CIB W96 Architectural Management

Atlanta, 19-20 May 2000

MANAGING WORK FLOW ON DESIGN PROJECTS

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Abstract:

Project management has neglected production. Its theory and techniques are devoted for the most part to the formation, award, and administration of contracts. Production management has equally neglected projects. Developed in manufacturing, theories and techniques of managing production focus almost entirely on the task of making multiple copies of a single design. Management of project-based production systems lies at the intersection of these two disciplines, is enormously important, and has been until recently almost entirely undeveloped.

Its development has occurred in connection with product development processes. Concurrent engineering is a term closely associated with the advent of new production management concepts and techniques, known variously as lean production, agile manufacturing, mass customization, etc. Regardless of the term, the underlying concept is of an integrated design of product and process; a concept in which designing and making are themselves integrated, as opposed to the traditional sequential processing. Consequently, production control techniques such as pulling information forward through the engineering process belong to the realm of concurrent engineering and to the theory and practice of project-based production systems.

A new project delivery process is emerging in the AEC industry. Its first module is production control, dedicated to the management of work flow between specialists. A new production control system, termed the "Last Planner" system, has been successfully applied both to construction and design phases of AEC projects. The paper describes its application to design, which is considered to be essentially a value generating process.

Keywords: Design, production control, value, work flow

INTRODUCTION

Project management has neglected production[1]. Its theory and techniques are devoted for the most part to the formation, award, and administration of contracts. Koskela and Huovila (1997) understand this phenomenon to be the result of a distortion in production theory, namely, exclusive focus on the goal of task completion and neglect of the equally vital goals of value generation and work flow management. An additional factor is arguably the desire to expand project management's domain beyond production altogether. The designing and making of artifacts is incidental to current project management theory, which lays claim rather to any type of 'problem solving' that occurs in teams.

Production management has equally neglected projects. Developed in manufacturing, theories and techniques of managing production have focused almost entirely on the task of making multiple copies of a single design. That changed with the emergence of the Toyota Production System[2]. Under the title "Lean Production", the system of production developed at Toyota became a model for a new way of designing and making things alongside the traditional craft and mass production systems[3]. One essential feature of this new approach was its focus on the system rather than component processes. Designing and making were no longer to be conceived as separate processes executed by different people with different interests and objectives.

This was a radical departure from mass production. The development of new products was traditionally done through a highly sequential process, the consequence of which was long cycle times, high rates of rework (high cost), and high risk of not meeting customer needs (poor quality). The cause of this poor performance was late recognition of the needs of those such as manufacturers and service providers, not to mention the neglect by upstream design and engineering disciplines of downstream disciplines.

Unlike the manufacturing for which it is the prerequisite, product development takes the form of projects. Unlike content-neutral project management, product development is centrally a production process. Further, given the influence of Toyota, production is conceived to include both designing and making. Repetitive production of multiple copies begins only after the production of the first copy; i.e., the prototype for both product and process. Thinking and practice in product development is now central to developing concepts and techniques for the management of project-based production systems. To mention but a few, contributions to this field include Clark and Fujimoto (1991), Reinertsen (1997), Sobek et al. (1999), Ulrich and Eppinger (1999), Ward et al. (1995), and Yazdani et al. (1999).

One of the challenges facing this new discipline is how to manage work flow, especially in the design phases of projects. Manufacturing has historically been able to govern work flow by the routing of intermediate products through a sequence of machining operations or assembly steps. In the architectural/engineering/construction industry (AEC), such routings are done through planning and control systems, with little reliance on the physical layout of work stations or the sequence and timing control of assembly lines. Consequently, the formulation of assignments is vital to the management of work flow on AEC projects. This paper proposes a system of production control, the "Last Planner" system (Ballard, 1994; Ballard and Howell,

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[1] Howell and Ballard, 1996b
[2] Ohno, 1988
[3] Womack et al.,1990; Womack and Jones, 1996

1997; Koskela et al., 1997; Miles, 1998; Ballard, 1999), which has been successfully applied both to the construction and design phases of capital facilities projects. The paper describes its application to design through a case study conducted during 1998 and subsequently incorporated into the PhD thesis of the author[4].

NEXT STAGE

Next Stage Development was created to design, build, and operate a series of 7,000 seat enclosed amphitheaters in various U.S. cities, accommodating Broadway shows and musical entertainment with amplified sound. Its first project was the Texas Showplace, located in Dallas, Texas. 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.

The general contractor and equity participant in Next Stage Development is Linbeck Construction, a founding member of the Lean Construction Institute, which was cofounded by the author and Greg Howell in August, 1997. Next Stage's management chose to implement elements of "lean thinking" in the design and construction of its facilities, specifically including the Last Planner method of production control. A Kickoff Meeting was held for the production team May 19-21, 1998 in Houston, Texas and 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 production of the design.

After the Kickoff Meeting, the design process continued, initially with a target completion date of 11/15/99. However, after roughly the middle of August, 1998, delays in arranging equity financing and performance commitments caused the construction start and end date to slip ever further out, until the project was finally suspended indefinitely.[5]
The design process was managed primarily through biweekly teleconferences. Tasks needing completion within the next two week period were logged as Action Items (Figurre 1), with responsibility and due date assigned. Tasks needing completion beyond the next two week period were logged as Issues. Design decisions were recorded in a Design Decisions Log. When action items were not completed as scheduled, reasons were assigned from a standard list (Figure 2) and a new due date was provided.

[4] Ballard, 2000. This paper reproduces in large part Ch. 6 of the author's PhD thesis.
[5] Design of the Texas Showplace was resumed in February, 2000.

Linbeck Next Stage Development
The Texas Showplace

Action Items Log

As of December 2, 1998 Project Progress Meeting — Revised: 12.14.98

Date Originated-Item No.	*Item Description*	*Action By*	*RNC*	*Date Required*	*Date Completed*
A. Site/Civil					
	Texas Accessibility Standards:				
AA07.01.98.01	• Provide TAS requirements to ELS	HA		07.07.98	07.07.98
AA07.01.98.02	• Identify preliminary and final TAS review process.	ELS		07.14.98	07.14.98
AA07.01.98.03	Resolve building storm/sanitary *site collection points* and pipe inverts; still lacking inverts. *Coordinate profiles with water line surrounding building to be deeded to City*.	CHPA/HA/ *LCC/TSPH*	2	07.10.98 07.31.98	08.02.98
AA07.01.98.04	Develop site and parking lighting *compatible with Lone Star Race Park* for site plan submission for Planning and Zoning approval *(Control Road "B")*.	TEE/*FE/ HA*	6	07.14.98 08.12.98	08.12.98
AA07.01.98.05	Provide color rendering for submission for Planning and Zoning review/approval; resolve landscape issues (IA07.01.98.05).	ELS	7	07.14.98 07.27.98	07.27.98

Figure 1: Action Items Log (excerpt)

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 or the Devil
9. Project changes
10. Other

Figure 2: Next Stage-Reasons for Noncompletion

PPC AND REASONS

The percentage of action items completed was tracked and published biweekly (Figure 3).

Week	7/1/98	7/15/98	7/29/98	8/12/98	8/26/98	9/9/98	9/23/98	10/7/98	10/21/98	11/4/98
4 week moving ave.				57%	60%	63%	64%	58%	57%	55%
PPC	46%	50%	63%	71%	57%	61%	68%	47%	54%	54%
Tasks Completed	28	33	48	37	29	36	26	20	26	20
Tasks Planned	61	66	76	52	51	59	38	43	48	37

Figure 3: PPC Data

The number of tasks or action items completed was divided by the number planned each two week period and a percentage calculated. For example, In the two week period beginning 11/4/98, 37 action items were assigned, of which 20 were completed, which amounts to 54%. In addition, a four week moving average was calculated in order to smooth the data and hopefully reveal trends. Through 11/4/98, the four week moving average was 55%, calculated by averaging the previous four weeks data. The columns in Figure 4 represent the aggregate average completion percentage for all teams for each two week planning periods. PPC rose from an initial measurement of 46% to above 70% in the 4th two week planning period. Subsequently, perhaps connected with the end date slipping out, PPC rose and fell in a generally downward trend, winding up around 55%.

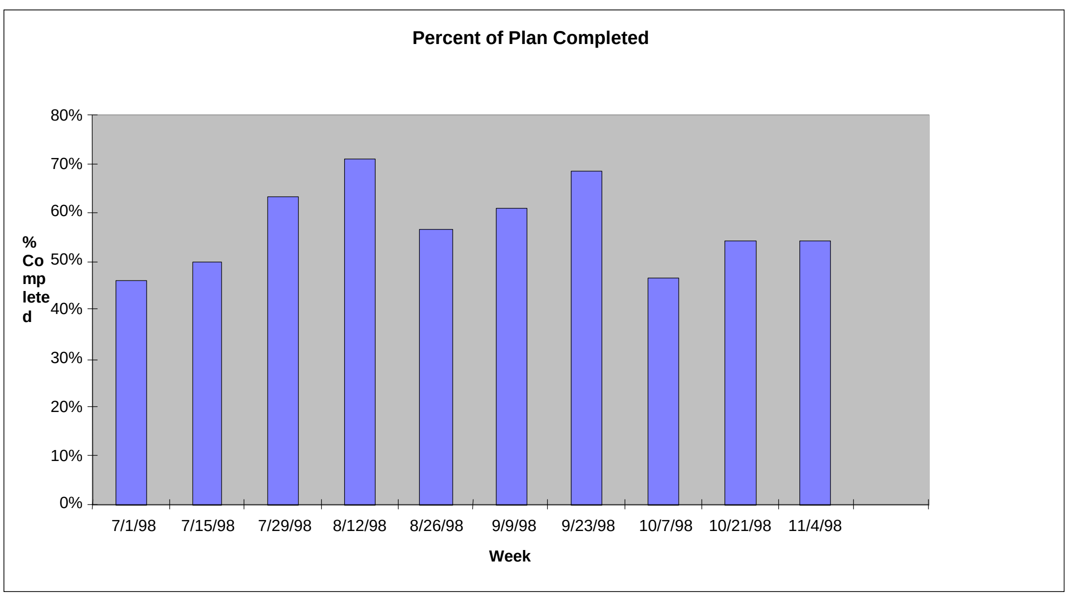

Figure 4: PPC Chart

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	85%

Figure 5 exhibits the reasons categories used on the project and the frequency of reason by category each week of the data collection period. It is apparent that three categories dominate; i.e., lack of prerequisite work, insufficient time, and conflicting demands, in that order. Unfortunately, such categories reveal little about root causes, so do not facilitate corrective action. The Activity Definition Matrix and associated analytical guides were developed in response to this problem.[6]

Reasons/ Date	**7/1/98**	**7/15/98**	**7/29/98**	**8/12/98**	**8/26/98**	**9/9/98**	**9/23/98**	**10/7/98**	**10/21/98**	**11/4/98**	**12/2/98**	**All Weeks**
Decision	1	1	3	1	1		1	3	3	3		17
Prerequisites	7	16	8	2	7	10	3	5	6	4		68
Resources		1	2	0								3
Priority Change	3	4	6	1		1						15
Insufficient Time	5	6	1	6	6	10	8	10	6	4		62
Late start		4	1	1				1		1		8
Conflicting Demands	7	7	3	1	7	2		4	6	5		42
Acts of God			3	0								3
Project Changes				0					1			1
Other				2	1							3

Figure 5: Reasons for Noncompletion

PLAN FAILURE ANALYSIS

In October, 1998, the Site/Civil team agreed to select five plan failures and analyze them to root causes by asking "Why?" up to five times in succession. Review of Site/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. This sample also raised significant questions about adherence to quality requirements for assignments. For example, why did Site/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?)?

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.

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[6] Ballard, 1999. See also the Glossary of Terms at <www.leanconstruction.org>.

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 is 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 borrow 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 Texas Utilities. 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 TU Electric due to the absence of key people." Failure to specify who was to do what prevented requesting a specific commitment from TU Electric. If TU Electric refused to make that commitment, Civil could have refused to accept its action item until receipt of their input. If TU Electric had committed, Civil might have been informed when key people were absent.

Low PPC was attributed by some members of the management team to the lack of a firm construction start date, and the consequent use by design participants of resources on more urgent projects. The high percentage of plan failures due to conflicting demands appears to support this claim. However, this reasons analysis exercise and observation of teleconferences suggests that contributing causes were failure to apply quality criteria to assignments and failure to learn from plan failures through analysis and action on reasons.

THE NATURE OF THE DESIGN PROCESS AND IMPLICATIONS FOR PROCESS CONTROL

Within the lean construction movement, production is conceived as the integrated designing and making of artifacts. 'Making' has the job of conforming to requirements. Design produces those requirements. If there were complete predictability of design's output, design would generate no value. Consequently, variability plays a different role in design as opposed to construction (Reinertsen, 1997). This raises the question of the type of control appropriate to generative processes like design.

Let us first consider more closely the nature of the design process. Consider the task of doing a piping layout for a given area versus the task of producing a piping isometric drawing. In order to do the layout, the designer must know where other objects are located in the space. She must know locations, dimensions, material compositions, and operating characteristics of end-points. Some of these constraints and conditions of her problem will not change. Some may well change in response to her difficulty achieving a satisfactory solution. Consequently, the final piping layout will emerge from a process of negotiation and adjustment, which cannot be determined in advance.

An example from the Next Stage case illustrates the point. The design team was faced with selecting the theater seats, which might appear at first glance to be a fairly simple problem of applying criteria derivative from the general level of 'quality' desired in the facility balanced against the purchase price of the seats. In fact, the criteria are far from straightforward or simple. Seats can either be mounted on the floor or riser-mounted, the choice between them being interdependent with the structural pads for the seats, which in turn constrains choices regarding the return air plenum, which can either go through the floor or risers. That choice in turn impacts cleaning time and cost: how quickly can they set up for the next show? As it happens, chairs come with different types of upholstery, which can change the amount and type of smoke to be removed.

Components such as chairs may not be offered in all varieties; e.g., although we might prefer a riser-mounted chair, such chairs only come with a certain type of upholstery that would overload current plans for smoke removal. Everything's connected to everything. We are designing one whole, so parts have the logic of part to whole, potentially conflicting properties, etc. Product design decisions can impact the entire range of 'ilties': buildability, operability, maintainability, etc. In this case, delay in selecting chairs delayed final determination of structural geometry, which in turn delayed completion of the 3D model of the structure.

Overly 'rationalistic' models of problem solving processes are inappropriate for the design process, which rather oscillates between criteria and alternatives, as in a good conversation from which everyone learns[7]. In their *Soft Systems Methodology*, Checkland and Scholes offer the same critique of 'hard' systems thinking as applied to action research; i.e., such thinking failed because it assumed that objectives were defined and the task was simply to determine how to achieve those objectives. Rather than conceiving the project process to consist of determining design criteria then applying those criteria in the production of the design, design should be conceived as a value generating process dedicated to the progressive determination of both ends and means.

Specialization is essential for successful design. No one can understand in detail all the different types of criteria, constraints, and alternatives that might be considered. However, specialists tend toward suboptimization because they become advocates for what they understand to be important, often without sufficient understanding of what else is important[8].

Given this value generating nature of design, controls based on the model of after-the-fact detection of negative variances inevitably focus entirely on controlling time and cost, leaving design quality as the dependent variable (p.199, Reinertsen, 1997). What is needed is a production control system that explodes tasks near in time to their performance, one that counteracts the tendency to suboptimization by explicitly focusing common attention on design criteria, one that facilitates value generation and information flow among specialists; i.e., the Last Planner system.

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[7] See Conklin and Weil's "Wicked Problems" for another presentation of this idea.

[8] See Lloyd, et al., 1997 for the tendency to see one's task in terms of one's 'product' rather than in terms of participating in an iterative, interactive, evolving process.

EVALUATION OF LAST PLANNER IMPLEMENTATION

Four Next Stage project managers evaluated implementation and effectiveness of the Last Planner system in response to a short survey produced by the author. The four rated Last Planner effectiveness relative to traditional forms of project control 5, 5, 6, and 7 on a scale of 1 to 7. However, examination of actual practice on the project suggests tremendous opportunity for further improvement.

Plus: -attempted to select only assignments needed to release other work
-measured and communicated PPC and reasons
Minus: -minimal preparation of participants
-no work flow control and make ready process
-poor definition of assignments
-no action on reasons

Each action item was determined completed or incomplete, and reasons were selected from the list of categories. However, no analysis of reasons was done, either during or between teleconferences. There was also no apparent attempt to act on the reasons that were identified. Work selection was tested against the 'pull' requirement by asking why it was needed to be done now, but rarely were assignments rejected for unsoundness or size. Frequently, it appeared that assignments were accepted with the implicit commitment to do one's best rather than an explicit commitment to complete based on knowledge of the execution process, understanding of relevant criteria, identification of needed informational inputs, and allocation of necessary resources. Assignments were not systematically exploded into an operations level of detail and, consequently, the interdependence of assignments was often not understood.

In summary, Next Stage did not fully change its production control system from the traditional, and either did not implement or did not implement completely the elements of the Last Planner system; i.e., work flow control, production unit control, and a learning process. Nonetheless, the Next Stage experience was valuable for its contributions to learning and further development of the Last Planner System. Much has been learned and developed since the Next Stage case. Opportunities and needs for the future are well summarized by Ed Beck in the following response to the author's survey question: *What improvements in LPS (Last Planner System) objectives, procedures, or implementation do you suggest for future projects?*

- Client buy-in at the user level
- Complete orientation of all participants
- A simpler value stream
- A more systematic format
- A better list of reasons to categorize planning failures
- Utilization of the 5 why's
- Utilization of the 6 week lookahead
- A more expeditious way to meet and create a weekly plan
- Periodic revisiting of the value stream
- Publishing graphs and reasons and answers to questions to all
- A tune-up meeting at strategic times along the course of the project
- Periodic assessment comparing what is happening versus what normally happens.

CONCLUSION

The Next Stage case study reinforced the need to improve plan reliability in design processes and also suggested improvements to the production control system required to achieve better plan reliability.

-make sure project management understands the production control system and its objectives
-provide additional training to participants
-include ‘puller’ on action item log
-explode scheduled activities using the Activity Definition Model; i.e., specify the process to be used to complete an assignment, the directives or criteria to which it must conform, the prerequisite work needed from others, and the resources necessary to do the work.
-establish a lookahead window with screening criteria for advancement of scheduled tasks.
-track the status of assignments as they move through the lookahead window
-adopt a sizing criterion for assignments that consistently demands less output from production units than their estimated capacity to accommodate variability in capacity. (This seems especially important for design. Other studies suggest that routinely 20% of capacity is used to do needed but previously undefined work each week.)
-improve the categorization of reasons and reasons analysis to facilitate implementation of the learning process, which consists of: analyze reasons to actionable causes, assign or take corrective action, and record results.

Further research is needed on controlling design work flow. This author and colleagues are working to integrate the Last Planner system of production control with other elements of design project management; i.e., post-occupancy evaluation, project definition/programming, least commitment strategies for design decision making, pull scheduling, shared geometries, etc. The overall approach is driven by the intent to make value generation and work flow control fundamental objectives of design projects.

ACKNOWLEDGEMENTS

Documentation and learning from this case study was possible because of Linbeck Construction's generosity and courage in making project meetings and data available to this author and in daring to try new ways of managing projects.

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