30: Annual weekly work plan (WWP) report for individual designer (Mia Design) – Improvement suggestions (Part 2 of 2)
(Courtesy of Romano Nickerson [Boulder Associates])

APPENDIX C – MANAGERS' SITE VISIT REPORT (Courtesy of Nick Loughrin [Boldt])

Boldt senior managers periodically visit the projects for which they are responsible. The site visit report (Figures 31, 32, and 33) is completed on each visit and goals for improvement are set with the project team.

Site Visit Report

Project: ______________ Project Start: ______________ Date Rev: ______________ Auditor: ______________

THE BOLDT PRODUCTION SYSTEM

IDEAL STATE	ALWAYS	SOME-TIMES	NEVER	N/A	UNSURE	COMMENTS / NEXT STEPS / OBSTACLES
LEVEL 1: STRATEGIC PLAN						
The project schedule (P6/MP) is updated weekly and visible to the project team						
All major and phase level milestones are identified in the project schedule, shared with project team and tracked for variances						
Goals identified for safety, quality, cost, schedule and people are well defined and shared with the project team						
Contracts are written to accommodate production language						
Boldt project team responsibilities are well defined and understood amongst the project team.						
Prior to commencing work, all subcontractors are introduced to Boldt's way of planning and the expectations of being part of the project team						
LEVEL 2: PHASE PLAN						
Phases are planned out at least (1) lookahead period prior to the start of work and are completed using pull planning techniques						
A plan is developed for prefabrication, preassembly, and modularization with the project team						
All phase plans are updated in the project schedule (P6/MP) and visual to the project team						
All procurement streams are aligned to each phase plan						
All work scopes identified are detailed in steps that identify past failures, lessons learned, best practices, and production and safety considerations						

BOLDT. Site Visit Report | 10/1/2020 Page 1

Figure 31: Site visit report (Part 1 of 3) (Courtesy of Nick Loughrin [Boldt])

IDEAL STATE	ALWAYS	SOME-TIMES	NEVER	N/A	UNSURE	COMMENTS / NEXT STEPS / OBSTACLES
LEVEL 3: PRODUCTION PLAN						
The production workflow is clearly defined into specific production areas, with visible flow, handoffs, trade sequence and crew capacity to level workflow across all trades						
Quality and safety considerations are built into all production plans						
All materials and assemblies arrive just in time and are stored at the point of use according to planned production work flow						
LEVEL 4: LOOKAHEAD PLAN						
The lookahead plan is based on a 6-8-week planning window, is updated weekly and visible to the project team						
Constraints are tracked visually and managed daily.						
Production boards are being populated with enough details for planned work that allows all trades to understand how their work impacts the production flow of the project						
The Owner, design team and subcontractors are engaged in the weekly constraint management						
All subcontractors are participating in all production planning meetings and freely bringing up issues or constraints that may impact their commitments						
Commitments are only being made to work that is constraint-free or work that has a high probability to be constraint free before work is planned to start						
Percent Planned Complete (PPC) is tracked and updated weekly and displayed visually to meet the goal of 100% PPC						
All reasons for variance to the plan are collected by using root cause analysis and documented to analyze trends						
Trade specific training is being held to ensure all new processes and procedures to uphold quality goals are understood and implemented by all field workers						

BOLDT. Site Visit Report | 10/1/2020 Page 2

Figure 32: Site visit report (Part 2 of 3) (Courtesy of Nick Loughrin [Boldt])

IDEAL STATE	ALWAYS	SOME-TIMES	NEVER	N/A	UNSURE	COMMENTS / NEXT STEPS / OBSTACLES
LEVEL 5: EXECUTION PLAN						
The weekly work plan is maintained and updated daily						
Daily Huddles are occurring at the production boards or as close to the work as possible						
Individual trades discuss their daily production targets and address any new constraints impacting their work with the team						
All trades are fully engaged in daily huddles and weekly work plan meetings.						
Continuously review metrics from performance made in production, quality and safety and adjust plan as needed based on variances observed						

BOLDT. Site Visit Report | 10/1/2020 Page 3

Figure 33: Site visit report (Part 3 of 3) (Courtesy of Nick Loughrin [Boldt])

APPENDIX D – MASTER PLANNING
(Courtesy of Rebecca Snelling [JE Dunn])

Figure 34: Master planning (Courtesy of Rebecca Snelling [JE Dunn])

APPENDIX E – PULL PLANNING

E.1 Phase Pull Planning (Courtesy of Rebecca Snelling [JE Dunn])

Phase pull planning starts with a blank sheet of paper; no calendar dates are shown. This helps the team focus on tasks and sequencing, without prematurely pinning down durations or dates. Trades select the color of their sticky note and create an index (upper left corner in Figure 35). The end milestone is identified (pink sticky note on the far right of Figure 35) and the team then works back in time to identify hand offs and tasks. This approach can also be used in a virtual setting (Figure 36).

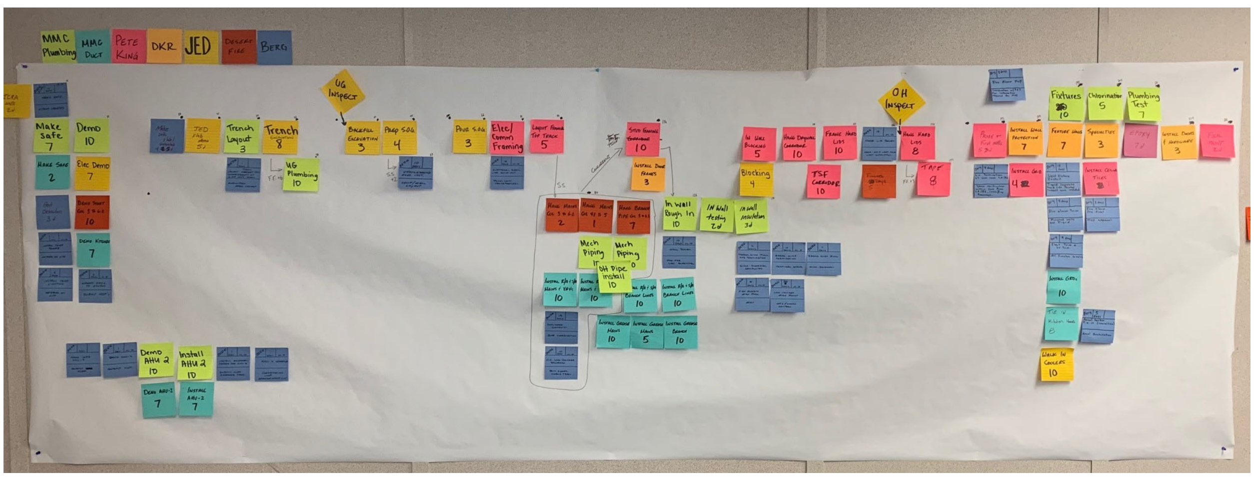


Figure 35: Phase pull plan starting with a blank sheet of paper
(Courtesy of Rebecca Snelling [JE Dunn])

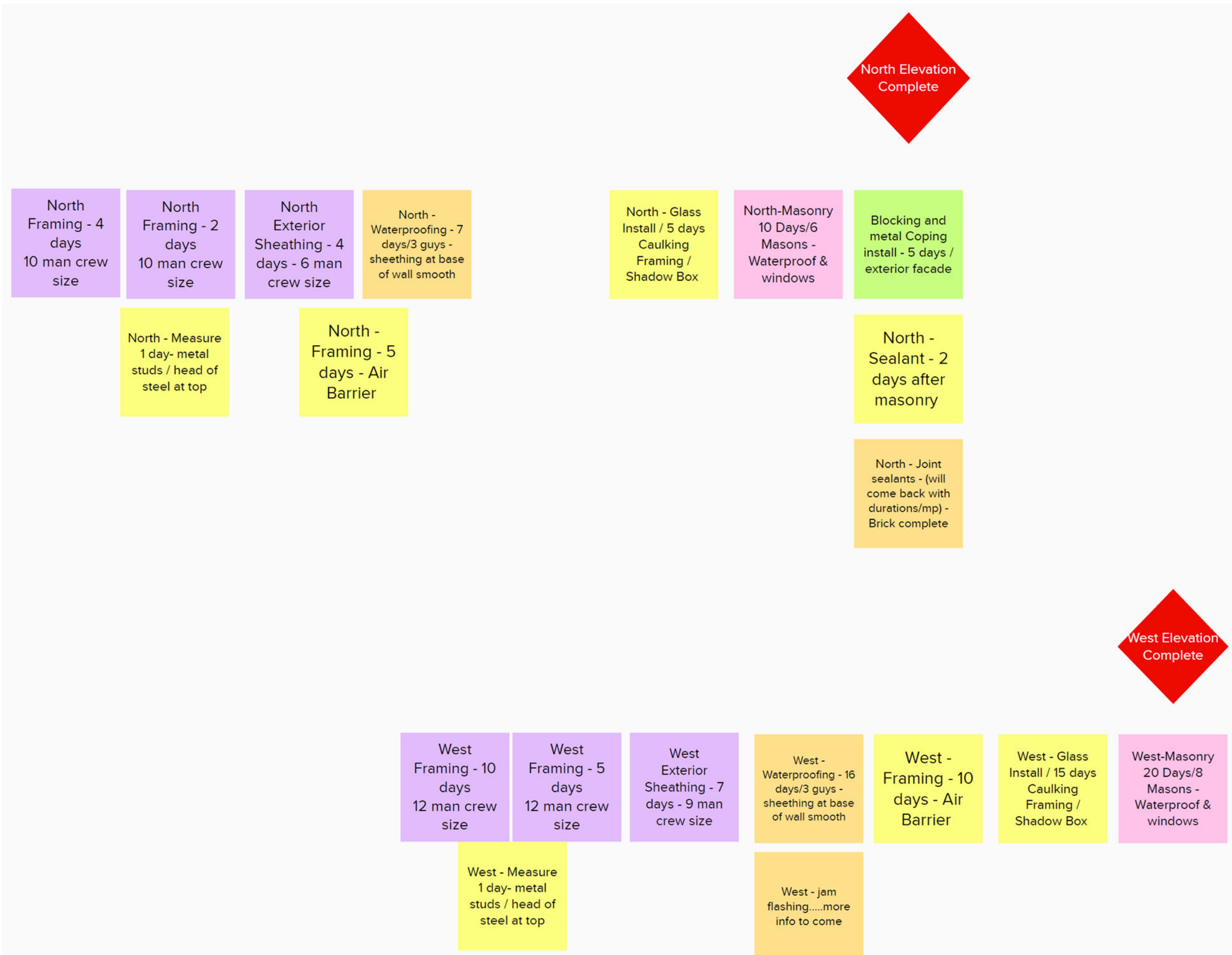


Figure 36: Virtual phase pull plan starting with a blank sheet
(Courtesy of Rebecca Snelling [JE Dunn])

E.2 Mural for Virtual Pull Planning (Created by Robins and Morton, Courtesy of Bernita Beikmann [HKS])

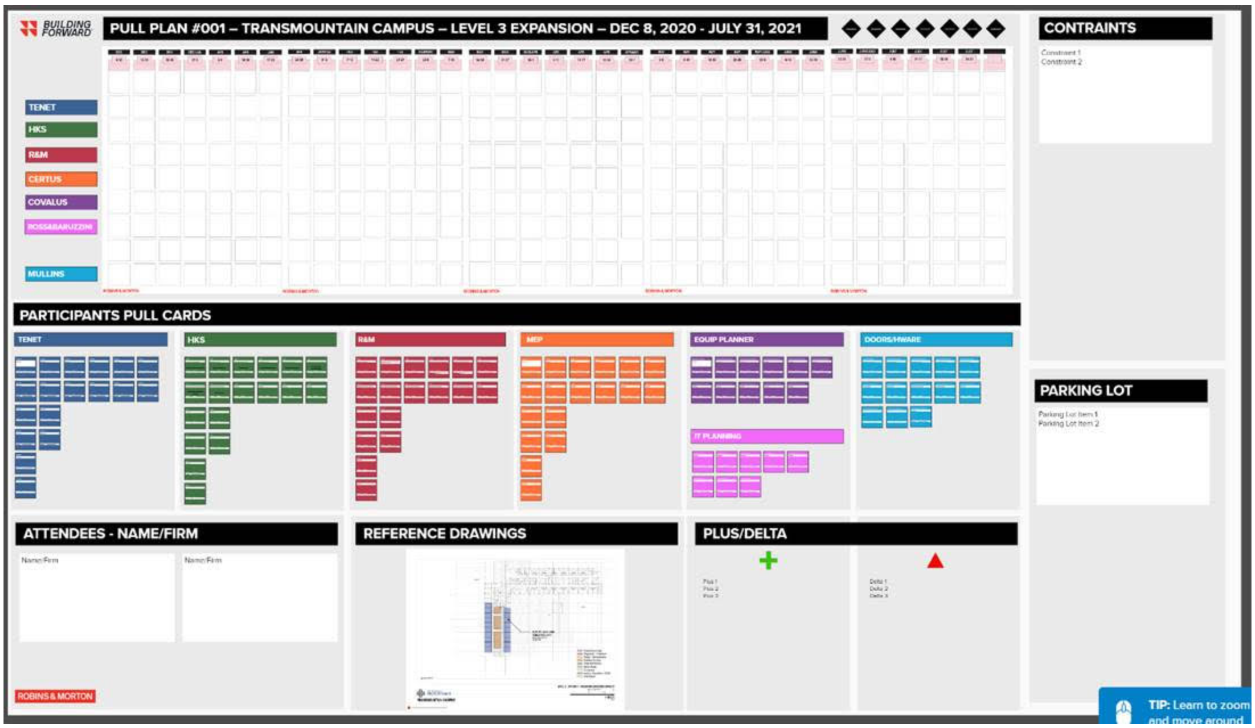


Figure 37: Mural for virtual pull planning
(Created by Robins and Morton, Courtesy of Bernita Beikmann [HKS])

E.3 Los Gatos Virtual Pull Planning (Courtesy of Romano Nickerson [Boulder Associates])

The following nine figures are from a slide deck that Romano Nickerson uses to coach a team in a virtual pull planning session (Figures 38 to 46).

VIRTUAL PULL PLANNING

1. Make Ready - pre-reading and prep
2. Lean Level Set - Toyota > Manufacturing > Lean Design & Construction > Last Planner System
3. Conditions of Satisfaction - What are we pulling today?
4. Standards of Completion - What does "done" look like for each discipline
5. Pull Planning - discipline by discipline
6. Documentation - data driven
7. Follow-On - status, capture variance, and re-plan work weekly

PROCESS GOALS

1. Accommodate a large number of users
2. Accessible to users without licensure
3. Zero cost for software
4. Low internet bandwidth need for users

Figure 38: Virtual pull planning (Slide 1 of 9) – Session outline and process goals (Courtesy of Romano Nickerson [Boulder Associates])

MAKE-READY

- Start one week prior to event
- Determine stakeholders and project data and logistics
- Schedule meeting - **voice call only** as we use the collaborative function of the Google Suite
- Distribute pre-reading materials from Transforming Design & Construction
  - Chapter 26: Reliable Promising
  - Chapter 25: Last Planner System
- Prepare Planning Template (Google Sheets) and Planning Whiteboard (Google Slides)

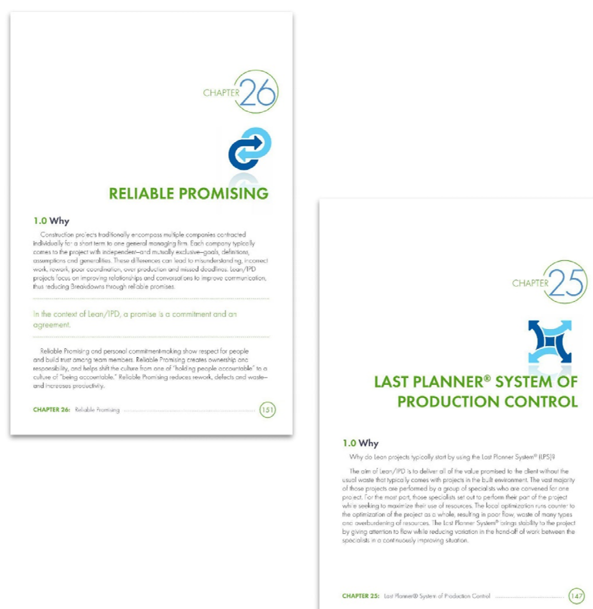


Figure 39: Virtual pull planning (Slide 2 of 9) – Make-ready tasks (Courtesy of Romano Nickerson [Boulder Associates])

LEAN LEVEL SET

- 20 minute duration
- Origins in Toyota
- Development of Lean Construction
- Last Planner System
  - Boulders
  - Cobbles
  - Gravel
  - Sand
- Commitment Madlibs

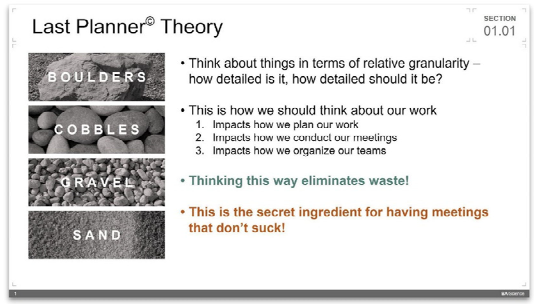


Figure 40: Virtual pull planning (Slide 3 of 9) – Review of lean principles and Last Planner System (Courtesy of Romano Nickerson [Boulder Associates])

CONDITIONS OF SATISFACTION

- 20 minute duration
- Answer the questions
  - "What are we pulling toward?"
  - "How will we use the deliverable?"
- Work to consensus
- Document the CoS live in a Google Doc
- Google Doc also serves as a parking lot for important issues throughout the day

2020-04-10
Conditions of Satisfaction (CoS)

- ASC Emphasis
  - Floor Plan
    - Layout plus equipment
- Underground Permit
  - Plumbing/Electrical
- Keep in mind that not everyone is in construction field, be mindful of terminology
- Identifying which elements will be in the package per stakeholder → Identify milestones → place on planning whiteboard
- Milestones: Finish DD (Design Dev) by July 15

Figure 41: Virtual pull planning (Slide 4 of 9) – Definition of conditions of satisfaction (Courtesy of Romano Nickerson [Boulder Associates])

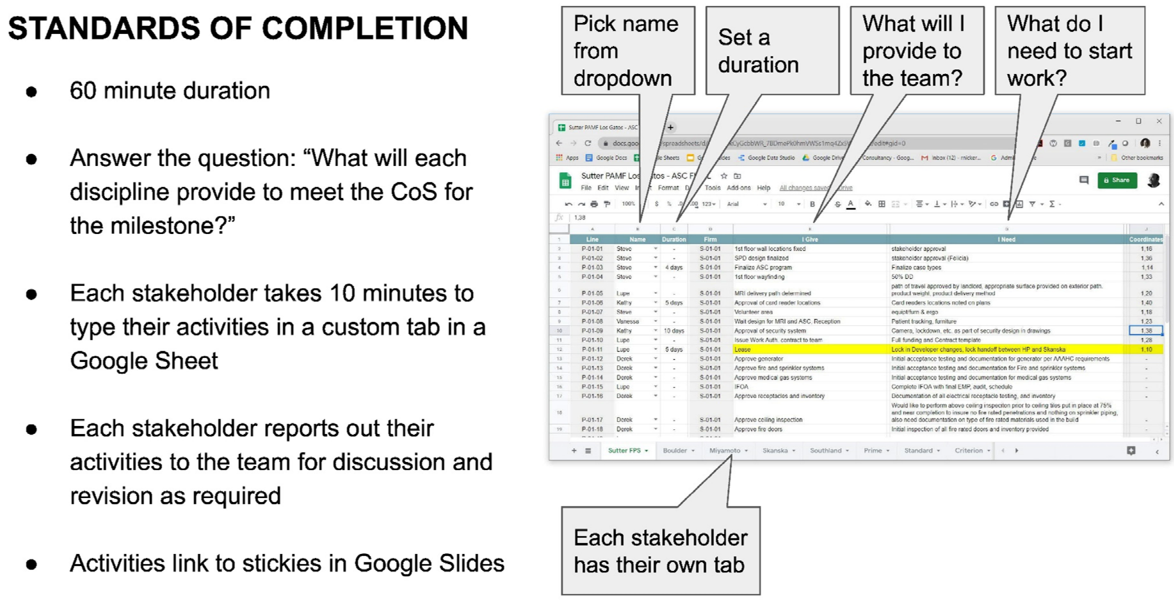


Figure 42: Virtual pull planning (Slide 5 of 9) – Definition of standards of completion (Courtesy of Romano Nickerson [Boulder Associates])

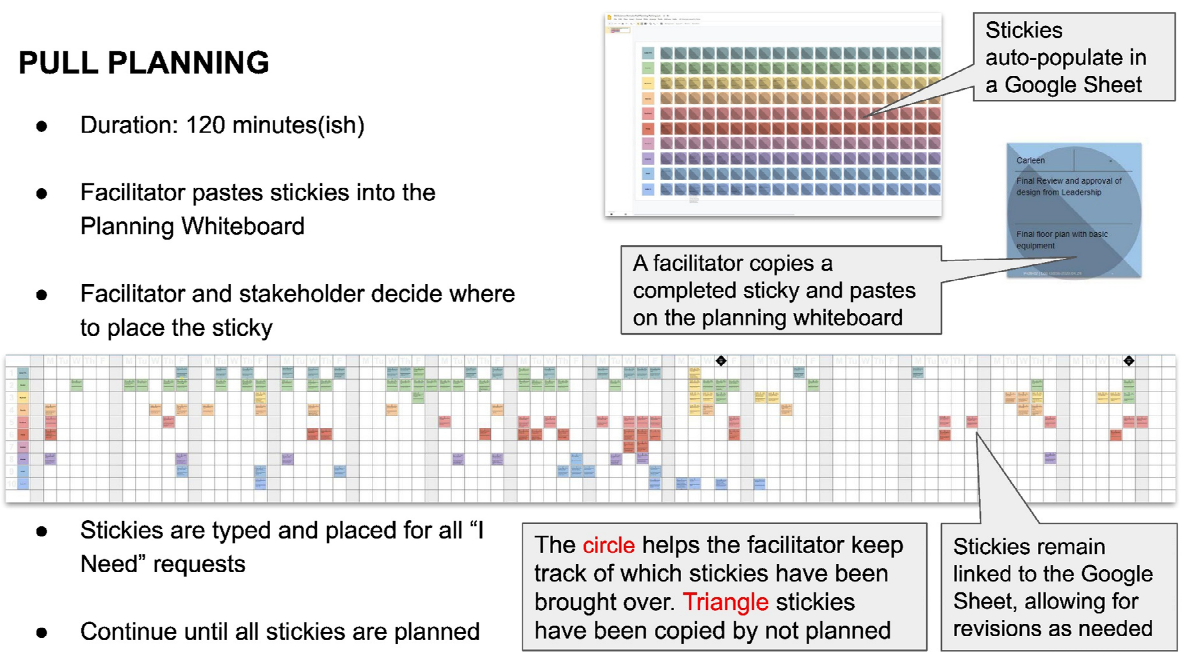


Figure 43: Virtual pull planning (Slide 6 of 9) – Guidance for pull planning session (Courtesy of Romano Nickerson [Boulder Associates])

DOCUMENTATION

- Duration: By CoB two days after event
- Grid location of stickies are mapped into the Google Sheet
- Record file and record PDF of the Planning Whiteboard are generated
- Record file of the Sheet is generated
- Gantt view PDF is automatically generated
- PDFs are distributed for review and comment

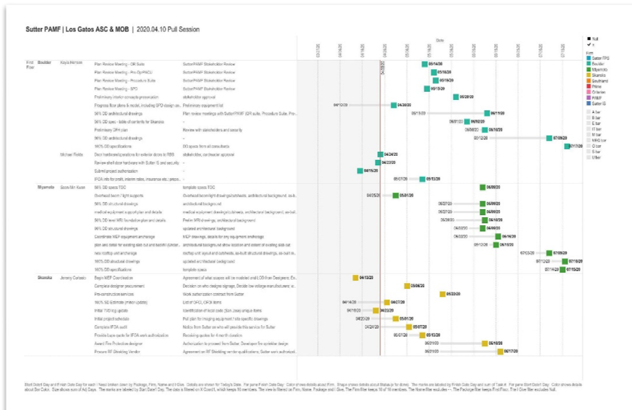


Figure 44: Virtual pull planning (Slide 7 of 9) – Documentation of results from pull planning session (Courtesy of Romano Nickerson [Boulder Associates])

FOLLOW-ON

- The team will work the plan as part of their regular team meetings
- Establish a Weekly Work Planning Cycle
- Remember, **plan is a verb, not a noun!**

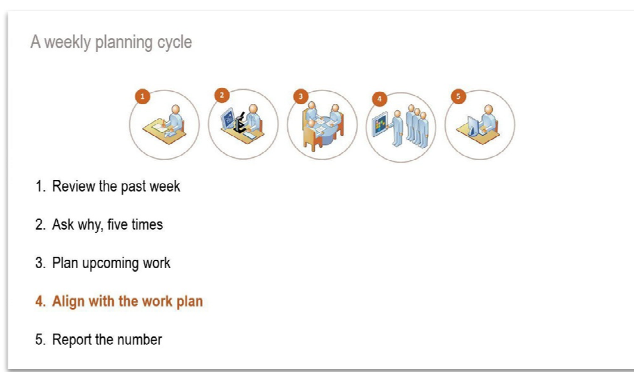


Figure 45: Virtual pull planning (Slide 8 of 9) – Follow-on tasks to pull planning session (Courtesy of Romano Nickerson [Boulder Associates])

PLUS | DELTA

- This was an experiment that worked better than we hoped

4/10/20

Plus / Deltas

Plus
- All stakeholders present
- Great tool for planning / Virtual tool
- Process helpful for dependencies
- Grateful that Google collaboration technology tools worked

Deltas
- Need to build more capacity into the tool
- The tool was unfamiliar to almost everybody, better way to get tuned in ahead of time
- Difficult to understand tool for those that have not participated in pull planning before
- Suggestion - if we could see each other, would like video. Collaboration with google doc suites and virtual meeting made it slow
- Images were tiny/difficult to see for those with laptop/small screen
- Process could have gone quicker if people prepopulated/did their homework
- Way to raise hand or make a comment so that we aren't talking over each other

4/17/20

Plus/Deltas

Plus
- Good that we're making a big investment by taking time to plan this

Delta
- We need more time than expected
- Cue earlier when we are off track (ie, getting into solving phase) if need to reset
- Order of entities, can we look at clinically oriented - schedule upfront so that they can get back to their clinic and work
- Improve by using this knowledge to be a little more prepared for the next session
- Connection was slower today compared to last time

Figure 46: Virtual pull planning (Slide 9 of 9) – Plus-delta lessons learned from session (Courtesy of Romano Nickerson [Boulder Associates])

APPENDIX F – WEEKLY PLANNING CYCLE

F.1 LeanProject's Recommended LPS Weekly Planning Cycle (Courtesy of LeanProject and Tom Richert)

FEBRUARY 22 2017 | TOM RICHERT[23] | LAST PLANNER® SYSTEM

Source: https://www.leanproject.com/news/the-recommended-last-planner-system-weekly-planning-cycle/ visited 6 JAN 2021

Standard work is a powerful Lean tool and should be applied toward planning the work as much as toward doing the work. The key to leveraging the power of standard work in weekly work planning is to develop an approach universally practiced by project team members, and then throughout the course of the project test possible adjustments to the planning approach that originate from the Weekly Coordination meeting Plus-Delta reflections.

We recommend project teams new to the Last Planner System start with the following weekly planning cycle (Figure 47).

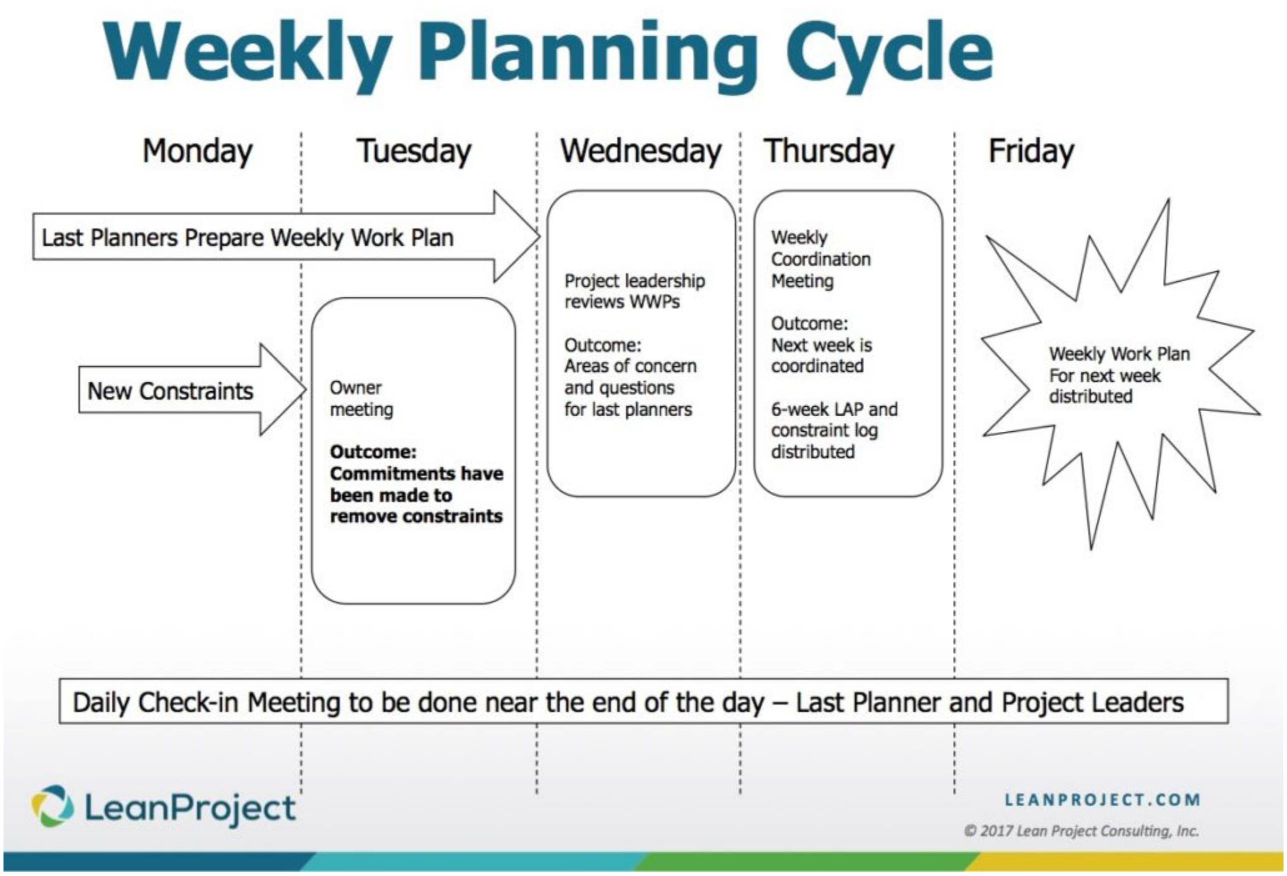


Figure 47: Weekly planning cycle (Courtesy of LeanProject and Tom Reichert)

[23] Tom Richert is now no longer with LeanProject.

***Monday**:* Project leaders distribute the lookahead plan to the last planners. For purposes of this post we will assume a six-week lookahead horizon is being used. Last planners review the lookahead plan to determine if any tasks beginning in week 6 are constrained. Last planners should identify constraints to the project leaders that day, as it is possible that meetings that do not include last planners, such as the traditional Owner-Architect-Contractor (OAC) meeting, will be held early in the week. These meetings often include players that unfortunately do not participate in the last planner Weekly Coordination meeting.

Last planners need to also be reviewing the lookahead plan to determine if any tasks in weeks 2 through 5 should be broken into more detail so that work between disciplines can be more effectively coordinated and to create better opportunities for learning about the work.

Last planners should also begin developing their weekly work plan for the following week, including make ready work for which they are responsible, and can make a reliable promise to complete. They rely primarily on the lookahead plan while preparing their weekly work plan, however any tasks they plan to accomplish the following week not included on the lookahead plan should also be listed on the weekly work plan, with the fact that the work was not anticipated highlighted for other on the team. Workable backlog should also be included on the weekly plan.

***Tuesday**:* Last planners should complete their draft weekly work plans, and submit them to project leaders by the end of the day.

***Wednesday**:* Project leaders consolidate the weekly plans from the last planners, organizing planned tasks to make the flow of the work visible. Any concerns and questions resulting from the leaders' review of the draft plan should be discussed during the day individually with the last planners. This is often an excellent coaching opportunity for project leaders needing to help last planners new to the Last Planner System.

Draft weekly work plans for the project are distributed to the last planners by the end of the day.

***Thursday**:* The Weekly Coordination meeting for last planners is held on this day. Any needed adjustments to the draft weekly work plan are discussed in the meeting. Make ready planning, including a review of the lookahead plan and constraint log, is also accomplished in this meeting.

***Friday**:* A final version of next week's weekly work plan is distributed to last planners, for distribution to all project team members.

We recommend the above planning cycle because Thursday Weekly Coordination meetings allow time for last planners to incorporate new information into their final weekly plans on that day. For different reasons some project teams will have their Weekly Coordination meeting on other days of the week. While shifting the planning cycle to different days can work and is sometimes necessary, the structure described above has proven to be a successful starting point for most project teams.

F.2 Weekly Meeting Calendar (Courtesy of Nick Loughrin [Boldt])

NOTRE DAME
WEEKLY MEETING CALENDAR

Time	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY
6:00 AM					
6:30 AM	Daily Huddle 6:30 - 6:45 AM SUPTS / FOREMAN	Daily Huddle 6:30 - 6:45 AM SUPTS / FOREMAN	Daily Huddle 6:30 - 6:45 AM SUPTS / FOREMAN	Daily Huddle 6:30 - 6:45 AM SUPTS / FOREMAN	Daily Huddle 6:30 - 6:45 AM SUPTS / FOREMAN
7:00 AM					
7:30 AM					
8:00 AM					
8:30 AM	Daily Issue Huddle 8:30 - 8:45 AM	Daily Issue Huddle 8:30 - 8:45 AM	Daily Issue Huddle 8:30 - 8:45 AM	Daily Issue Huddle 8:30 - 8:45 AM	Daily Issue Huddle 8:30 - 8:45 AM
9:00 AM	Daily Make Ready Team Huddle 8:45 - 9:00 AM	Daily Make Ready Team Huddle 8:45 - 9:00 AM	Daily Make Ready Team Huddle 8:45 - 9:00 AM	Daily Make Ready Team Huddle 8:45 - 9:00 AM	Daily Make Ready Team Huddle 8:45 - 9:00 AM
9:30 AM					
10:00 AM					
10:30 AM					
11:00 AM		OAC Meeting 11:00 AM - 12:00 PM			
11:30 AM					
12:00 PM					
12:30 PM			Safety Meeting 12:30 - 1:00 PM ALL HANDS		
1:00 PM					NO MEETING ZONE
1:30 PM				Update Planner Boards 1:45 - 2:00 PM	
2:00 PM		Weekly Make Ready Work Planning Meeting 2:00 PM - 3:00 PM (BOLDT STAFF MTG)		Weekly Production Planning Meeting 2:00 - 3:00 PM SUPTS. / PMS	
2:30 PM					
3:00 PM					
3:30 PM					
4:00 PM					
4:30 PM					

KEY:		
	PRODUCTION TEAM	Boldt & Trade PM's, Supers, Foreman
	SAFETY TEAM	ALL HANDS
	OAC TEAM	Tom, Curtis, Kurt, KFI, ND
	ISSUE MGT TEAM	Boldt & Trade PM's, KFI
	MAKE READY TEAM	Boldt PM's / FE's

Figure 48: Weekly meeting calendar (Courtesy of Nick Loughrin [Boldt])

The agenda for the weekly Last Planner meeting, held on Thursdays, is shown in Figure 50.

APPENDIX G – WEEKLY WORK PLAN MEETING AGENDA

G.1 Agenda for Weekly Work Plan Meeting (Courtesy of Pankow)

Pankow
THINKING BEYOND THE BUILDING

Weekly Work Plan Meeting

Duration*: Approximately 60 min

Location: Office (either jobsite, or other, dependent on project phase)

Attendees:

a. Required: Pankow Superintendent(s), Project Engineer(s) responsible for the work being reviewed, Last Planners

b. As needed: Subcontractor or Design Project Managers, Pankow Foreman

Agenda*:

1. Safety, security, operational concerns (5 min.)
2. Review current week's performance (5 min.)
   a. Current week's PPC (Plan Percent Complete) – Are we on target? Trends?
   b. Variance Data/Chart – How do we improve next week?
3. Finalize next week's Weekly Work Plan (25 min.)
   a. Coordinate the work and **Confirm** commitments
   b. Agree on workable backlog
4. Review weeks 2 & 3 Work Plan (10 min)
   a. Discuss constraints that need to be removed (these are now high priority)
   b. Determine whether any activities need to be broken down into further detail
5. Review weeks 4-6 Work Plan (5 min.)
   a. Review the new activities added in week 6
   b. Review weeks 4 & 5, as needed - only for new exceptions that arise
   c. Review constraint log and discuss constraint removal
6. General discussion to raise new issues (5 min.)
7. Plus/Delta (5 min.)

*Time durations are only an estimate and will vary dependent on project complexity

Figure 49: Agenda for weekly work plan meeting (Courtesy of Pankow)

G.2 Agenda for Weekly Last Planner Meeting (Courtesy of Nick Loughrin [Boldt])

Weekly Last Planner Meeting

(1:45 pm Thursday)
Attendees: PMs, Supts. working in next 6-8 weeks

Agenda:

1. Update Planner Boards (1:45-2)
    a. Week 3 board
    b. Other boards as necessary

2. Review week ending (2-2:05)
    a. CSI/Safety
    b. Percent Planned Complete & Variance Tracking for week

3. Review and Commit Next 3 weeks – by contractor (2:05-2:35)
    a. Review Week 1, 2, & 3 weekly goals
    b. Are any tasks constrained?
        i. Does each task have all the information, materials, tools, external approvals, man power, and work methods?
    c. Status existing constraints
    d. Is there any workable backlog for this week?

4. Review week's 4, 5, 6, 7 and 8 milestones (2:35-2:40)
    a. Ask for any questions

5. Scan for Constraints – all at wall with constraint checklist (2:40-3)
    a. Any constraints that we did not catch?
    b. Right size any work not in a weekly chunk

Figure 50: Agenda for weekly Last Planner meeting (Courtesy of Nick Loughrin [Boldt])

APPENDIX H – WEEKLY WORK PLANNING / COMMITMENT MAKING WITH SPACE COORDINATION (Courtesy of Dan Murphy [Turner Construction])

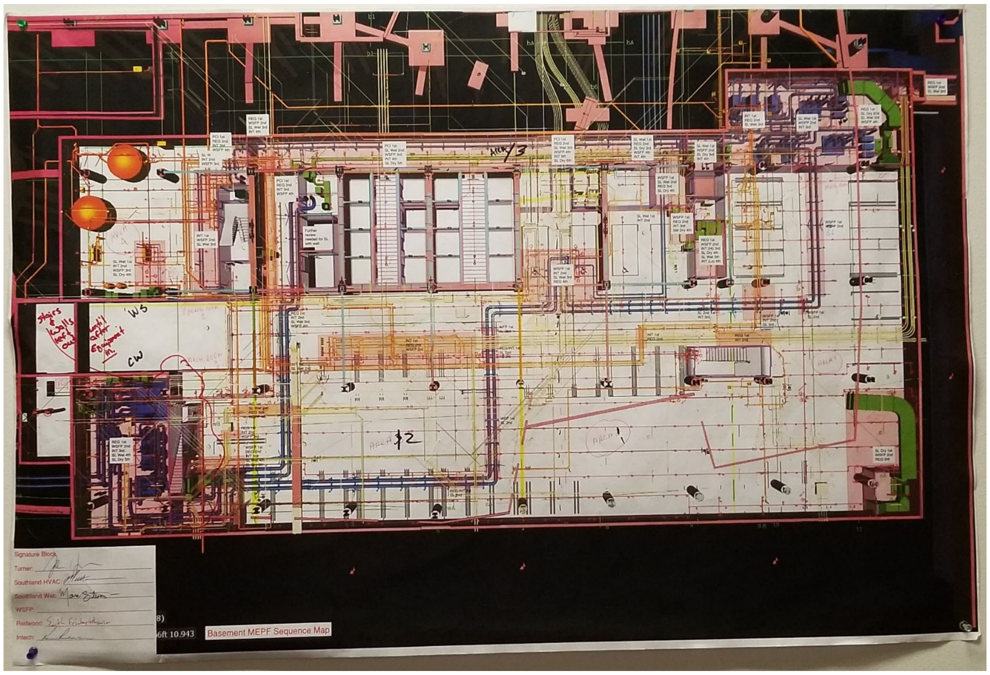


Figure 51: Detailed projections of building floor plan used as reference in weekly work planning (Courtesy of Dan Murphy [Turner Construction])

Figure 52: Commitments (color-coded sticky notes) posted on building floor plan used in weekly work planning (Courtesy of Dan Murphy [Turner Construction])

APPENDIX I – DAILY HUDDLE

I.1 Agenda for Daily Huddle led by Superintendent (Courtesy of Nick Loughrin [Boldt])

Daily Huddle

(6:30 am daily)
Attendees: Supts. / Foreman

Agenda:

1. Safety
   a. Any challenges yesterday?
   b. Any challenges today?

2. Review Daily Commitment – by contractor (move stickies to plan)
   a. Did you get your commitment done from yesterday?
   b. What is your commitment today?
   c. Any constraints or anything standing in your way?
   d. Are you on track to meet your weekly milestone?

3. Equipment
   a. Crane use or other?

4. Deliveries
   a. Any deliveries today?

5. Anything else?

Figure 53: Agenda for daily huddle led by superintendent
(Courtesy of Nick Loughrin [Boldt])

I.2 Agenda for Daily Foreman Check-in (Courtesy of Pankow)

Pankow
THINKING BEYOND THE BUILDING

Daily Foreman Check-In

Duration: 5-15 minute standup meeting

Location: Recommended in the field, when on-site conditions allow

Attendees: Pankow Superintendent(s), Pankow Foremen, Project Engineer(s) responsible for the work being reviewed, Subcontractor Foremen (Last Planners)

Agenda:

Review Weekly Work Plan (WWP) and ask these questions:

1. Did you get done today what you said you would?*
2. If not, what happened?
3. How do we adjust? What is our recovery plan? How can we prevent this from happening again? ***(Avoid blame, focus on learning from experience)***
4. Go through work planned for tomorrow and confirm with each subcontractor that they are on track to meet their commitment(s) for that day. ***(You must get a verbal commitment from them)****
5. Are there any new constraints that we need to add, or safety concerns we need to address?

*Note: Questions are worded for an afternoon Daily Foremen Check-In. If you hold your Daily Foremen Check-In in the morning, adjust the questions to address what was done yesterday, and confirming the commitments for the current day.

Figure 54: Agenda for daily foreman check-in (Courtesy of Pankow)

I.3 Agenda and Stand-up Board for Daily Crew Coordination Meeting (Courtesy of KHS&S)

KHS&S has daily 15-minute team coordination meetings. In Figure 55, note the color-coding of agenda items and matching colors on the clock to help manage time visually.

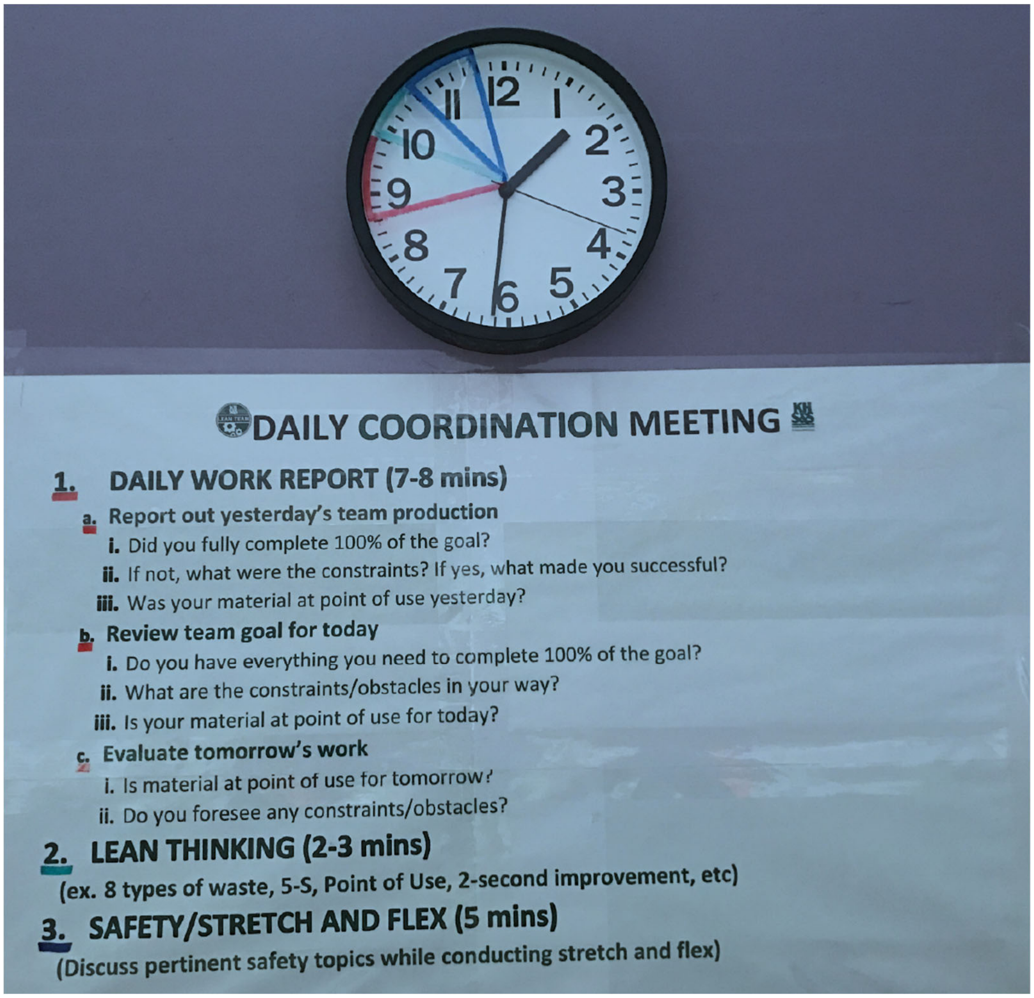


Figure 55: Example agenda for daily huddle led by foreman
(Source: KHS&S' Lean Stand Up Board, An Onsite Visual Management Tool, 2020-07-02)
www.youtube.com/watch?v=ALaQmJAilAs visited 2021-01-05

KHS&S has developed a Lean Stand-up Board as a visual management tool to facilitate jobsite communication among field personnel. Each crew of 10-15 people uses theirs to share and track weekly work plans maps and daily production goals. These boards are visible to the entire project team and are discussed daily at the stand-up meetings (after www.khsswest.com/lean/ visited 2021-01-05; also see KHS&S Contractors, Creating effective contractor communication through a Lean Stand-Up Board, 2016-08-31, www.youtube.com/watch?v=eK4aaGThgxU&t=1117s).

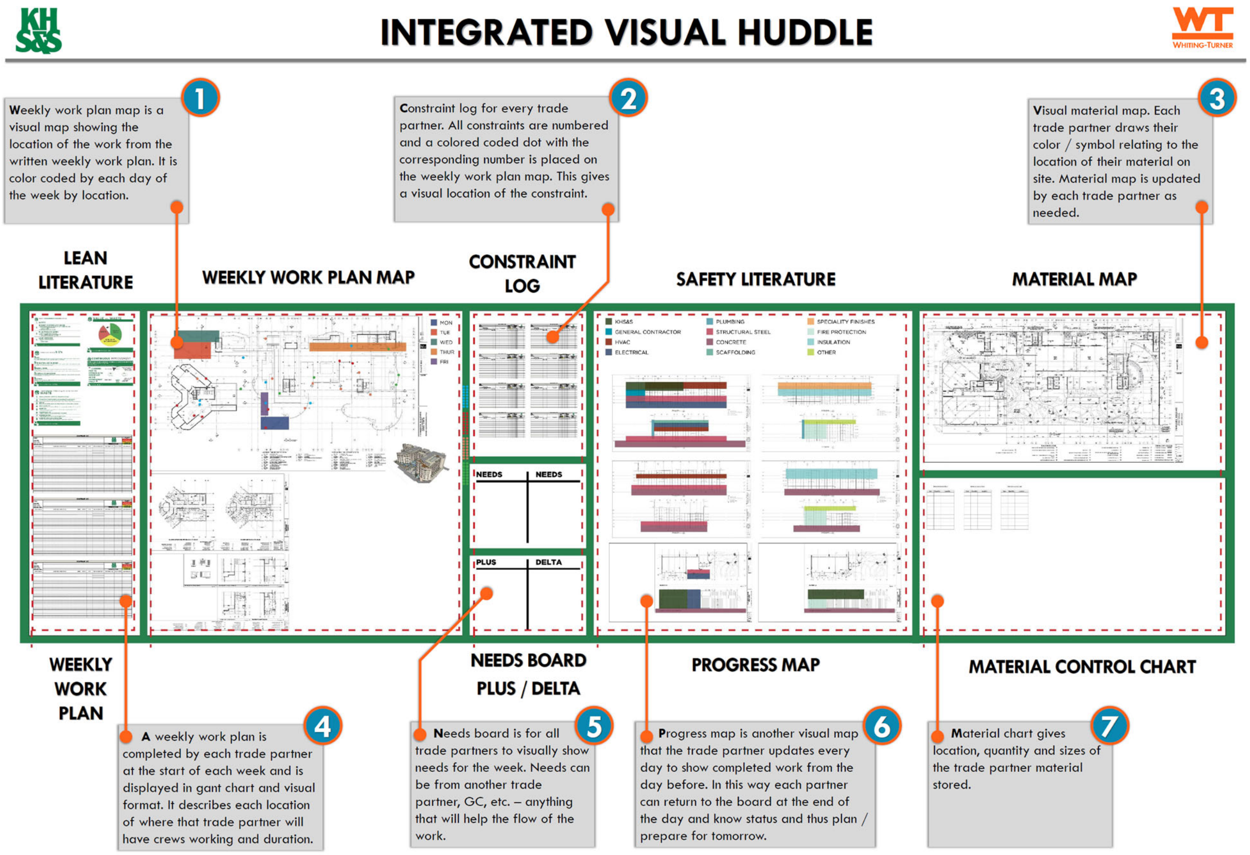


Figure 56: Integrated visual huddle board (online at www.lcicongress.org/pdfs/2018/THB8-A-Chavez_Branham_Stedman_Betts.pdf visited 2021-01-06)

Figure 57: Crew coordination using stand-up board (From slide 17 in www.lcicongress.org/pdfs/2017/WB4%20Creating%20effective%20communication%20and%20empowering%20the%20workforce.pdf visited 2021-01-06)

APPENDIX J – VISUAL MANAGEMENT OF WEEKLY WORKPLAN (Courtesy of Digby Christian [Sutter Health] and Samir Emdanat [vPlanner])

The following two figures offer examples of visuals Sutter Health uses to control its riskiest projects. Figure 58 is an excerpt of a vPlanner schedule that includes attributes at the task level, including specifics of where in the agreed geography of a project each task is taking place. This makes it easy to pull apart a large, complex plan and focus on discrete parts.

Every week, the project team reviews late paths (red-lined paths in Figure 58). Each path indicates precisely how late the task is compared to when it needs to be done in order to keep the downstream milestone on time.

Figure 59 shows the three key metrics the project team tracks each week. Their focus is mostly on Commitment Level (CL), a little less on Percent Required Tasks Completed (PRC), and only somewhat on Percent Plan Complete (PPC).

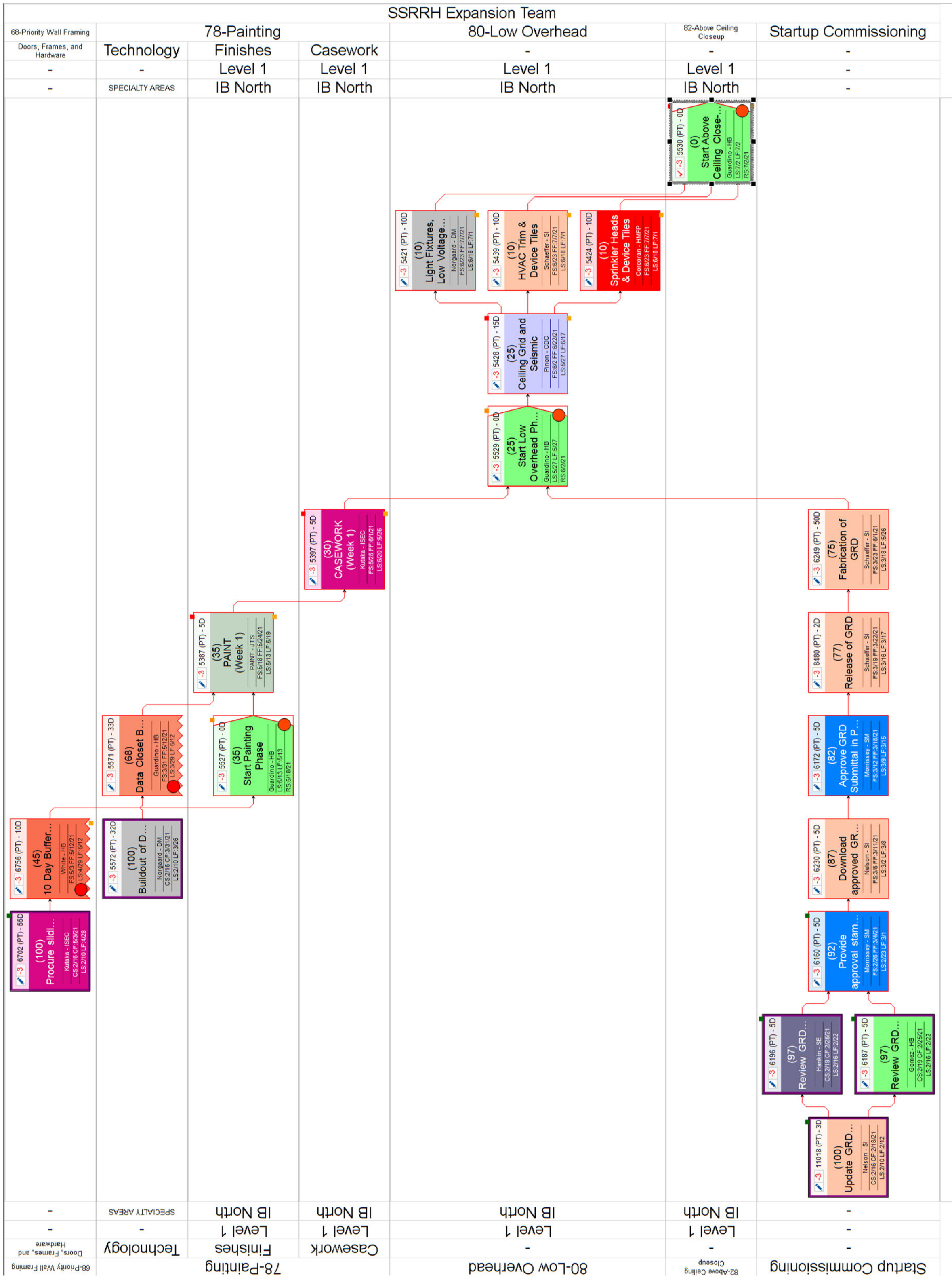


Figure 58: Task-level schedule in vPlanner including location attributes specified by task (Courtesy of Digby Christian [Sutter Health] and Samir Emdanat [vPlanner])

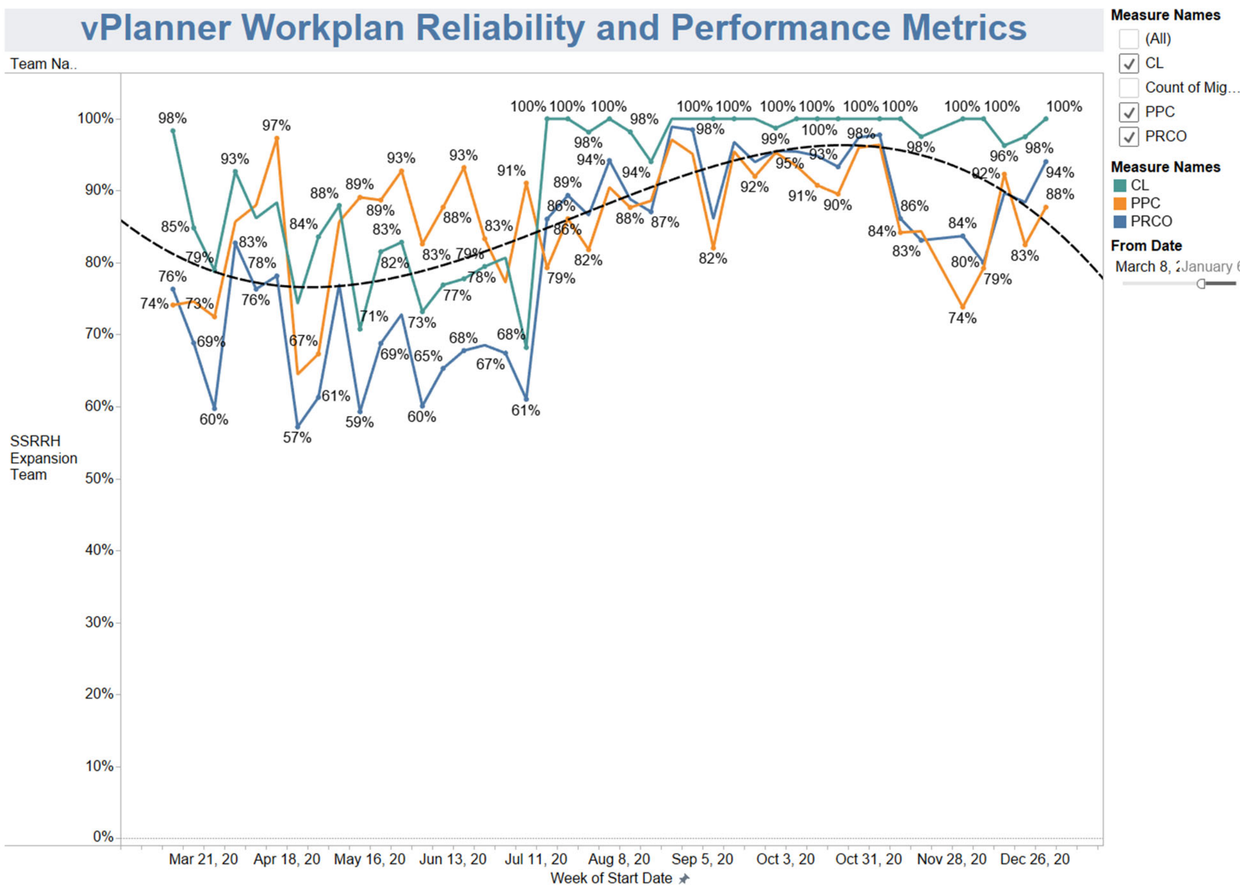


Figure 59: vPlanner workplan reliability and performance metrics
(Courtesy of Digby Christian [Sutter Health] and Samir Emdanat [vPlanner])

APPENDIX K – LEARNING

K.1 Swimlane Diagram and Process Steps for Lessons-learned Session (Courtesy of Pankow)

The following images are from an A3 that Pankow teams use to coach a learning-team session.

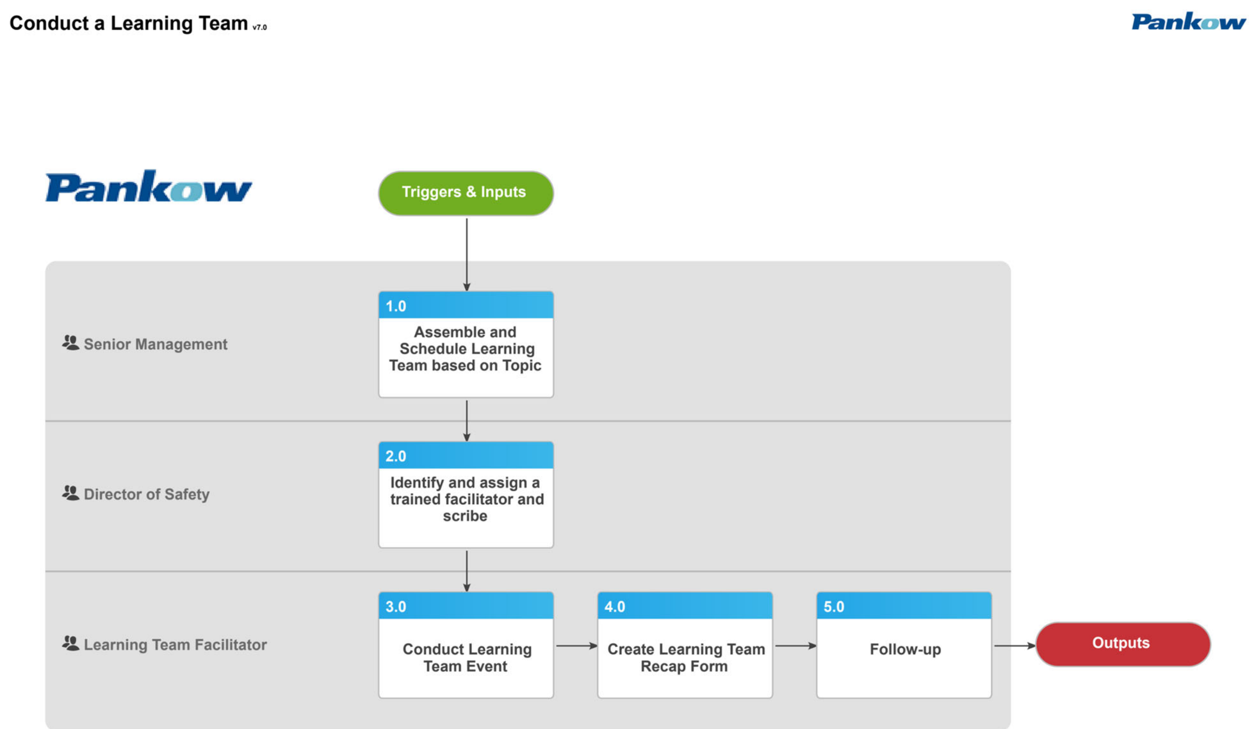


Figure 60: Swimlane diagram with steps for learning session
(Courtesy of Pankow)

Conduct a Learning Team v7.0

Summary

Objective
To provide guidance to Teams wanting a process to improve current work practices.

Background
As we continue on our journey becoming a Learning Organization, this process outlines activities that provide a safe forum to learn and improve.

Owner Shawn Connick

Expert Cindy Perez-Enriquez

Procedure

1.0 Assemble and Schedule Learning Team based on Topic
Senior Management

a Select Learning Team participants

NOTE **Best Practice is 4-6 participants**
Bring in the experts, the persons that perform and understand the work best. Supervisors are typically excluded but that could be determined based on the Learning Team topic.

b Schedule Learning Team

NOTE **If Learning Team is triggered by an Event, schedule meeting within 5-7 days**
Work with project team to identify best time to facilitate a Learning Team

NOTE **Best Practice: Schedule Learning Team event before or after the work day**

2.0 Identify and assign a trained facilitator and scribe
Director of Safety

NOTE **As this time, there should be a facilitator and scribe for each Learning Team event.**

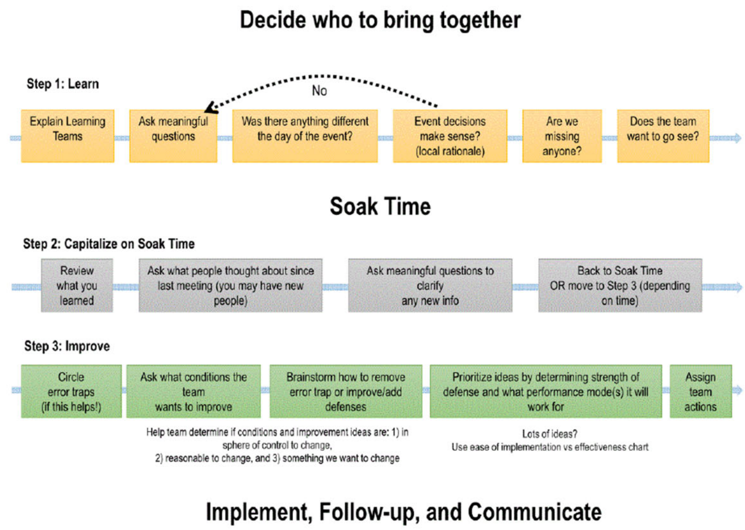
NOTE **Approved facilitators: Shawn Connick, Cindy Perez, Shaun Trussler, James Downey, JR Gunter, Sarah Zdarko, Christian Merz, Jim Norris, Oscar Jimenez, Adrian Jauregui, Bill Bramschriber, Margarett Bushkamp and Ashley Hogue**

3.0 Conduct Learning Team Event
Learning Team Facilitator

a Review learning tip forms before the event to understand how to conduct the learning team event

Figure 61: Learning-session summary and procedure (Part 1 of 4)
(Courtesy of Pankow)

Pankow



Learning Team Tips (4) Page 004.gif

Learning Team Tips 2.pptx

b If needed, meet with those requesting the Learning Team to go over the process and identify an area focus if it hasn't been identified.

c Facilitate a discussion by asking meaningful questions to learn about a process in the first session (approximately 1 hour)

NOTE **Scribe's Role:**
Scribe will write down on large sticky post-it the discussion and is able to engage by asking for clarification or additional questions.

d Capitalize on "Soak Time." When day 1 is complete, explain to the team to reflect overnight and think about the discussion and share any new thoughts the following session.

e At the beginning of Session 2, Facilitator will discuss the purpose of the second session.

f Scribe will begin by reviewing notes written down from first session (approximately 10-15 mins)

g Facilitator will ask if there is additional information or ideas not previously discussed (approximately 15 minutes)

NOTE **Facilitator can also ask additional questions is they feel they need more clarification**

h Ask what conditions the team wants to improve (approximately 45mins)

i Discuss the Sphere of Control and ask participants to categorize each solution

Suggested Defenses.png

NOTE **One star is for a solution the participant has control to make that change. Two star is for a solution the participant might need to influence someone else to make the change. Three star for is for a solution that is more concerning and requires more attention and more influence to make this change.**

j Schedule meeting with superintendent/supervisor to review learning team notes

NOTE **Purpose of the meeting is to share the information and determine if solutions can be implemented**
It is recommended to meet with supervisor after the Learning Team. If permissible, allow supervisor to come into the Learning Team after the solutions have been categorized to determine which items can be implemented.

k Identify solutions supervisor has selected and establish a date the item will be completed.

NOTE **Facilitator will follow-up with supervisor after established date to view implementation**
Facilitator could visit the jobsite or receive an email, picture from the supervisor of the implementation

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4.0 Create Learning Team Recap Form
Learning Team Facilitator

a Create a draft document from the learning team notes immediately after the learning team

Figure 62: Learning-session summary and procedure (Part 2 of 4)
(Courtesy of Pankow)

NOTE **Scribe sends draft to the facilitator to review and makes final edits**

Learning Team Recap- Template.docx

b Send the completed form to supervisor.

NOTE **Learning Team Recap should be completed and sent within 3 days after Learning Team event**

5.0 Follow-up

Learning Team Facilitator

a Check in with supervisor on the solutions selected on the established dated

Triggers & Inputs

TRIGGERS

Starts	Frequency	Volume
When there is an incident of high frequency and/or of high risk.	Adhoc	N/A
An opportunity to learn and improve from a high frequency and/or high risk process	Adhoc	As capacity allows

INPUTS

None Noted

Outputs & Targets

OUTPUTS

Output	To Process	How Used
A summary of defenses, best practice,s and innovations from workers	NA	To increase knowledge for continuous improvement and operational excellence.

PERFORMANCE TARGETS

None Noted

Process Dependencies

PROCESS LINKS FROM THIS PROCESS

None Noted

PROCESS LINKS TO THIS PROCESS

Process Name	Type of Link	Assigned Role
Safety Incident Analysis	Process	Learning Team Facilitator

RACI

RESPONSIBLE

Roles that perform process activities

Director of Safety, Learning Team Facilitator, Senior Management

Systems that perform process activities

None Noted

Figure 63: Learning-session summary and procedure (Part 3 of 4)
(Courtesy of Pankow)

ACCOUNTABLE
For ensuring that process is effective and improving

Process Owner	Shawn Connick
Process Expert	Cindy Perez-Enriquez
Approvers	Shawn Connick, Brad Whitaker

CONSULTED
Those whose opinions are sought

STAKEHOLDERS
Bill Bramschreiber, James Downey

STAKEHOLDERS FROM LINKED PROCESSES

Process	Owner	Expert	Process Group
Safety Incident Analysis	Shawn Connick	Cindy Perez-Enriquez	Safety

INFORMED
Those notified of changes

All of the above. These parties are informed via dashboard notifications.

Systems

None Noted

Tags

None Noted

Process Approval

Date	Approver	Type
Approval bypassed	Margarett Buschkamp	Process Group Approver
Approval bypassed	Brad Whitaker	Process Group Approver
Approval bypassed	Cindy Perez-Enriquez	Process Expert
Approval bypassed	Shawn Connick	Process Owner
18-02-2020 (GMT)	Margarett Buschkamp	Promaster

Figure 64: Learning-session summary and procedure (Part 4 of 4)
(Courtesy of Pankow)

K.2 Process Description for Lessons-learned Session (Courtesy of Tony Lowe and Phillip Phillips [both with Southland Industries])

DESCRIPTION FOR LESSONS-LEARNED SESSION

Purpose

Capturing and sharing Lessons Learned is critical to ensuring continuous improvement. Whether positive, or not, it's important to identify and communicate any areas for improvement, and to celebrate and repeat the activities or processes that are most effective.

The primary objectives are to ensure:

- Positive results are celebrated
- Less than positive results are identified
- All Lessons Learned are captured and shared with the team and other affected stakeholders
- A culture of continuous reflection and improvement

Process

We define two types of lessons learned: **Critical Issues** & **Project Reflection**.

Critical Issues: Involve a particular product or material or are related to safety or quality; should be addressed when they occur and documented in the **Critical Issue Lesson Learned Document Library**.

Project Reflection: Identified during reflection meetings held at the end of each phase (sales, design, construction); should be captured at the end of each phase and then communicated to the broader group. Reflection meetings can be held at any time, but should occur at the end of each phase at minimum. How these Lessons Learned are communicated to the broader group may vary dependent upon many factors (the phase, team, division, group, etc.), but they must be shared with everyone applicable.

Meeting agendas should include discussions regarding the following questions:

- What went well? What process worked well?
- What didn't go well? What process didn't work well?
- What did you find most frustrating?
- What could the leadership team have done better to assist you during the process?
- What areas could you make improvements in?
- Are you proud of the team's effort?
- Are you proud of your individual effort?
- If yes to either of the two above, what was good about it?
- If no, what makes you feel that way?

This meeting could be a more detailed deep dive or a simple Plus/Delta format. The information must be gathered and shared, and all discussions must be appropriate for the effort/project.

At the completion of the project, these Project Reflection Lessons Learned should be compiled and documented in the **Project Reflection Lessons Learned Document Library**. This is also a good time to ensure that Critical Issues, if any, have been individually posted to the **Critical Issue Lesson Learned Document Library**.

Project / Deliverable

- Critical Issue Lesson Learned: Lesson Learned documents saved to the **Knowledge Center Lesson Learned Document Library (Critical Issue)**.
- Project Reflection Lessons Learned: Lessons Learned documents saved to the **Knowledge Center Lesson Learned Document Library (Project Reflection)**.

Notes / Comments

This is about the process, not the people with an acute focus on continuous improvement of the process. Be sure to focus on the issues, not the people.

Meeting Attendees

- All appropriate team members for any given phase or process.