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Implementing Lean Construction: Improving Downstream Performance*

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1 INTRODUCTION

1.1 Overview

The conversion process model would have us attempt to achieve performance improvement on complex, fast track projects by separately reducing the cost and time of Engineering, Procurement and Construction, without regard to their interdependencies. The lean construction model facilitates performance improvement by revealing those interdependencies. This not only avoids sub-optimization. The logic of lean construction implementation requires a certain sequence of initiatives, which progressively reveal additional opportunities for improvement.

Ohno and Shingo (1987), two of the principal architects of the Toyota Production System, argue persuasively that manufacturing be conceived in two complimentary but different ways (Figure 1): (1) As a process, i.e. the course of events through which material is changed into a product, and (2) As an operation, i.e. the course of events through which man and machine work on the product. They also argue that process must be balanced and managed prior to addressing operations.

We are following Ohno and Shingo when we advocate implementation of lean construction in three phases, beginning with stabilization and reducing in-flow variation (process), and finally turning to operations.

1.2 Realizing Potential Gains

It is often possible to reduce the cost or time of operations taken singly on the order of 25-50%. However, it is not so easy to realize those gains in actual cost or time savings. Excess manning of operations may signal failure to balance flows. Lack of discipline in planning and execution will vitiate attempts to implement improvements. Stabilization is a prerequisite for operations improvement (Figure 2).

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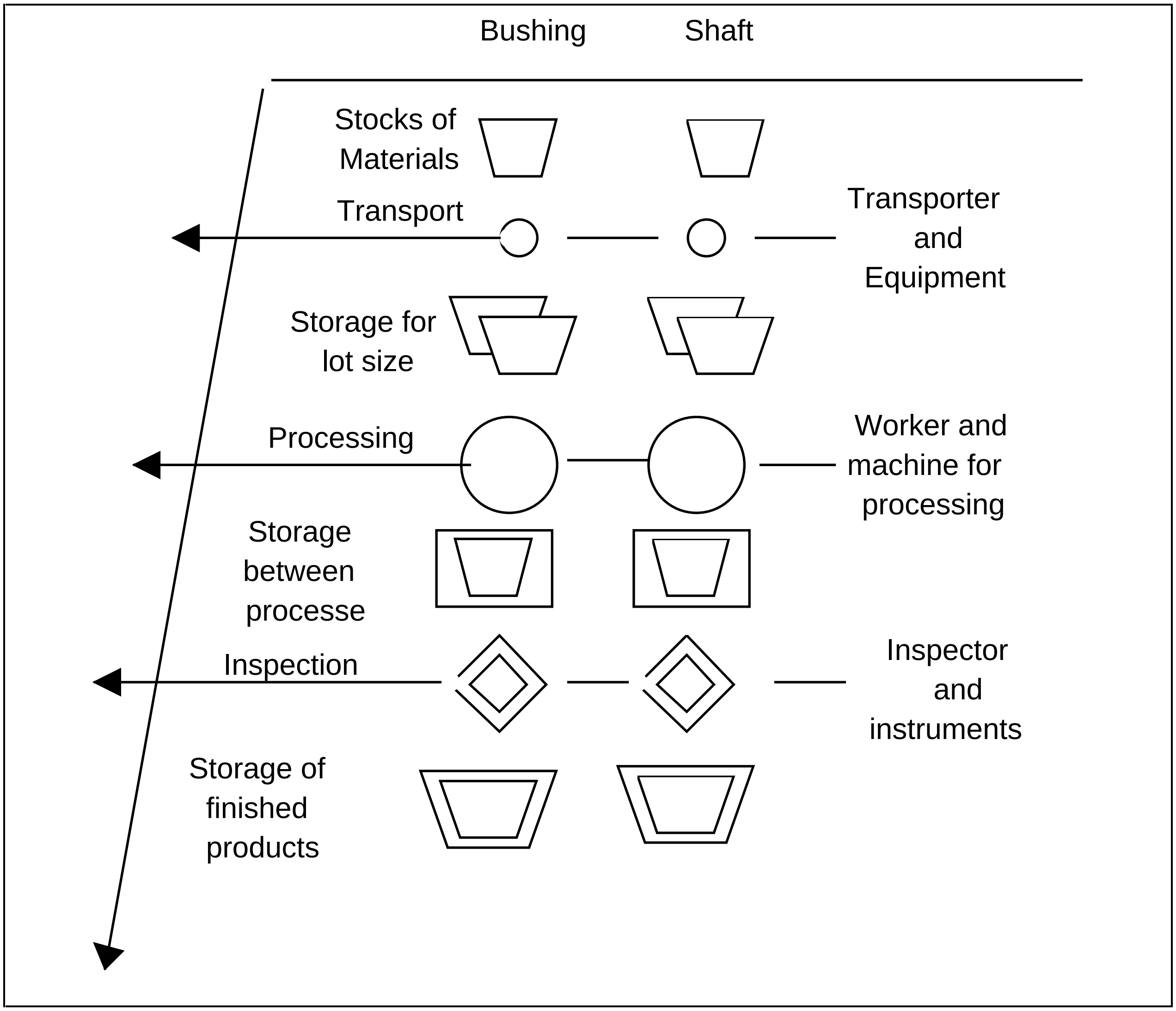

Figure 1: Process and Operation (adapted from Shingo)

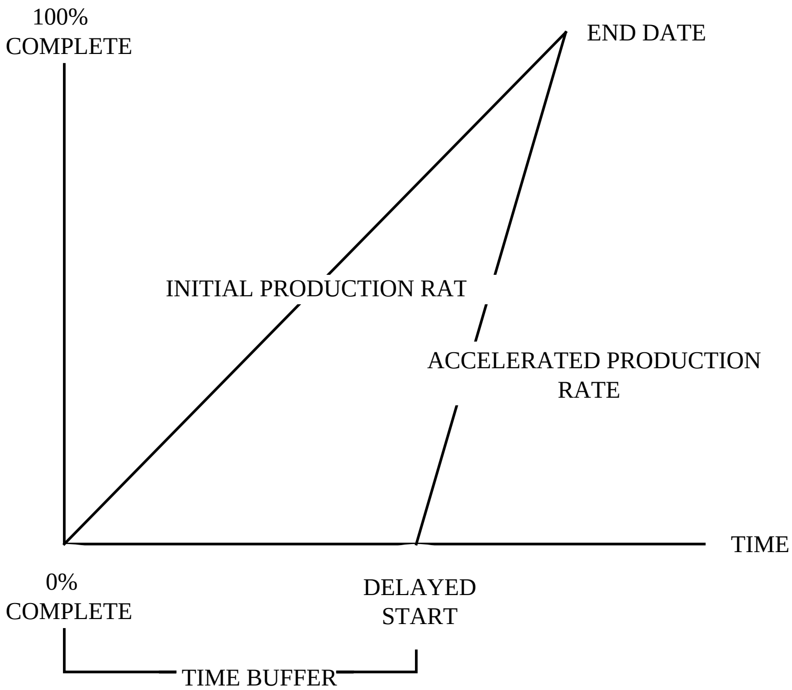

Figure 2: Wait to Start, then Go Faster

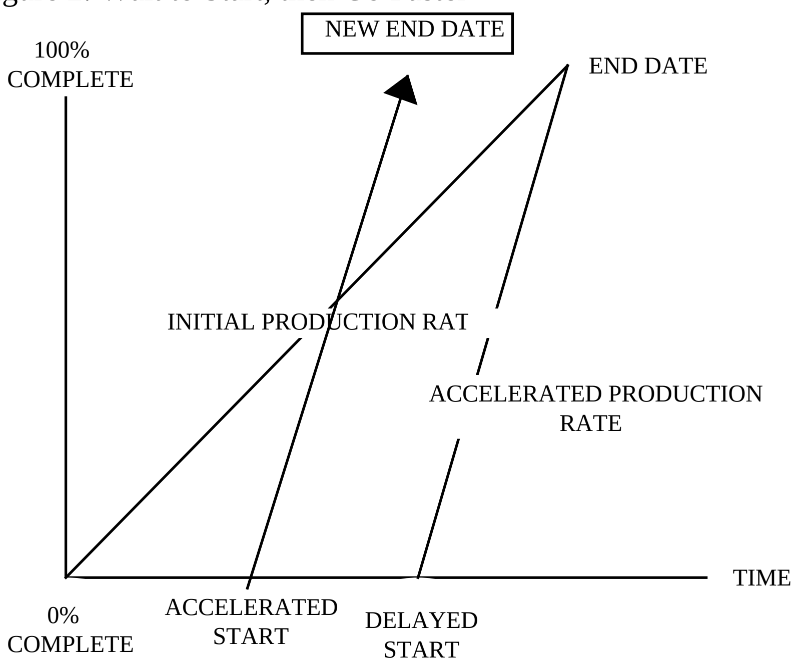

Figure 3: Reduce Flow Variation, then Start Sooner

Once the work environment is stabilized, substantial improvement in operations becomes possible, and the potential gains can be realized in cost or time savings.

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Reducing in-flow variation brings additional benefits and opportunities for improving operations. An immediate benefit is illustrated in Figure 3. As delivery variation declines, so does the size of backlogs required to initiate work without risk of interruption, thus advancing phase initiation, e.g. construction mobilization. With a more certain in-flow of work, more optimum sequences can be selected and better matching of labor resources can be done. Further, there will remain opportunities for squeezing time from processes that occur within engineering, construction, etc. —primarily from reducing operation cycle times and from better coordination of interdependent disciplines or crafts.

1.3 Are Foremen the "Last" Planners?

It now becomes possible to improve performance by changing the way work is done, as opposed to managing the conditions in which it is done. However, that does not mean turning immediately away from planning to execution. Flow management extends into the different project functions, as well as between them. Consequently, planning also must be extended downwards. In addition, planning addresses both process flow and operations design.

Even when PPC (Percent Planned Activities Completed) analysis reveals no plan quality failures from upstream planning processes, there may remain plan quality failures. The Weekly Work Plan is not the last plan, so strictly speaking, the producer of the Weekly Work Plan is not the Last Planner. Planning goes on at every level of the organization until work has been executed. The distinction between plan quality failures and execution failures is relative to the division of planning responsibilities made at each level of the planning system (Figure 4).

In construction, the effective point of intervention has proven to be the Weekly Work Plan, because that is where work is selected and commitments are made, and the key to stabilization/reduction of uncertainty is improving the ability to keep commitments through better selection of work to be done. Nonetheless, planning goes on beyond the selection of work to be done next week, often by foremen, subcrew and individual craftsmen as they produce assignments, daily plans and work methods (Howell et al. 1993). Consequently the first task is to follow the planning system through its final levels, assessing and improving plan quality.

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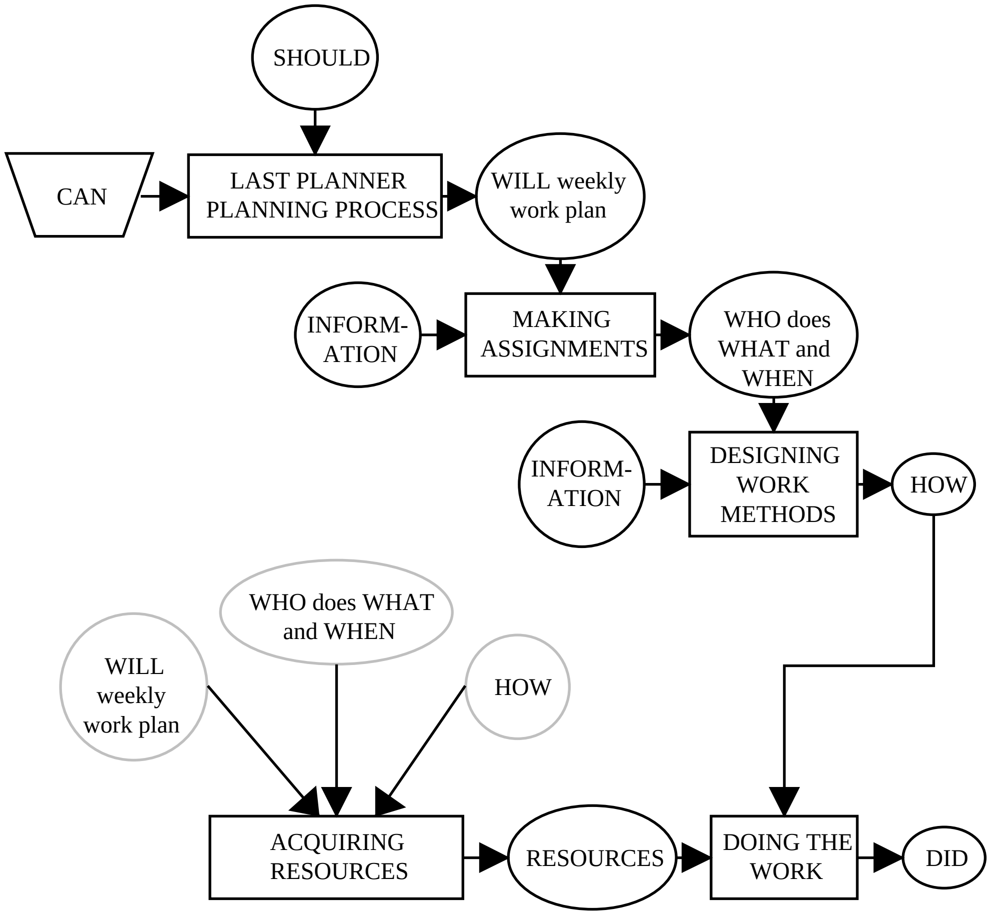

Figure 4: Are Foremen the Last Planners?

2 WORKING THE PLAN

2.1 Performance Standards

First there is the issue of working the plan; i.e., making the plan the standard of performance for work execution (Table 1). This is an issue because many instances have been observed where Weekly Work Plans are not used to develop assignments, or the assignments do not include the goals necessary to be achieved in order to complete planned work. This is obviously in part a function of the degree of definition in the Weekly Work Plan itself. When a bar chart is produced showing the durations and sequencing of assignments by sub-crew for each day of the week, simply providing the bar chart to the sub-crews may be an effective method of driving work execution with the Weekly Work Plan. However, having such a bar chart and using it may be two very different things.

Table 1: How Foremen Set Standards

* Keep busy
* Do as I would
* Make the craft standard
* Make the budget: average for aggregate work
* Make the target: budget adjusted for work mix and conditions

In some sectors of the construction industry, it has been customary for upper levels of supervision and management to monitor productivity and progress, while simply urging lower levels and direct workers to push and work harder. Indeed, many "good" foremen only control against inactivity, and have no explicit goals at all. In some cases, they are so absorbed in removing obstacles that little time or energy remains. In other cases, they assume that eliminating constraints that cause inactivity produces optimum performance, so setting goals would be irrelevant.

Another group of foremen control against standards formed from their personal experience: "How long would it take me to do that work?" With them, we move from activity levels to assignment durations as the locale in which standards are established—definitely a step forward. The next group establishes expected assignment durations from budget unit rates or craft rules of thumb that serve the same purpose. As an example, I know whole tribes of pipefitters in the southeastern United States who figure everything will be all right if they can average 10 linear feet of pipe per crew member per day—and they're usually right!

The best way to set standards is to draw them from the specific work to be done. That is the intent of the rule to "select the right amount of work to be done next week." Craft rules of thumb or budgeted unit rates are not themselves the standards directly governing assigned work. They inform the planner regarding the aggregate quantities and costs, which the planner adjusts in application to a specific mix of pipe material types and sizes, in different locations, some behind obstacles, etc.

The planner may also adjust the standards to reflect broader performance goals such as completing the piping work 15% under the direct labor budget.

2.2 Goal Setting Theory and Worker Motivation

Research on the motivational impact of goals on performance contributes these two important findings (Locke & Latham 1990):

(1) Given capability, difficult, specific goals lead to better performance than "do your best" goals.

(2) As tasks become more complex, performance becomes less dependent on mere motivation and more dependent on the quality of task strategies, i.e. work methods.

The most popular way of setting goals in assigning work assumes that "do your best" is the best that can be done. It is also widely held that motivation is more important than the quality of planning and know-how. It is also important to note that there is no support in research for the widely-held belief that participation in goal setting increases motivation to achieve goals. We suspect that understanding goals is more important for performance than participating in goal setting. That does not mean workers have no role in planning. However, it is not increasing motivation, but improving plan quality that is the reason for involving direct workers in planning; especially in planning how to do the work.

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3 IMPLICATIONS FOR PROJECT CONTROL

3.1 Identifying Variances

We believe that the current approach to cost and schedule control in the construction industry is fundamentally flawed in some respects. It is assumed that aggregate averages (budget unit rates) are applicable to each component, and variances are measured from those aggregate averages (Figure 5). Superintendents and foremen have been well indoctrinated in the importance of productivity, but the attempt to assess performance against false standards inevitably has bad consequences:

1) Near impossibility of identifying a real variance when examining short-term results, and the resultant focus on blaming rather than analyzing, and

2) Failure to direct actual production towards project objectives through the provision of reasonable goals, and

3) Waste of craft supervision's energies and time spent selecting work and shaping reports so they appear to be working as closely as possible to aggregate averages, and thus avoid "drawing fire".

The change needed is to decide before work begins if the right work has been selected in the right amounts, given the work mix and conditions. Plan execution is the right standard of performance for a week. Its measures are Percent Planned Activities Completed and Planned Productivity. Budget unit rates are the right standard of labor consumption for a project, and serve as means of calculating and assessing PPAC and planned productivity. When you shift your control focus to adjusted standards, variances can be identified and can be analyzed using reasons why planned work was not done, and you have a chance of improving performance and avoiding repetitive errors. With the prevailing approach to controls, its use of false standards and inability to identify variances, performance improvement is accidental.

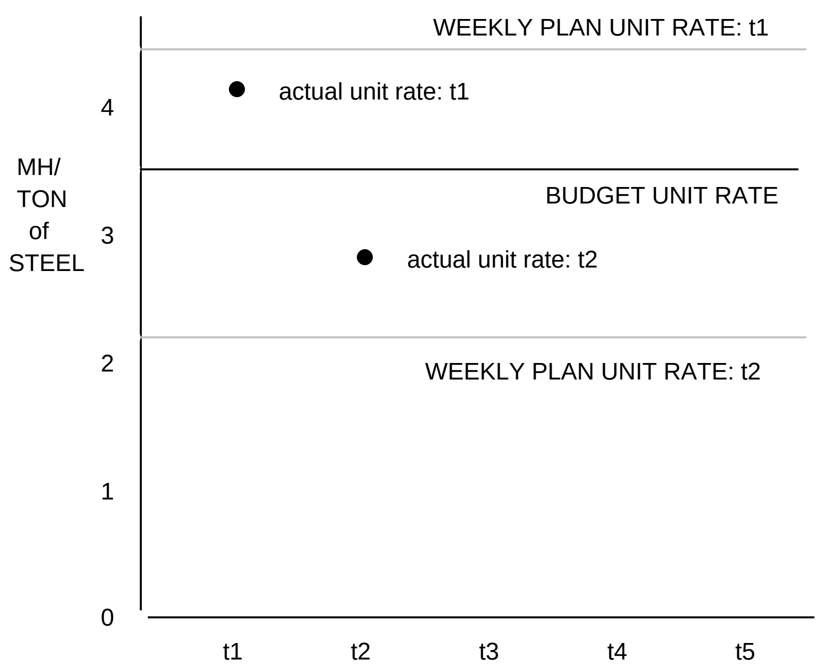

Figure 5: What variances are significant?

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3.2 Proactive Control of Plan Quality

When the field planning system begins to work properly, you will know before-the-fact if labor is matched with work to be done, if planned productivity is reasonable, if the right work is being done in the right amount, etc. After-the-fact analysis can then focus on Percent Planned Activities Completed, and can identify when a performance variance (positive or negative) is due to plan quality or to execution. Variances will then be assessed relative to planned performance, not against aggregated standards, thus providing a more efficient variance analysis than one which begins by discounting most variances as apparent rather than real, and providing a more effective analysis because the standard has already been adjusted to reflect work mix and difficulty. Incidentally, this way of operating removes incentives for crafts to move manhour charges around to reduce apparent variance, and so improves accuracy. (Use of statistical analysis to interpret variation is also sadly missing, but unfortunately cannot be addressed in this paper from lack of time.)

Controls should be focused on improving PPC (Percent Planned Activities Completed), improving on-time resource deliveries, and matching labor to resource deliveries (Figure 6). Now control consists of determining if the total project and its component parts (by discipline and area) are on schedule and budget, but generates little if any information useful in determining causes of variance or acting on them.

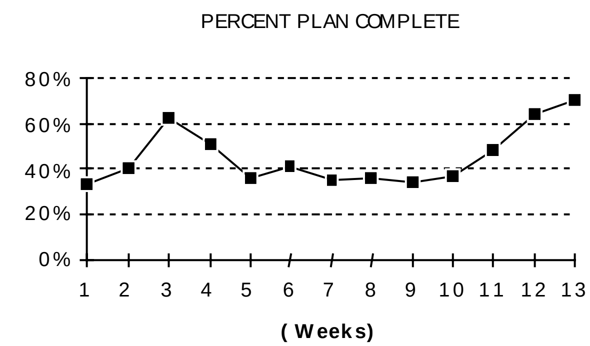

Figure 6: Percent Plan Complete

4 REMOVING OBSTACLES

4.1 Reasons Why Planned Work Does Not Get Done

When attempts are first made to shield direct production from inflow variation, the primary reason for failing to complete planned work is usually lack of materials. Once it has become second nature to select assignments from workable backlog, missing materials begins to disappear as a reason, and is replaced by items more within local control, such as coordinating interdependent work activities and shifting priorities (Figure 7).

Identifying and eliminating root causes is analogous to stopping the manufacturing production line, something we rarely if ever do in construction.

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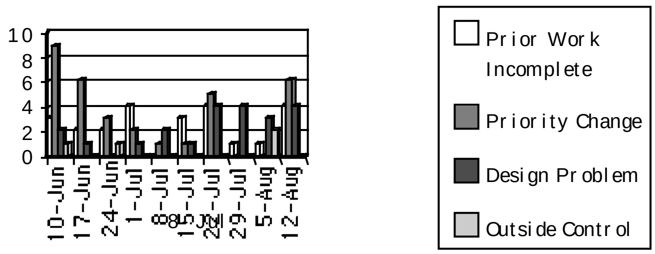

Figure 7: Reasons

4.2 Resource Utilization Studies

Acquiring and coordinating the use of shared resources is one of the major planning activities that must occur between committing to a Weekly Work Plan and executing that plan. Some shared resources are coordinated by means of scheduling; e.g. tower cranes. When it is not feasible to schedule the use of shared resources, other means are needed to match supply with demand.

Utilization rates have proven useful as partial measures of that match. In the case of light, mobile cranes, some slack is needed for traveling and to accommodate uneven demand. (Although, Ohno and Shingo would likely chastise our faintheartedness in pursuing waste reduction.) Sampling-based measurement of utilization shows the extent to which current capacity is being absorbed, and provides data to consider alongside complaints and requests for more.

It is obvious that low utilization can co-exist with high delays. This occurs when the allocation process is ineffective, or when user planning is poor. Low lead time and lumped requisitions signal poor planning. Tracking and eliminating such practices can allow reducing the number of items of equipment, maintaining a high utilization rate, and reducing craft delays. On the project from which the graphic data was taken, equipment leasing and labor costs were 15% under budget.

4.3 Performance-Based Budgeting Of Support Crafts

Another promising approach to managing shared resources is to determine resource sizing by reference to maintaining a service level. An example is scaffolding during intensive piping work on industrial projects. Scaffolding becomes a support craft and has often been sized as a certain percentage of total primary craft labor hours. On one recent project, the scaffolding "budget" was 15% of piping labor hours, but we concluded the project at under 12%, and saved a pile of money.

What we did was make a deal between scaffolding and piping. If piping foremen would provide at least 48 hours lead time in their requests to have scaffolding erected, scaffolding labor force and materials would be adjusted to maintain a 48 hour response time. Lead time and response time were monitored and made available to both scaffolding and piping. This information helped management make the right decisions about the amount of investment needed in scaffolding resources, as well as the corrective action needed in pipe foreman planning.

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5 CHANGING HOW WE DO THE WORK

5.1 First Run Studies

The way work is done is called a work method. All kinds of work can be represented in methods charts and can benefit from redesign and streamlining, especially with the involvement of a team consisting of representatives of the different functions involved. Administrative and resource management processes should be first on the list because they support all different types of production processes. Planning systems and processes have already been singled out for special attention. Other administrative processes that are likely candidates include RFIs and change orders. Resource management processes that should be examined include small tool supply and distribution, construction equipment supply and distribution, purchasing, requisitioning, delivery/material handling, hiring and in-processing, etc.

As soon as craft work is ready to begin, the first run of each type of craft operation should be examined in detail, ideas and suggestions solicited from all parties, and experiments performed to explore alternative ways of doing the work. The result will be a performance standard, for both results and the methods for achieving them. This standard is best used not as a rigid procedure, but as a challenge to meet or beat the best done thus far.

As was mentioned at the beginning of this presentation, it is often possible to reduce the time or cost of operations, or to improve their safety or quality on the order of 25-50%. Simple but powerful tools can easily be taught to craftsmen and craft supervisors, including process charts for representing work methods and systematically seeking ways of eliminating, reducing or making concurrent the steps represented on those process charts. It is certainly true that such training occurs too infrequently, but that signals the fact that the problem is not technical but philosophical.

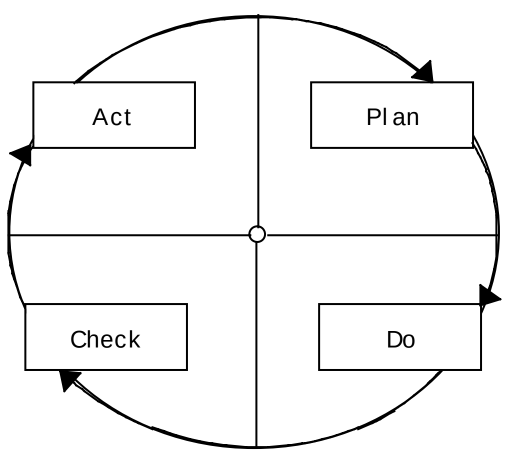

Figure 8: PDCA Cycle

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Theory comes before policy and policy comes before training. Hopefully the development of Lean Construction theory will soon move us into the policy phase. As regards policy, we recommend adaptation and use of the traditional PDCA cycle (Figure 8) developed in the 1930s by Walter Shewhart, perhaps better known as W. Edwards Deming's mentor.

PLAN

1. Select work processes to study.
2. Before the first run of each process, assemble people with input or impact.
3. Bar chart the work process steps.
4. Brainstorm how to eliminate, reduce or overlap process steps.
5. Check process designs for safety; anticipate hazards and specify preventions.
6. From past experience, list probable errors and specify preventions.
7. Assign optimum labor, tool and equipment resources.

DO

8. Try out your ideas on the first run.

CHECK

9. Describe and measure what actually happens:
    - -process steps, sequences and durations
    - -errors, omissions and rework
    - -accidents, near misses and hazards
    - -resources used (labor, tools, equipment, support crafts, etc)
    - -outputs

ACT

10. Reconvene the team, including those who actually did the work, review data and share ideas. Continue until opportunity for improvement is exhausted.
11. Communicate the improved method and performance as the standard to meet or beat.

The intent is to thoroughly plan and study first runs of major operations, using past studies as guidelines, and producing standard work methods designs for use on the project. This experiment-based approach produces a tested method that can be taught to all crews, thus reducing cost, errors and accidents. Use the standard PDCA cycle for improvement, involve everyone who could help or hinder, establish standard methods to be met or improved upon on this project and on future projects. First Run Studies can be a substantial part of a contractor's investment in innovation, and an arena within which direct workers can make a significant contribution. When these studies are a routine part of your business, it will be easy to experiment with new work process designs, new technologies and tools, new crew mixes, etc. Once workers see that you are interested in finding better ways of doing work, they will develop and share their ideas.

An important feature of First Run Studies is to integrate all performance dimensions into work process design, with safety first, then quality, time and cost. You can apply the same

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control and improvement strategy to this level of planning as we have recommended for the selecting of work for Weekly Work Plans. Plan as well as you can, then analyze actual performance to distinguish between plan quality and plan execution failures, so each can be addressed and improved.

5.2 Inspection and Testing

5.2.1 What is Rework?

Rework has traditionally been defined in terms of errors requiring work to be redone. A typical list might include design errors or changes, vendor errors, and installation errors. We suggest adding two more items to the list: incompletions and rehandling (Table 2).

Table 2: Components of Rework

TRADITIONAL COMPONENTS:	PROPOSED ADDITIONS:
* Design errors	* Incomplete installations
* Design changes	* Rehandling materials
* Vendor errors	
* Installation errors	
* Damage by other crafts	

Incompletions occur when a task that should have been completed was not. This occurs quite commonly, sometimes from the habit or tradition of dividing work into ever smaller parts, and sometimes from the lack of materials or completed preprequisites. In either case, there is a cost of incomplete work; e.g. the costs associated with returning and gaining access, which is often more difficult after other items have been installed. There is also the cost of replanning and supporting additional assignments. And finally, there is the risk of misinformation between those who did the original work and those who are completing it.

I was perversely delighted to see that Toyota had to fight through the perception that early deliveries were on-time (4) We struggle so hard in construction to get what we need to do work that it may seem foolish to complain about something coming before scheduled arrival. Nonetheless, there is a substantial cost involved in early deliveries. Attention is usually focused on the cost of capital tied up in unneeded inventory, but the greater cost is rehandling. Think what we could save if we were able to place all equipment, steel, and piping directly into final position off the delivery vehicle, thus avoiding off-load, reload, haul to work area.

5.2.2 Linking the Planning and Inspection Systems

The construction industry has practiced the "inspect quality into the product" approach rather than designing quality into the work process. One of the primary foci of process improvement activities should be the inspection processes associated with each craft and its work. The objective is to reduce the time and cost of inspection by increasing the frequency of getting it right the first time. The amount of time spent doing work over has never been accurately measured, but can safely be said to be substantial, absorbing perhaps as much as 25% of paid labor time. Much of this time is expended after work is reported to be complete, i.e. during the punch-out and correction phase.

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We have had some success in piping using the following approach. First of all, we stopped putting pressure on hydrotest to test x number of feet per week. Instead, the decision was made to try and get it right up front; both in terms of production quantities and quality of work. A vital part of that effort was assigning inspectors to work informally with piping as work was being installed, so those doing the work would get feedback as quickly as possible, and would be able to make corrections. This effectively substituted in-process inspection for the traditional end-of-line inspection. (Figure 9 is a small part of a larger flow chart describing the piping inspection and hydrotesting process.)

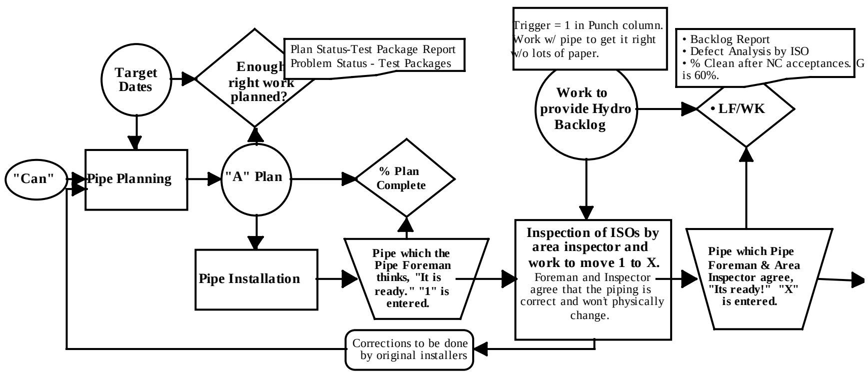

Figure 9: Inspection and Turnover

Not only did production quantities increase by 50% (linear footage of test package piping turned over for hydrotest each week), but over the life of the last unit, repetitive errors dropped from one every 21 feet in an earlier unit to 1 error every 42 feet, a 50% reduction in error rate.

By the end of the project, 80% of test packages were passing final inspection "clean". If that level can be achieved upstream, all later inspections can be eliminated. Owner companies with which we have worked now intend to eliminate one of the two end-of-the-line inspections, and ultimately involve their people doing the in-process inspection.

We have an opportunity to develop more beneficial ways of involving foreman and crew members in reducing rework. Among the many possibilities to explore: provide craftsmen laminated lists of things to check before walking away from an installation, find a way to "stamp welds" applicable to other types of work, provide better and more timely feedback regarding repetitive errors, and improve the in-process inspection process.

6 CONCLUSION

6.1 Engineering, Procurement and Construction

This talk has focused on improving performance on the construction site. Obviously, other locations will also enjoy opportunities as a consequence of stabilization and reduction of in-flow variation. In Engineering, concurrent engineering is the primary model and engine for reducing project duration. In addition to the aspects developed in manufacturing, the construction industry needs to understand how to execute the work of interdependent engineering disciplines simultaneously, as well as simultaneously addressing all life cycle design criteria. One idea is to apply both technological and organizational tools developed in manufacturing, i.e. electronic data

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interchange and cross-functional teams. Even though engineers are assigned to large projects under the control of strong project managers, in a task force mode, there remain tremendous problems coordinating across disciplines. Contractors implementing the strategy we have presented will experiment with mixed teams, with joint responsibility for a set of interdependent deliverables, and considerable autonomy at managing the internal interfaces.

Procurement can reduce the time required for acquisition of resources by eliminating wasted time in information flows, reducing transport distances by selection of local suppliers (or the more expensive use of local staging areas), and by the use of blanket purchase orders that get some steps in the cycle done ahead of time. Vendors and fabricators will benefit from the increased certainty in work flow to them, and will be able to more reliably serve the needs of their downstream customers.

In addition, Procurement must work with Construction on timing of deliveries. The goal is for Construction to release resources for delivery just when needed. This reduces on-hand inventory, space requirements, and multiple handling when equipment and materials can be placed directly into final position off delivery vehicles.

6.2 Review

The fast track, complex projects of the manufacturing and process plants sector offer some of the greatest challenges to the construction industry. It is vital that we learn how to manage in conditions of rapid change and uncertainty because those conditions are becoming the norm for all types of construction. Lean production concepts and techniques offer help in meeting those challenges.

The first step in applying lean production to construction is to shield direct production from variation and uncertainty in the flows of directives and resources. The second step is to reduce flow variation. The third step is to improve performance behind the shield; i.e., to improve operations within a context of managed flows (Figure 10).

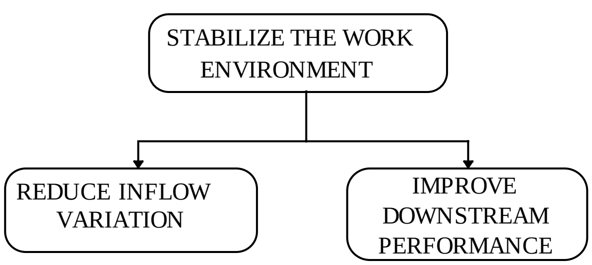

Figure 10: Improvement Strategy

Many opportunities exist for improving operations, but the logical starting point in each case is extending the planning system down to execution, first addressing the making of assignments (goal setting, division of labor), then acquisition and management of shared resources, and finally the design of work methods.

We advocate involving direct workers in the planning and execution of experiments in work methods design, a practice we have titled First Run Studies. We also advocate extending the

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concept of rework to include incompletions and rehandling, in order to draw attention to the benefits of task completion and the avoidable costs of rehandling materials.

Implementation of lean production concepts and techniques in the construction industry is the way to the future, but following that path requires letting go of traditional thinking. We hope to have shown how to make the first steps on the way.

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