# Combating Uncertainty in the Workflow of Systems Engineering Projects


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**Abstract.** Throughout the Systems Engineering Lifecycle events require personnel, systems, equipment, facilities and information to converge on time and at the right place in order to achieve a program objective. Unpredictability in any predecessor event can mean unpredictability for the overall project. The Last Planner is a production and planning method initially deployed in 1992 in the building construction industry as part of an effort to reduce work flow variability and improve production efficiency in the construction industry. The two key elements of the Last Planner are (1) a change in project management from a task-oriented to a work-flow oriented model and (2) processes to improve reliability of the workflow within the team or group performing the work. This paper examines the systems engineering lifecycle as a production lifecycle and explores the application of key elements of the Last Planner as a tool for system engineers to address uncertainty and unpredictability in the execution of a project.

## Introduction

The systems engineering project development lifecycle often suffers from cost and schedule overruns on large projects. Regardless of effort spent in up-front planning, unplanned events create delays and often result in re-planning and unplanned work in an attempt to recover budget and schedule. In manufacturing and construction industries, this is defined as uncertainty and unreliability in the work flow.

Starting in the early nineties researchers in the construction industry have been examining its processes in the context of the changes and improvements seen in manufacturing production. While manufacturing has seen substantial improvements in production efficiency and elimination of waste through the adoption of so-called Lean techniques, production processes in the construction industry had not taken advantage of these techniques. Significant research has since been done in the construction industry to analyze and define a theory of construction production, and to understand the mechanisms that affect productivity and predictability for project completion. A production planning and management method, known as the *Last Planner* (Ballard 2000), was developed as a mechanism to address problems of high work flow variability in the building construction lifecycle, and low productivity by construction crews that don't have all of the necessary pre-conditions completed in order for them to begin a scheduled task. "The Last Planner is an active production control system that actively causes events to conform to plan rather than responding to after-the-fact detection of variance to plan" (Ballard 2000).

Ballard took inspiration from Lean manufacturing concepts. He introduced a task "pull" concept into a traditionally task "push" environment determined by a master schedule. Pulling is a work scheduling method in manufacturing to reduce buffer waste that accumulates from pushing work downstream regardless of downstream needs and readiness. Ballard also uses a Lean "stop the assembly" concept that refuses to accept tasks from the master schedule that are not ready for execution, and a Lean "continuous improvement learning" concept that examines when master scheduled tasks are not ready as scheduled and seeks a correction of root cause. His focus is driven by a need for more efficiency (higher utilization of work crews) with less waste (no work crews idled while waiting for precursor tasks to complete). He directly attacks inefficiency of work crew application and schedule slips due to accumulated work flow interruptions.

According to Wikipedia, the first two doctoral degrees concerned with the field of study known as Lean Construction were awarded in 2000: a Doctor of Technology to Lauri Koskela at the Helsinki University of Technology in Finland, and a Doctor of Philosophy to Glenn Ballard at Birmingham University in the United Kingdom. Koskela explored a production theory and its application to construction. Ballard explored the more narrow area of a work flow process for production control in construction. It is not our intention to review Koskela's work or Lean Construction in general, which has a large span of interest, but rather to focus on Ballard's work that specifically deals with project work flow management, to see how his conclusions might apply to those systems engineering projects that share similar work flow issues to construction projects.

Necessarily, we review in some detail Ballard's dissertation and papers, and his related collaborative work with Koskella, Greg Howell, and Iris Tommelein, with references as the discussion arises. Ballard and Howell founded the non-profit Lean Construction Institute in 1997, now headquartered in Arlington, VA (www.leanconstruction.org), which continues research and is a storehouse of publications focused on adapting lean manufacturing concepts to project management in the construction field. A rich history of Lean Construction research publications is available from the International Group for Lean Construction (http://iglc.net/?page_id=6), holding annual conferences since 1993.

An analysis of the Systems Engineering Development Lifecycle as a "production" lifecycle, and comparison to the building construction lifecycle, shows that both follow the classic three phase production model depicted in Figure 1, where the "production units" are teams of people engaged in construction/assembly.

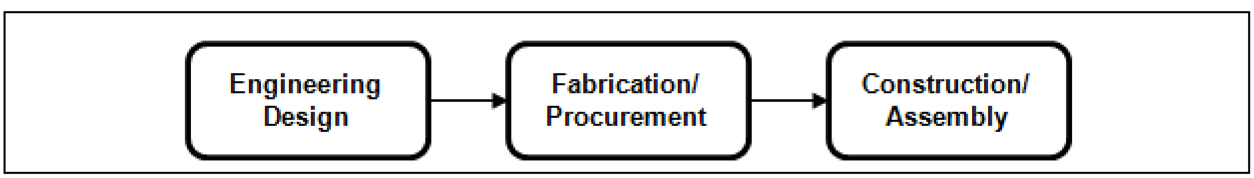


**Figure 1. Typical three phase production lifecycle model.**

Figure 1 is deceptively simple, as it represents only a single task in a construction project of thousands of tasks, all in sequence dependency with prior and subsequent tasks. In the macro model almost everyone is a provider to or a customer of someone else. Problems that begin in early phases propagate to the later phases where they drive unpredictable performance in cost and schedule.

Complex systems engineering projects can conform to the same macro model. Integrated product teams (IPTs), test teams, development teams, and subcontractor teams are the “production units” in the Systems Engineering Lifecycle. Systems Engineering Integration Teams (SEIT), Chief Engineers and IPT Leads are project managers. A number of parallels can be drawn between the construction lifecycle and the Systems Engineering Lifecycle. This paper explores the potential application of the Last Planner as a candidate approach to address the high work flow variability seen in product development lifecycles, and the productivity and efficiency problems experienced in later phases of a project. The principles identified and implemented through the Last Planner directly address real problems faced by systems engineers in the product development lifecycle.

Ballard’s choice of “Last Planner” as the title for his methodology reflects the hierarchy of planners in a complex system. Planning at the global level focuses on objectives and constraints affecting the entire project, and results in a master schedule of tasks. Objectives drive lower level planning that deals with methods for achieving project ends. At the lowest level someone plans what will be done tomorrow. In construction  that lowest level plan results in production crew assignments, which drive direct work rather than other plans. The person or group that creates immediate assignments is called the last planner, who is often saddled with unrealizable tasks because prior master scheduled work hasn’t been completed.

## Three State Planning: Should – Can – Will

(Ballard and Howell 1998) refine these three hierarchical levels of planning for construction production:

- Initial Planning (Master Planning) - produces the master schedule and triggers the initial push system for material flow. The master plan defines what “should be done.”
- Lookahead Planning – takes into account that current status of the production system and proactively adjusts budgets and schedules, pulling resources into play in order to avoid or mitigate deviations from the master plan. The lookahead plan works to create a backlog of tasks that “can be done.”
- Commitment Planning – takes into account the actual completion of prerequisite tasks and actual availability of material and defines what “will be done.”

For most projects in both the construction industry and systems engineering development, generation and maintenance of Integrated Master Plans (IMP) and Integrated Master Schedules (IMS) are standard processes (what should be done.) Similarly, functional organizations, teams and work crews generally produce weekly work plans to guide the efforts of individuals and groups (what will be done). The problem is the gap between what “should be done” and what “will be done”. Problems occur when projects fail to recognize this gap. Failure to meet any of the preconditions for a task can prevent a task from meeting what “can be done”. Master schedules do not include sufficient detail to reflect all of the relevant interactions and dependencies between production units (Tommelein and Ballard 1998). Because so many of these interactions are part of the “standard process”, they are not reflected in the project plans at all, but left as references to organizational procedures. Finally, there are limits to the detail that can be included and maintained in a master schedule. The result is a planning and control system that clearly identifies the project milestones and objectives but does little or nothing to actually help the IPT Lead or Chief Engineer meet those objectives.

While many system engineering projects may successfully use the master schedule to forward plan, the lookahead window augments this traditional transformational management approach with a lower level of planning that implements workflow management.  The lookahead window is intended to address those details, invisible in the master schedule, that determine the difference between what should be done and what will be done.

## The Last Planner System of Production Control

The Last Planner has been in development since 1992 (Ballard 2000). It employs five principles originally defined in (Koskela 1999).

**Principle #1** - Work assignments should be sound regarding their prerequisites. Work should not start until all the items required for completion of a job are available.

**Principle #2** - The realization of assignments is measured and monitored. The primary metric, Percent Plan Complete (PPC), is the number of planned activities completed, divided by the total number of planned activities. PPC is primarily related to Production Unit Control and maximizing efficiency of the production crews. The metrics are used for root cause analysis to improve work flow.

**Principle #3** - Causes for non-realization are investigated and those causes are removed.

**Principle #4** - Maintain a buffer of tasks which are sound for each crew. In a traditional Last Planner system, this means avoiding lost production due to insufficient backlog of "sound work" (either due to lack of resources or suboptimal conditions).

**Principle # 5** - For work in the lookahead window, the prerequisites of upcoming assignments are actively made ready. This is effectively a pull system.

From these principles Ballard derived the following guidelines as design criteria for the Last Planner Production System (Ballard 2000). These are summarized as follows:

- Control work flow variability – actively manage the work flow and ensure outputs from predecessor activities are ready when needed; anticipate the problems and solve them before they occur.
- Ensure assignments are sound - don't assign tasks that can't be performed due to lack of needed prerequisites.
- Measure and report why tasks were not performed on time and investigate the causes.
- Create a buffer (backlog) of sound assignments for each crew or production unit.
- Supplement the IMS driven schedule push systems with pull techniques.
- Distribute decision making.
- Resist the tendency (by functional departments and teams) toward local sub optimization.

The Last Planner implements these principles and guidelines with a set of rules, procedures and tools directed at the two components of production control: (1) work flow control and (2) production unit control.

Work flow control coordinates the flow of design, supply, and installation between processes, teams and organizations (Ballard 2000). Work flow control actively operates to make tasks ready to be converted to assignments. It looks at the plan and the actual project conditions to determine if tasks are ready or to determine what is needed to make them ready. It is performed by the lookahead team, consisting of foremen and supervisors for the tasks involved, and is implemented by active management of the tasks in what Ballard calls the lookahead window.

Production unit control coordinates the execution of work within production units (the team or group performing the work). It determines what "will be done." Processes for improving and stabilizing the reliability of work flow within the production unit include techniques such as shielding (explained later), under-loading (providing slack in task scheduling), and tracking Percent Plan Complete at the assignment level.

#### Examples of Last Planner Effectiveness

Case studies of the application of Last Planner within the construction industry are available through the International Group for Lean Construction and the Lean Construction Institute. One example is the construction of a McDonald's restaurant in Rio de Janeiro in which the construction team experienced a decrease in construction time from 90 days to 83 days, approximately a 25% decrease in site manager and foreman time during the last two weeks, and a 75% decrease in the number of defects at final inspection (Auada 1998). Another example is a housing construction project in Nigeria that achieved a 50% reduction in construction time and a 50% reduction in construction labor cost when compared to traditional methods of construction project management. Other case studies show improvements in PPC from 50% to 75% with some cases achieving 90% PPC (Adamu 2012).

Though some forms of lookahead planning are undoubtedly employed by some organizations engaged in systems engineering projects, it is the experience of one of the authors that this is not the case everywhere. The Last Planner approach is being suggested as a formal model, employed with documented success in selected construction projects, for application where standard system engineering processes lack or can improve this discipline with concepts from the Last Planner approach.

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#### The Lookahead Process

A key feature of the last planner is the lookahead window which bridges the gap between the master schedule (what should be done) and the reality-constrained daily work plan at the production site (what will be done). It consists of six functions performed on a weekly basis (Ballard 1997):

- Shape work flow sequence and rate.
- Match work flow and capacity.
- Decompose master schedule activities into work packages and operations.
- Develop detailed methods for executing work.
- Maintain a backlog of ready work.
- Update and revise higher level schedules as needed.

Additionally, Ballard proposes three rules for allowing scheduled activities to remain or enter into each of the three primary levels of the scheduling system:

- Rule 1: Allow scheduled activities to remain in the master schedule unless positive knowledge exists that the activity should not or cannot be executed when scheduled.
- Rule 2: Allow scheduled activities to remain in the lookahead window only if the planner is confident that the activity can be made ready for execution when scheduled.
- Rule 3: Allow scheduled activities to be released for selection into weekly work plans only if all constraints have been removed; i.e., only if the activity has in fact been made ready.

The lookahead window depicted in Figure 2 is an arbitrarily chosen 6-week window, where 5-12 week windows may be more appropriate for specific projects. The actual duration of the window depends on the nature of the project, the reliability of project status information, and reliability of the project work flow. Using a 6-week window example shown in Figure 2, the process begins with the lookahead planning that deals with the tasks  scheduled to start in the next six weeks, moves tasks that are ready to work into a task backlog buffer, and concludes with the commitment of work tasks that will be begin  immediately. The tasks in the lookahead window are monitored, and if on track to start on time, are allowed to move forward to the subsequent week's expected schedule. Tasks that are not on track are actively addressed, with corrective action taken to make them ready. If they cannot be made ready on time they progress no further, and the master schedule is revised to reflect the actual status of the task and the effect on the project.

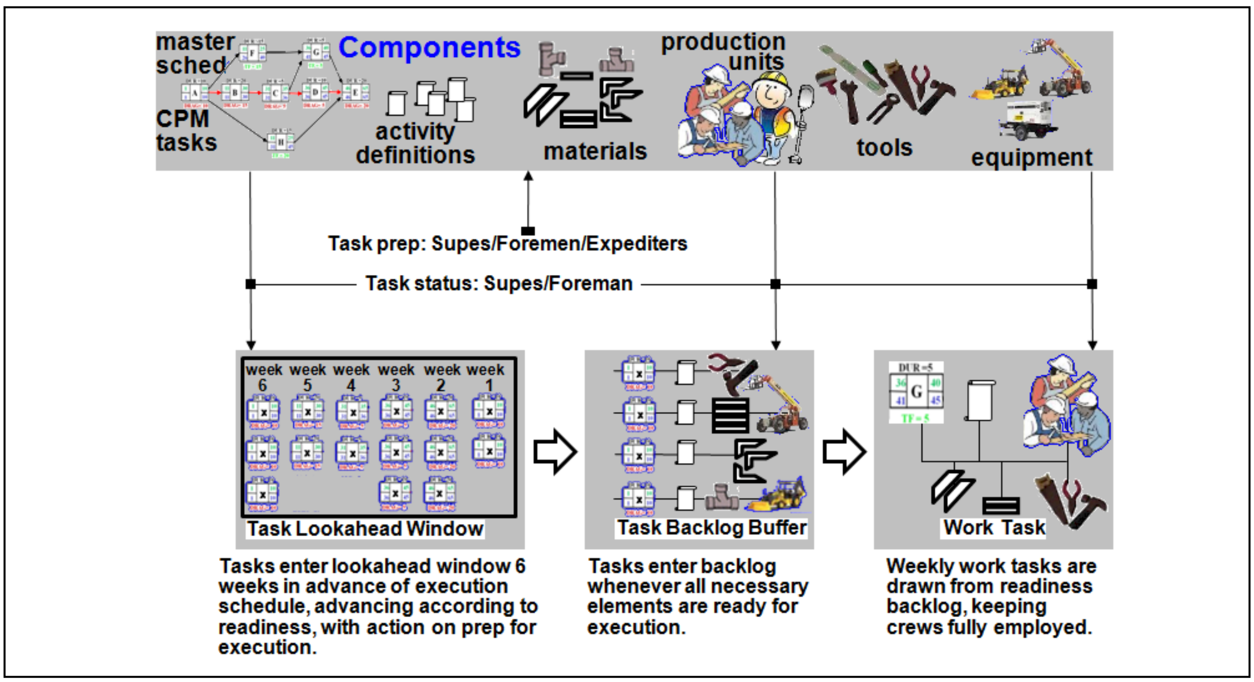


**Figure 2. Lookahead planning with backlog buffer and immediate work commitment**

In Figure 2 the supervisors and foremen manage the tasks in the lookahead window, advancing them according to readiness, migrating them to backlog when they are ready, and eventually making immediate work task assignment drawn from the backlog of ready work. Task in the lookahead window that fail to progress in readiness as scheduled are actively prepared for readiness by expediters as well as supervisors and foremen.

In addition to planning and coordinating the scheduled work, the lookahead team also pulls work forward from the master schedule that can be made ready. In a project, every team is a predecessor or successor of someone else. The objective is to improve the reliability of the work flow between teams to prevent work stoppage due to delays in completion of predecessor tasks (starvation) or due to insufficiently-planned resources (overloading).

#### Managing Workflow versus Managing Tasks

In his paper describing the need for a theory of construction (Koskela 2000) proposed that there were three working theories of production, the transformational view, the flow view and the value generation view.

- The transformation view focuses on identification of tasks within a project. It focuses on the transformation of inputs to outputs. Its deficiencies are that it does not acknowledge other phenomenon during production and it does not address the criteria that make the transformation valuable, i.e. the customer requirements.
- The work flow view focuses on the movement of work and materials between resources. It focuses on the elimination of waste from the flow process and is the foundation of just-in-time and lean production.
- The value generation view focuses on achieving best possible value from the point of view of the customer. It is characterized by rigorous requirements analysis and systemized flow down of requirements.

The key weakness in the transformational view is that it views the entire project as individual tasks to be decomposed into smaller tasks, each minimized in terms of cost and schedule. It ignores everything else. As stated in (Ballard and Howell 1994), *"the conversion process model conceals everything that needs to be revealed, particularly the design of systems and processes to manage work and work flow."* It also fails to recognize that a task based model of the project may not be a complete, accurate or an up to date representation of the project. It assumes that the project consists of a management element and an execution element. The transformation view creates an environment where interaction between project management and executing organization takes on the characteristics of contract management, where the plan becomes the agreement and how the executing organization gets the job done is "their business", as long as they meet their commitments of budget and schedule.

The flow view model brings visibility to time and work flow variability, the primary sources of waste. The lookahead process implements the work flow model for the project. The work flow view addresses flow of material and information (processing, inspection, moving and waiting) and focuses on elimination of waste, time reduction, and variability reduction. It brings practices such as continuous flow, pull production control, and continuous improvement into play. Finally, it focuses on minimization of unnecessary activity (Koskela 2000).

A direct analogy exists in military operations. Battle planning consists of two groups, the planning cell and the operations cell. Before combat begins, the planning cell develops operational plans and orders and issues those orders to subordinate units. Subordinate units then plan their detailed operations accordingly. However, once combat begins, detailed command and control of subordinate units falls to the responsibility of the operations cell. The operations cell monitors the real-time battle conditions and issues real-time orders and changes based on what is really happening on the ground. The operations cell coordinates the work flow between subordinate units. Project management would benefit by adopting the project equivalent of the operations cell, to actively coordinate project execution throughout the project.

#### Shielding - Enforcing Quality Criteria for Assignments

While the lookahead window addresses variability in work flow between tasks and teams, an additional mechanism is needed to address the variability within the team or group performing the work. Shielding, a key principle of the Last Planner, is the primary means for reducing variability within the production unit. Shielding is achieved through enforcement of quality criteria on assignments in the weekly work plan (commitment plan). The intent is to stop the unplanned effort required when tasks are started before they are ready, before materials are available, or before predecessor tasks are at the required level of completion. By ensuring that every task can be performed at the planned level of productivity with the planned resources, shielding reduces work flow uncertainty within the production unit, allowing the production unit to improve their own work flow reliability, and reducing the work flow variability downstream (Ballard and Howell 1998). The negative consequences of starting work before its preconditions have been met include productivity impacts such as increased work in progress (WIP), lower quality, higher rework rates, lower throughput, increases in complexity and coordination, and less effort and motivation by the project to correct the problems (Ronen, 1992).

(Ballard and Howell 1994) identified five key quality criteria of weekly work plans:

- Definition – work assignments are specific enough that right type and quantity of materials can be identified, work can be coordinated with other production units, and it is possible to tell at the end of the week of the assignment was completed.
- Soundness – material is on hand, prerequisite assignments are complete, and coordination with other production units has been done.
- Sequence – the assignment advances the progress of the production effort and is sound with respect to the construction order of tasks (predecessor tasks).
- Size – the assignment is sized to the production capacity of the work crew or production unit, and can be completed within the plan period.
- Learning – assignments that are not completed within the plan period are analyzed and reasons are identified and tracked.

These quality criteria are very much in contrast to the most common strategy seen in construction (Ballard and Howell 1998) and in systems engineering projects - flexibility. Instead of applying production controls to manage work flow variability, the flexibility strategy consists of reacting to whatever work, tasking, or lack of work flows to the production unit; and then mobilizing resources, adjusting work schedules or changing work sequence to match the latest events (Ballard and Howell 1998). In other words, flexibility accepts suboptimal work conditions within the production unit.

It is the very act of ignoring that there is a difference between SHOULD and CAN that makes management control ineffective. Enforcing quality criteria on the weekly work plan is the equivalent to the Toyota principle of stopping production rather than passing a bad product down the production line (Toyota n.d.). *Shielding* is the enforcement of the 5 quality criteria, and defers work that is not ready. Commitment to shielding runs the risk of reducing production capacity and affecting schedule performance; however, it reveals what is truly affecting the project and what management truly needs to control (Ballard and Howell 1998). It also has the benefit of protecting low density, high value resources or any critical resource from expending cost and schedule on tasking that may not be ready or may not be correct.

However, shielding itself is not a sufficient strategy (Ballard 1997). There are typically significant negative impacts to cost and schedule when the project fails to complete tasks on the critical path when they need to be done. Also, work sequencing cannot be ignored. Failure to complete precursor tasks can create work stoppages down stream. The key is to only commit to work that can truly be accomplished, and to also report, track, and mitigate the barriers to task completion.

## Application of the Last Planner to the Systems Engineering Lifecycle

The lookahead window process can be applied to any activity that requires key personnel, labor resources, materials, equipment, or facilities to come together at the right place at the right time; or any project lifecycle where task and activities are highly sequenced with tight linkages between tasks. Example activities include decision gates, coordination of design activity in which multiple teams, contractors or subcontractors are involved, integration, and testing. Integration and testing efforts all require materials, specific labor resources, facilities, and tools to be ready and available at the right place at the right time. Once it is recognized that data and information are the material flows of the design process, the lookahead window can be equally applied throughout the systems engineering lifecycle to actively shape the work flow and cause events to conform to plan.

Shielding can be applied to any lifecycle activity in which work flow reliability and predictability is needed for the group performing the work. Enforcing shielding changes the project from a culture of hero's using reactive flexibility as their primary tool, to a culture in which problems are addressed at their source. For shielding to succeed, the lookahead window must provide a backlog of workable work for progress to continue. Shielding may not be applicable in cases where the downstream processes experience work starvation or when the subject task is on the critical path and cannot be delayed. However, shielding does make the project recognize the problems and the associated throughput and productivity impacts resulting from the decision to proceed under sub-optimal conditions.

The Last Planner method tries to maintain a backlog of workable tasks so that crews can be gainfully employed when planned tasks are not ready to be worked as scheduled. Drawing from experience at L3, where a considerable amount of systems engineering contract work is on aircraft refurb, repair, and mission system upgrade, there are many tasks that can run in parallel independent of each other if precursor tasks are completed. Such tasks lend themselves to workable backlog. Additionally, some personnel resources do not belong to the project of interest, but are "matrixed assets" provided to the project as temporary assignments. With lookahead advance warning that scheduled projects will not be ready on schedule, there is time to reassigned these resources elsewhere.

In systems engineering the lookahead window would be managed by a lookahead team, consisting of the chief engineer and the IPT team leaders.

### Benefits of Applying the Last Planner Process to Systems Engineering

The Last Planner's value lies in its ability to reduce cost, reduce schedule, and improve the predictability of the products and processes in the value stream of the project or business. These benefits are achieved primarily through the analysis of work flow status and detailed planning and coordination of work flows by the lookahead team. While effort to perform this detailed planning and active coordination will require additional resources, there is potential for significant benefits including:

- Reduced Production Cost and Schedule - The fundamental purpose of the Last Planner is to remove or eliminate anything that creates delays and inefficiencies during the project lifecycle, with the overall goal of reducing cost and schedule.
- Provide a Capability to Mitigate Project Variability – The primary cause of production inefficiency is variability in the precursor tasks. Because real world variability cannot be eliminated and can barely be controlled, a key strategic goal of the Last Planner is to provide a mechanism to proactively respond to project variability in order to mitigate cost and schedule impacts.
- Improved Resource Utilization – In any project, resource utilization affects cost. The Last Planner process improves the utilization of resources within the teams or groups performing the work by having work in backlog and by having work that can be accomplished.
- Improved Predictability of Project Delivery – Project variability is a key component of unpredictability. The final goal of the Last Planner is to improve the predictability of project completion by managing and mitigating the effects of project variability on the program lifecycle.

## A Lean Process Enabled by an Agile Architecture

Ballard refers to his Last Planner work exclusively as a Lean process, but in fact his focus is on an agile process as it deals specifically with uncertainty by employing an agile process architecture (Dove 2012). This point is worth discussion, as it illuminates the responsibilities necessary in any process that would sustain its ability to deal with uncertainty.

Lean, in its manufacturing origins, is concerned (among other things) with streamlining workflow by removing non-value-added inventory and activities. Agile, in its manufacturing origins (Nagel 1992) , is concerned with responding effectively to uncertain and unpredicted operating environments. Work flow uncertainty is the situation Ballard deals with. Lean wants to eliminate buffers - a useful practice in a stable environment. But when there is uncertainty about the scheduled ability to accomplish a task, task buffers and readily invoked schedule reconfiguration options offer methods for continuing work. An agile process can be synergistic with lean buffer-reduction forces in working toward optimal work flow, as is evidenced in the combining of Lean and Agile principles in recent agile software development practices (Poppendieck 2003).

Effective response under uncertainty requires that a system (of scheduled tasks in the Ballard and systems engineering cases) can be changed appropriately when faced with a newly discovered situational need. Emerging requirements are one typical and pervasive example in systems engineering projects – in one sense emerging requirements are the only factor of interest as we can reduce all new response needs to an operational requirement that must be addressed…now.

Agility is concerned with the ability to respond effectively under uncertainty. It has been shown in (Dove 2001) that effective response has four metrics: timely (fast enough to deliver value), affordable (at a cost that leaves room for an ROI), predictable (can be counted on to meet the need), and comprehensive (anything and everything within the mission boundary).

Achieving good agile response metrics is enabled or hindered by architecture. One fundamental Architectural Concept Pattern has emerged from extensive investigation and appears both necessary and sufficient. It will be recognized in a simple sense as a drag-and-drop plug-and-play architecture, with some critical aspects not generally called to mind with the general thoughts of a modular architecture. In a functional sense this is the agile Last Planner (Figure 3) concept.

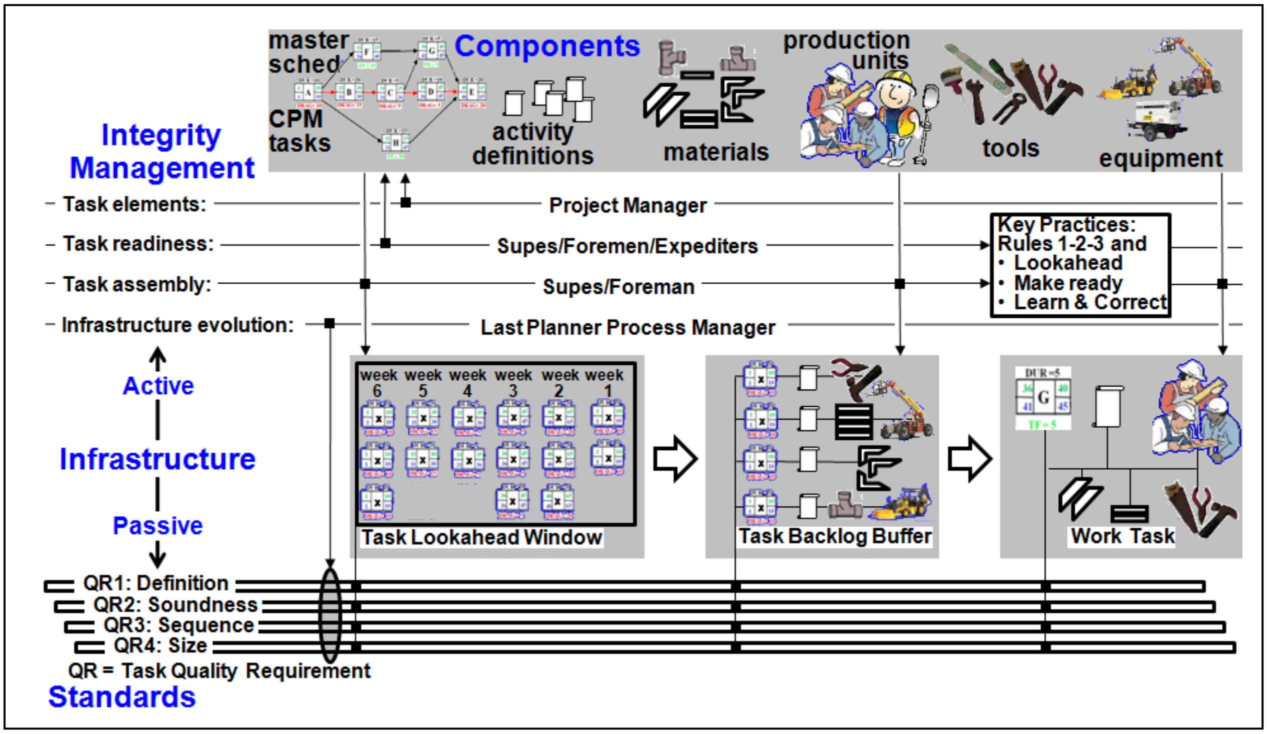


**Figure 3 – Ballard's Last Planner cast as an Agile Architectural Concept Pattern**

There are three critical elements in the architecture: a catalog of drag-and-drop *encapsulated* components and the components pools in which they belong, a catalog of the passive infrastructure rules and standards that enable and constrain plug-and-play operation, and the designation of the active infrastructure of four specific responsibilities that sustain agile operation. When the architecture is diagramed conceptually, a fourth element typically shows three or so varieties of response systems that can be constructed from the components, as shown in Figure 3.

- Components – Components are self contained units complete with interfaces which conform to the plug-and-play passive infrastructure. They can be dragged-and-dropped into a system of response capability with relationship to other components connected through the passive infrastructure, and not connected directly component-to-component. Components are encapsulated so that their interfaces conform to the passive infrastructure but their methods of functionality are opaque to other modules. New components can be added to component pools and new pools of components can be added asynchronously. Component pools provide variation and diversity among components - often with duplicate versions of components in a pool to enable increased functional capacity of like-component deployment.
- Passive Infrastructure – Sometimes called middleware in IT systems, the passive infrastructure provides drag-and-drop connectivity between component. Its value is in isolating the encapsulated components so that unexpected side effects are minimized and

operational functionality is rapid. Selecting passive infrastructure elements is a critical balance between requisite variety and parsimony – just enough in standards and rule to facilitate component connectivity but not so much to constrain mission-required system configurations. Passive infrastructure typically evolves, but slowly, generally when migration to next generation capability is appropriate.

- Active Infrastructure – An agile system is not something designed and deployed in a fixed event and then left alone. Agility is most active as responsible parties assemble new system configurations in response to new requirements – something which may happen very frequently, even daily in some cases. But in order for new configurations to be enabled, three more responsibilities are required: the collection of available components (tasks in our case) must always be what is needed, the tasks that are available must always be in deployable condition, and the passive infrastructure must have evolved when new configurations require new standards and rules. Four responsibilities must be designated with responsible parties or processes that ensure effective response capability is possible at unpredictable times.
    - Task Elements – Who (or what process)  is responsible for ensuring that new tasks are added to the pools, tasks in the pools are upgraded, and new task pools are created, in time to satisfy response needs?
    - Task Readiness – Tasks in pools must be ready for deployment at unpredictable times. Designated parties internal or some natural external process must be responsible for ensuring that sufficient tasks are ready for deployment.
    - Task Assembly – Who assembles new task configurations when new requirements require something different in capability? Are they trained and knowledgeable in resource deployment and configuration methods?
    - Infrastructure Evolution – Who ensures that the infrastructure and process is improved and evolved with new knowledge and experience? No fixed infrastructure of standards and rules is appropriate for all of time – witness the evolving infrastructure of standards that has enabled home entertainment systems to accommodate new technologies such as video and Internet connectivity.

## Barriers to Successful Implementation

As with any process change or innovation, the Last Planner methodology will experience barriers to implementation in systems engineering. In addition to the normal barriers to innovation, such as organizational, cultural and human behavior, there are several barriers specific to elements of the Last Planner:

- Problems are ignored or not seen – This barrier is the refusal to acknowledge that there is a problem, or that there is room for improvement and innovation. Because so many problems are a direct result of the transformational view of project management and are so systemic, they are viewed as "normal features of the business" (Koskela and Vrijhoef 2000). Unless projects, and organizational teams acknowledge the need for change and innovation, many key elements of the Last Planner may be "off the table" for discussion. To mitigate this barrier, projects will typically require a champion from within the systems engineering organization to rally support from senior leaders and other functional organizations.
- Can-Do culture – A major barrier to implementation of the Last Planner is the project

culture itself, also mirrored in the construction industry. (Ballard and Howell 1994) characterized the culture with the slogan "CAN DO!". This culture makes it difficult for the subordinate team to refuse poor assignments. This culture is fostered by the management approach of "management as planning" and is the defensive response to control as corrective action and punishment for non-conformance to plan. This attitude will be a barrier to acceptance of shielding and enforcement of quality criteria on work assignments. Overcoming this barrier may require collection and analysis of actual project cost data with clear cause and effect results associated with non-adherence to quality assignment principles. This barrier can also be mitigated by a strong process oriented project environment.

- Planning is hard work **-** Another barrier is the resistance to perform continuous detail planning throughout the project. Ballard observes that planning is simply hard work. Most organizations find it easier to react to events than to work to prevent the problem in the first place. The industry seems dominated by crisis junkies (Ballard 1999). The "CAN DO!" attitude combined with the resistance to perform the hard work of detailed planning also reinforces the strategy of reactive flexibility as opposed to production control as the means to address work flow variability and uncertainty. In addition to cost and schedule evidence in support of detailed planning, a pilot project with positive results may be needed to mitigate resistance.
- The belief that shielding is impossible **-** An argument for reactive flexibility as a strategy is rooted in the culture and belief that shielding is impossible and production resources cannot wait for quality assignments to materialize. A belief that no other strategy can meet project schedules in an environment of work flow uncertainty (Ballard and Howell 1998). While there are cases where short term productivity losses may be needed in order to meet project schedule constraints, projects must re-evaluate reactive flexibility as the primary mitigation strategy. As with the barriers to detailed planning, acceptance of shielding will likely require data and results from a pilot project to mitigate resistance.

## Conclusions

There are significant parallels between building construction and the systems engineering product development lifecycle with regard to the sources of work flow variability and problems encountered at the job site by teams or crews performing the work. Both industries are burdened with a management culture that tolerates problems from upstream activities to flow downstream.

Koskela presents a sound basis for needed innovation though analysis of construction production from the perspective of production theory and through the identification of five principles of production management. The focus of the last planner is in two areas:

- Increased work flow reliability and productivity within the production unit
- Changing project managements from a task or transformation view to a work flow view.

Each of the five principles of the Last Planner directly addresses the uncertainties present in the Systems Engineering Lifecycle:

**Principle #1** - Work assignments should be sound. Enforcing soundness criteria causes corrective action to occur at the source of the problem as opposed to the strategy of flexibility and "Can Do" in an attempt to resolve every problem downstream. By adopting the "flexibility" strategy and forcing problems to be absorbed downstream from their source, the leadership team is relived of the pressure and incentive to address the real issues.

**Principle #2** - The realization of assignments is measured and monitored. Measuring and reporting Percent Plan Complete measures the reliability and accuracy of planning within the production unit. Without accurate and predictable planning, the production crews have not basis to evaluate their own performance or to measure improvement.

**Principle #3** - Causes for non-realization are investigated and those causes are removed. Identification of issues causing unreliable work flow allows root cause analysis and corrective action to take place. This is critical to removing sources of uncertainty and waste from the work flow.

**Principle #4** - Maintain a buffer of tasks which are sound for each crew. Pulling tasks forward where possible and maintaining a backlog of workable work provides a work flow buffer against task starvation, maintains project throughput, and reduces work flow variability downstream.

**Principle # 5 -** For work in the lookahead window, the prerequisites of upcoming assignments are actively made ready. The most critical element of the Last Planner is a project control element that pro-actively shapes events to keep the project on plan as opposed to after-the-fact detection of plan deviation. It acknowledges the fact that even the best master plans are insufficient for effective project control. The objective is to minimize or eliminate variability and uncertainty from the work flow and prevent problems from propagating downstream. Reducing variability and waste reduces time, which reduces cost.

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