IMPROVING WORK FLOW RELIABILITY

Glenn Ballard[1]

ABSTRACT

Improving work flow reliability is important for the productivity of linked production units, and consequently for project cost and duration. One measure of work flow reliability is PPC, the percentage of planned assignments completed. A proposal is made for experiments to increase PPC. Four actions are proposed and explained. Only the fourth action, underloading resources relative to capacity, is developed in detail in this paper. The potential impacts of improving PPC on project cost and schedule are described.

KEY WORDS

Capacity, decomposition, design process, explosion, flow, last planner, lean construction, load, productivity, project planning and control, reliability, throughput, variability.

[1] Director of Research, Lean Construction Institute, and Lecturer, Construction Engineering and Management Program, Dept. of Civil and Environmental Engineering, University of California at Berkeley, 4536 Fieldbrook Road, Oakland, CA 94619, 510/530-8656, FAX 510/530-2048, ballard@ce.berkeley.edu

INTRODUCTION

In production lines or networks, work flows through multiple production units (PUs), each performing different operations on materials or information. Predictability of arrivals is important for PU productivity and line throughput, especially on complex projects driven for speed. The production plans of upstream PUs is one source of information regarding work flow to downstream PUs. Consequently, a measure of work flow reliability is PPC, percent plan complete, calculated by dividing the number of near-term assignments completed by the total number of assignments made for the plan period, typically 1-2 weeks.

Work flow reliability in the industry has been repeatedly measured at levels ranging from below 30% to 60%, with rare exceptions above those levels. Improving PPC is expected to significantly improve project performance because it allows the application of planning to production. If you know what work you will be doing at a future time, you can prepare to do it. According to Ballard and Howell (1997), the quality criteria for assignments are definition, sequencing, soundness, sizing, and learning. Most previous efforts to improve PPC and the work flow reliability it measures have focused on shielding; i.e., attempting to make only assignments/commitments that can be accomplished (Ballard and Howell 1997). Shielding appears to have been generally successful in raising PPC to the 70% level. To go beyond that level and to reach 90% and higher PPC appears to require additional actions. Based on related research and consulting experiences, one of which is reported in section 2.0 below, four actions appear to be key:

1. full empowerment of last planners to refuse assignments that do not conform to quality criteria,
2. further improvement in definition by using First Run Studies in construction and Activity Definition Models in design,
3. consistent analysis and action on reasons for failing to complete assignments, and
4. adopting a sizing criterion for assignments that consistently demands less output from production units than their estimated average capacity in order to accommodate variability.

In the following, a case study is presented, then each of the first three actions above are briefly explained. The fourth action, underloading, is presented in more detail, with suggestions for implementation. Finally, potential benefits of improving PPC are proposed and future research collaboration is suggested.

THEATER PROJECT CASE

The Theater Project's task was to design and build a large performing arts theater. Architect, design consultants, engineering firms, fabricators, and construction contractors were selected based on qualifications and willingness to participate in the project. The intent was to create an All-Star team by selecting the very best. All participating firms shared in overruns/underruns of actual construction costs against target costs.

Project management chose to implement elements of "lean thinking" in the design and construction of its facilities, specifically including the measurement components of the Last Planner method of production control (Ballard and Howell 1997). A Kickoff Meeting was held for the production team in May 1998 and was co-facilitated by the author. Key outcomes of the meeting were (1) forming the fifty plus individuals and multiple companies into a team, and (2) collectively producing a "value stream" (Womack and Jones' [1996] term for the flow diagram of a production process that produces value for the stakeholders in the process).

In the Kickoff Meeting, the participants were divided into a number of different teams, corresponding roughly to the facility systems: Site/Civil, Structural, Enclosure/Architectural, Mechanical/Electrical/Plumbing/Fire Protection, Theatrical/Interiors, and Project Support. These teams remained intact as the administrative units for execution of the design.

Subsequent to the Kickoff Meeting, the design process was managed primarily through biweekly teleconferences. Tasks needing completion within the next two week period were logged as Action Items, with responsibility and due date assigned. When action items were not completed as scheduled, reasons were assigned from a standard list (Table 1) and a new due date was provided.

Table 1: Reasons for Noncompletion

1) Lack of decision
2) Lack of prerequisites
3) Lack of resources
4) Priority change
5) Insufficient time
6) Late start
7) Conflicting demands
8) Acts of God
9) Project changes
10) Other

The percentage of action items completed was tracked and published biweekly. The columns in Figure 1 represent the aggregate average completion percentage for all teams for each two week planning period.

There was considerable variation between teams. Through 9/9/98, PPC of the various teams was as follows:

Site/Civil	78%
Structural	35%
Enclosure/Architectural	62%
Mechanical/Electrical/Plumbing/Fire Protection	55%
Theatrical/Interiors	52%
Project Support (Mgmt)	85%

In October 1998, the Civil Team selected five plan failures and analyzed them to root causes using the '5 Why's' technique. Review of Civil's analyses revealed that failure to understand criteria for successful completion of assignments was the most common cause. Generally, failures were caused by not understanding something critically important: City requirements for traffic analysis, applicable codes for drainage, actual soil conditions, who had responsibility for what. Presenting reasons were often quite distant from root causes and frequently the failing party did not control the root cause. In addition, this sample raises significant questions about adherence to quality requirements for assignments. For example, why did Civil accept #1 (were they sure they had the capacity to take on this additional task?) or #2 (why did they think Mechanical would give them the information they needed in time for Civil to do its work?)?

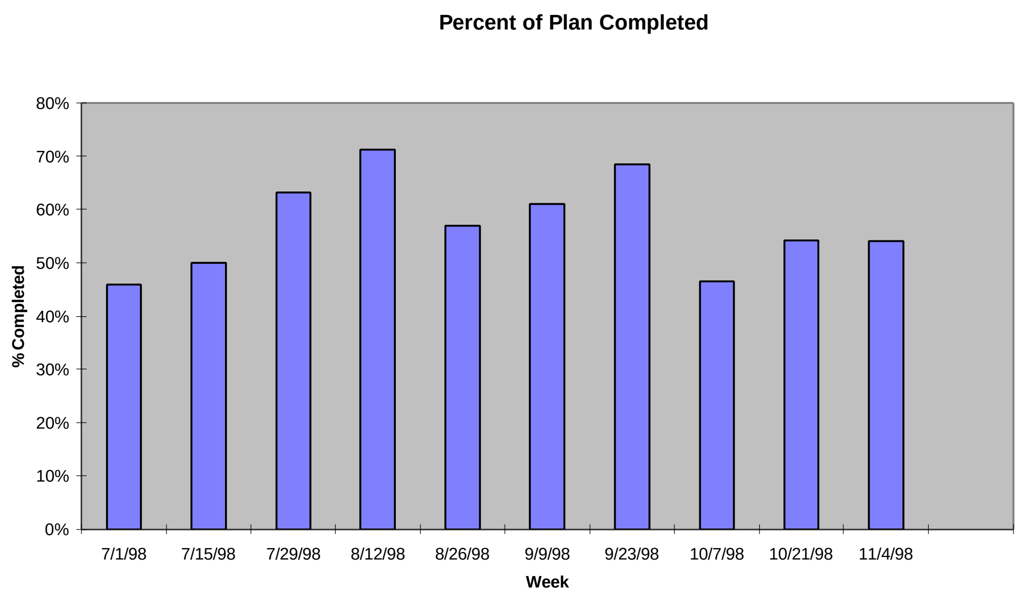

Figure 1: Percent Plan Complete (PPC)

Failure #1: Failed to transmit site plan package to the general contractor as promised. Reason provided: conflicting demands—"I was overwhelmed during this period." 5 why's revealed that the required time was underestimated for collecting the information needed because the City's requirements for traffic analysis were different and greater than had been assumed.

Failure #2: Failed to revise and submit site drainage for revised commissary roof drainage. Reason provided: prerequisite work. The mechanical contractor originally provided drainage data on pipe sizes, inverts, etc., then discovered that City codes required additional collection points. Civil was waiting on Mechanical to provide data on these additional collection points.

Failure #3: Failed to complete Road "D" plan to support easement and operating items. Reason provided: prerequisite work. The root cause was the same as for #1; i.e., failure to understand City requirements for traffic analysis.

Failure #4: Failed to make an engineering determination from 3 alternative pavement designs provided. Reason provided: prerequisite work and insufficient time. “This item was not anticipated. Why was it not anticipated? The City refused to accept our pavement design. Why did they refuse to accept our pavement design? Soil conditions were different from past projects. The lack of prerequisite design work referred to the soil borings in the barrow site. We also are investigating other sources for dirt. Why was time insufficient? We neglected to plan for the time required to mobilize soils testing.” The root cause was assuming soil conditions would be the same. A process flow diagram might have revealed the significance of that assumption.

Failure #5: Failed to determine/coordinate location of easements after final design by the local utility. Reason provided: prerequisite work. “Prerequisite design work involved the determination of routing and service options. There was confusion over who was responsible. There were delays on the part of the local utility due to the absence of key people.” Failure to specify who was to do what prevented requesting a specific commitment from the local utility. If the local utility refused to make that commitment, Civil could have refused to accept its action item until receipt of their input. If the local utility had committed, Civil might have been informed when key people were absent.

The fundamental causes of noncompletions were failure to apply quality criteria to assignments and failure to learn from plan failures through analysis and action on reasons.

This case reveals several things relevant to this paper. First of all, the PPC of design processes is not very high. Second, and closely related, some type of explosion or decomposition of design tasks is needed in order to identify what needs to be done to make assignments ready to be performed. Given the evolving nature of the design process, such explosions must occur near in time to the scheduled execution of those tasks. Third, and something repeatedly observed during teleconferences, participants hesitate to refuse assignments that are poorly defined or otherwise not in conformance to quality criteria. Fourth and last, analysis of reasons for plan failure reveals rich information regarding how the production system actually functions and what might be done to improve it.

JUST SAY NO!

Why is it so difficult to ‘just say no’ to poor assignments? The phrase itself prompts one to consider addiction, but in this instance, addiction to certain habits of thought and action rather than to drugs. Greg Howell long ago characterized the current industry mentality in terms of the slogan CAN DO! (Howell and Ballard 1994). Overcoming that mentality will not come easily.

Another tradition is threatened by requiring underlings to reject poor assignments. It violates traditional protocol. “I’m the boss. That means you do what I tell you to do!” This attitude is based on an underlying mental model that sees the organization as a chain of command, a mechanism for communicating directives from the brain at the top to the 'hands' down below.

A less grand, but nonetheless significant obstacle lies in the fact that planning is hard work. It is much easier to react to events than to investigate the conformance of assignments to quality criteria. Perhaps here addiction is the proper term. We seem to have attracted to the industry or perhaps trained its participants to be crisis junkies.

Overcoming these obstacles will require management patience and persistence, plus consistency of practice at every level of the organization. Research is currently underway at the University of Birmingham[2] on this and other lean organizational issues.

ACTIVITY DEFINITION MODEL

The precondition for effective use of pull techniques is a window of reliability greater than supplier lead times (Ballard 1998). As indicated by the Theater Project, the current way of managing the design process yields very low reliability. Consequently, it is necessary to increase plan reliability in order to make the use of pull techniques feasible. The Last Planner system of production control is proposed as a means for increasing plan reliability in design. Previous applications of Last Planner to design have proven effective (Koskela et al. 1997, Miles 1998).

More specifically, a technique is proposed for decomposing design tasks so that they can be proactively made ready to be performed when scheduled. Pulling is one of the make ready techniques. Effectively, this decomposition improves the definition of design assignments; definition being one of the quality criteria of assignments incorporated into the Last Planner system. This technique, the Activity Definition Model, is to be incorporated into the lookahead process, a component of the Last Planner system dedicated to work flow control.

Each control system includes a lookahead window, which usually covers the next 3-6 weeks. Activities included in the master schedule are allowed into or advanced through the lookahead window only if the planner is confident they can be made ready when scheduled. That confidence is tested and made operational by exploding the activities in accordance with the Activity Definition Model.

The scheduled deliverable is the Output desired. Criteria for that output are specified or actions to specify/clarify are listed. Prerequisite information is noted or actions to request or obtain that information are listed. Resources needed are noted as are actions to reserve or allocate them. (Resources are labor or instruments of labor, and consequently have capacities relative to the loads that can be placed upon them.) Actions regarding criteria, prerequisites, and resources are included in the assignments to be performed and scheduled in the lookahead window in accordance with the lead times required for their clarification or acquisition[3].

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[2] For example, see Seymour and Hill (1995).

[3] Such make-ready tasks need not be included in a higher level schedule intended to coordinate multiple PUs. The PU itself is responsible for reliably completing its assignments or for providing advance notice of inability, so replanning can occur with more lead time. Failure to improve PPC over time indicates lack of a functioning production control system.

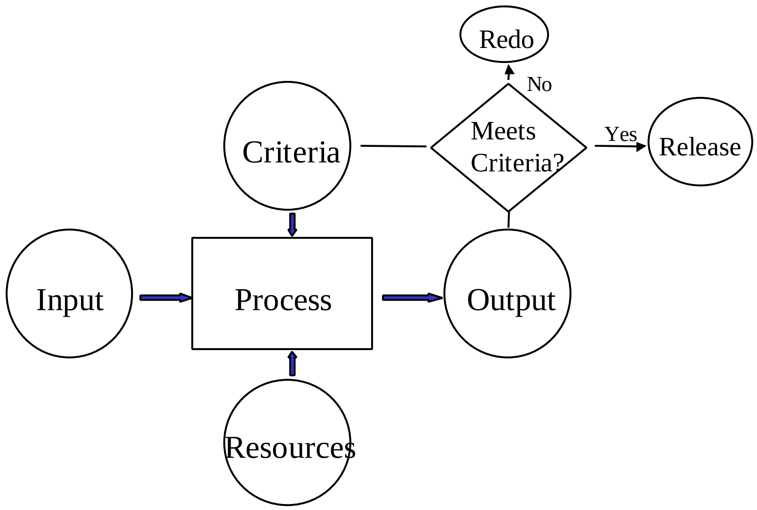

Figure 2: Activity Definition Model

As indicated by the Theater Project case, a key issue is clarification of design criteria. Those who are to use the output of the design process are effectively 'pulling' that output into their process. Joint assignment of design tasks to both provider and puller promotes common understanding of criteria and also ensures that resources are used first to do work that is needed now by someone else. Prior to releasing the output to those pulling it, it is tested against the criteria, and redone if needed.

LOAD/CAPACITY

DEFINITIONS

- A **production unit** (PU) is an individual or a group performing some production tasks. PUs receive assignments. PUs include design squads and construction crews.
- **Capacity** means the amount of work a PU can do at any point in time with given tools and work methods in given conditions. A crew may be able to produce 50 units of output (linear feet of pipe, tons of steel, cubic yards of concrete, etc.) under current conditions. That is their capacity; the amount of work they are capable of accomplishing.
- **Throughput** is the actual amount of production output in a given time.
- **Load** is the amount of throughput we demand or expect of a PU. Common practice in construction at present is to load to 100% of estimated average capacity. In our example, that means we would assign 50 units of output to be produced by the crew each day.

VARIABILITY IN PRODUCTIVITY AND IN WORK FLOW (PLAN RELIABILITY)

Loading at 100% of capacity would be acceptable if capacity were accurately predictable and deterministic. However, actual production varies widely over time even for a single PU, and varies even more widely across different units. In addition, as previously noted, work flow is not highly reliable. Indeed, even when we try to make good assignments, PPC is now often below 70%. In such circumstances, loading at 100% capacity decreases the probability that assignments will be completed as planned.

Coming from another angle, we can assume that there is a 'natural' variability of capacity (what Hopp and Spearman call "randomness") even when methods, technology, and conditions are fixed. Further, there is the difficulty of accurately estimating even average capacity when there are changes in these variables or when the type of work changes or there is some change in crew or squad composition. Even manufacturing is plagued with variability[4]. Since we don't make identical products in controlled conditions, capacity variation is a fact of engineering and construction life. Current production management techniques ignore this fact, as is evident in loading practices.

UNDERLOADING

Underloading can reduce the immediate productivity of a PU, assuming that no non-schedule-driven work (workable backlog) is available to absorb unused capacity. However, underloading, along with other elements of the Last Planner system of production control, helps assure that the PU's plan reliability or PPC is higher, thus providing better advance notice to downstream PUs of work flowing toward them, and thus allowing them to increase **their** productivity. Since all but the very first in a chain of PUs receives work from others, potentially all the rest benefit from adopting practices that improve PPC. Consequently, the next step in improvement of both plan reliability and productivity will most likely occur on projects where the various design and construction specialists practice some form of gainsharing, or at least collectively recognize their interdependence and potential gains. Otherwise, no one will be willing to sacrifice, even temporarily, for the sake of the whole.

We can say that initial, unilateral improvements in PPC and productivity need now to be superceded by collaborative improvements in PPC and productivity based on increasing the predictability of work flow across PUs.

DON'T LOAD TO 100% OF CAPACITY

Rather than loading to fully absorb their capacity, it is better to underload production units in order to allow for variability in production, which is itself partially a function of variability in the flow of work to those production units. Underloading reduces the achievable output of a PU. They have more capacity than load. However, underloading also increases the capacity (potential throughput) of following PUs through its impact on work flow reliability. Since virtually everyone is a 'customer' of someone else, better work flow reliability improves everyone's productivity. We may need to pool our money and pay the first guy in line to

[4] Even in manufacturing, variability is considered to be a prime problem. See Hopp and Spearman, 1996, Chapter 9: The Corrupting Influence of Variability, pp 282-315.

sacrifice his immediate productivity for the sake of higher flow reliability. Remember the "Parade of Trades" (Tommelein et al. 1999)!

IMPACT OF SOUND ASSIGNMENTS

It makes sense that the productivity of a production unit increases when we make more assignments to that unit that are sound; i.e., assignments from which all constraints have been removed. Design information is current, resources are on hand, work space has been allocated, requirements are clear, etc. More of total labor time is spent actually doing work instead of looking for missing ingredients, switching between tasks, and returning to finish work left incomplete.

PU productivity results from a utilization rate and a fruitfulness rate. The PU utilization rate is the percentage of paid resource hours spent working as opposed to waiting, traveling, looking, etc. The hours actually spent working have a certain fruitfulness or production rate that results from skill levels, degree of effort and application, work methods and technology, design constructability, the inherent difficulty of the work to be done, etc. Consider some likely numbers:

BEFORE:

- initial average capacity is 50 units per day, calculated from historical records.
- 50% of the labor hours expended to produce that 50 units are actually wasted on rework and nonproductive waiting, looking, revisiting, etc. (utilization can be estimated by surveys or activity sampling.)
- It is apparent that the underlying fruitfulness rate is one unit of output per productive time unit.
- PPC of the PU is 50%.

AFTER:

- PPC increases to 70%, as a result of improving the soundness of assignments.
- Nonproductive time (delays and rework) falls to 35% vs the previous 50%; i.e., productive time increases from 50% to 65%.
- Given the same underlying fruitfulness rate, new capacity is 65 units per day.

This amounts to a 30% improvement in PU productivity. Previously 50% of total labor hours were expended in the production of 50 units of output. Assuming no change in skills, effort, technology, or work methods, after the improvement in the soundness of assignments and consequent increase in PPC, the PU expends 65% of its total labor time on production and produces 65 units of output.[5]

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[5] We could choose to say that the underlying productive capacity of a unit of productive labor remains the same; i.e., one unit of output per unit time for each productive unit of labor. However, it appears preferable to say that the capacity itself of the PU changes through the impact on resource utilization of increasing plan reliability, just as we would

Note that a 30% improvement in productivity of PUs has been observed on numerous occasions when PPC has been improved largely as a result of making sound assignments (Ballard and Howell 1997).

POTENTIAL IMPACT OF THE NEW SIZING CRITERION

With PPC at 70% throughout a chain of PUs, a PU still has considerable uncertainty about what work is actually going to be released to it by upstream PUs only one move away; usually as little as one week in advance. The next wave of increases in PPC will come from a number of different initiatives, including underloading sufficiently to allow for variability in PU productivity. In the absence of real data on capacity variability, assume loading at 90% of the estimated (average) capacity of PUs, which can be adjusted in response to empirical results.

Underloading should improve PU PPC, thus increasing the lead time downstream PUs have to make work ready. Speculative results:

- loading of PU_1 is at 90% of capacity; i.e., 59 (.9 * 65) units are assigned to be produced each day.
- productive time of the downstream PU (PU_2) increases to 80% from the previous 65%
- new capacity of PU_2 is 80 units per day.

WHAT HAPPENS WHEN SIZING COMBINES WITH SOUNDNESS

Underloading upstream production units increases the productivity of downstream production units, just as making only sound assignments increases the productivity of the production unit receiving those assignments. Consequently, assuming the 90% loading of upstream PUs has contributed to an improvement of PPC to 90%, and assuming that has caused a corresponding improvement in resource utilization to 80%, the new capacity of the linked PUs, with the possible exception of the first, is 80 units per unit time.

Assuming that we continue to load at 90% of capacity and that the new capacity is 80 units per day, load and productivity would be 72 units per day. an additional increase of 23% above the 58.5 units previously achievable, and a 44% improvement above the initial 50 units per day. However, as rising PPC reduces variation in capacity, we can increase load accordingly, thus further improving productivity. Supposing a 95% loading, output would be 76 units, an improvement of 52% above the initial 50 units per day.

EVEN BIGGER GAINS ARE POSSIBLE IN THE FUTURE

This 52% improvement in productivity results only from increasing the percentage of paid labor time available for production; i.e., labor utilization. Another variable determining capacity is the fruitfulness of productive labor time, which is a function of operations design (work methods), task difficulty, design constructability, skills training, worker motivation,

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say that capacity changes when technological innovation causes an increase in fruitfulness.

etc. The 5-10% nonloaded time will be invested in precisely these areas. In fact, we may find it beneficial to keep loading at 90% or possibly even less in order to free labor time for investment in fruitfulness. Workers will be asked to spend time doing First Run Studies or defining design activities; providing feedback to upstream players on the adequacy and clarity of design criteria or design constructability; undergoing training in craft and managerial skills; etc. etc. We break even if we invest 10% of paid labor time and increase capacity enough to offset that cost; i.e., in our example, increase from 72 to 79 units per day.

If this analysis and these numbers are plausible, you can see the tremendous potential for improvement offered by lean construction concepts and techniques. Current productivity levels will be eclipsed.

MOVING FORWARD

Improving work flow reliability offers tremendous potential improvement in engineering and construction performance. Four actions have been proposed to improve PPC and the work flow reliability it measures:

- full empowerment of last planners to refuse assignments that do not conform to quality criteria,
- further improvement in definition by using First Run Studies in construction and Activity Definition Models in design,
- consistent analysis and action on reasons for failing to complete assignments, and
- adopting a sizing criterion for assignments that consistently demands less output from production units than their estimated average capacity in order to accommodate variability.

Of these, only the last, underloading, was presented in detail in this paper. More detailed presentation of concepts and findings regarding empowerment of last planners, improving assignment definition, and reasons analysis and action will be made available in future papers. Industry researchers and practitioners are invited to comment on the appropriateness of these recommendations, to implement those they find (or can be persuaded are) reasonable, and to document and share the results.

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