CAN PULL TECHNIQUES BE USED IN DESIGN MANAGEMENT?

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ABSTRACT

Concurrent engineering has a longer history in manufacturing than it does in construction. In manufacturing, it is closely associated with the advent of new production management concepts and techniques, known variously as lean production, agile manufacturing, etc. Concurrent engineering is the name used to signify the structuring and management of product development processes within the new management philosophy. Consequently, production control techniques such as pulling information forward through the engineering process belong to the realm of concurrent engineering.

Pull techniques for managing work flow were developed in manufacturing and have recently been applied to construction. Can pull techniques be used in the management of design as well? Pull techniques are explained and obstacles to their application in design are reviewed. Benefits and preconditions of pulling are also presented. Concepts and techniques are proposed to overcome obstacles and satisfy preconditions for pulling. Future research is suggested in the application and testing of these concepts and techniques.

Keywords-Design, production control, pull, work flow

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INTRODUCTION

Concurrent engineering is understood in a variety of ways. The essential features of concurrent engineering assumed in this paper are the integration of product and process design, and the 'simultaneous' consideration of all design criteria, deduced from the needs of the various users of the product or participants in the process. Traditionally, product and process were designed sequentially, by different parties. The design of the product was done by one set of functional specialists, architects and design engineers from the various relevant disciplines. The design team then made a handoff to another set of specialists, general and specialty contractors, for design of the process. "Concurrent" indicates the intent to integrate those teams and to integrate the production of product and process design.

The design, both of product and process, can be understood as a type of production, and so requires production planning and control. Design and engineering planning and control has previously been dominated by traditional project management techniques such as CPM scheduling and controls accounting. This paper is part of an extension of the new manufacturing philosophy and thinking to architectural/engineering/construction projects conceived as product development processes. A primary technique of the new production management thinking is pull.

Theorists of manufacturing management distinguish push and pull as two primary techniques for the management of work flow (Hopp and Spearman, 1996). Push-based systems release work into production processes based on pre-established delivery dates. Pull-based systems allow work into production processes based on the state of the process. For example, MRP systems are push systems. The classic criticism of MRP is that it assumes infinite capacity; i.e., SHOULD disregards CAN.

A simple type of pulling is to limit the amount of inventory that can be placed between manufacturing work stations, for example, by providing a bin or marking a space on the floor. Consequently, materials can be sent forward to the next workstation only when the inventory space is empty. This is an instance of pulling because it meters work flow based on the amount of work-in-process inventory. Inventory-based systems can be applied to extended production lines consisting of multiple work stations. Other systems, such as the various forms of kanban, use more defined signals from 'customer' to ‘supplier’. In those instances, readiness for what is pulled is directly communicated to the ‘supplier’. Pull signals can also be communicated over an extended production chain. In general, we can say regarding pull systems that CAN overrides SHOULD.

In the construction industry, work flow is managed predominately through schedules, which are sometimes followed slavishly, in disregard of actual capacity or availability of prerequisites. More rationally, schedule adjustments are made in the design office or at the construction site based on the readiness and need for the next work activity to be performed. The extreme in the pull direction is to manage by the seat of your pants, and entirely disregard the project master schedule except for contractual obligations such as end dates. It would appear reasonable that a combination push and pull system of work flow control is appropriate for the design and construction of capital facilities, given the long lead times for acquisition and completion and the enormous amount of coordination needed among the many specialists involved (Tommelein and Ballard, 1997b).

Some materials and selected services have traditionally been pulled to construction sites as needed; ready mix concrete being perhaps the most obvious example. Within construction sites, materials are routinely pulled from stores to the place where they are to be installed. Attempts have been made to pull fabricated items such as structural steel or pipe spools through the fabrication process and onto job sites (Tommelein, 1997).

The question considered in this paper: Can pull techniques be used also in the design and engineering phase of projects?

1 POTENTIAL BENEFITS OF PULLING IN DESIGN

The potential benefits of pulling in design are the same as those in construction and manufacturing; i.e., to manage the sequence and rate of production so as to provide maximal customer value while conforming to stakeholder needs and demands.

Pulling is a technique for matching up the various elements needed to actually perform work. Exclusive reliance on schedules crafted far in advance of doing the work inevitably degenerates into doing that work for which the elements happen to be available, or else doing work in the absence of some elements, which degenerates quality or adds cost or time.

Failure to supplement schedule-push with pull techniques effectively deprives designers of planning as a weapon for causing the desired future. When the delivery of prerequisite information, approvals, or design criteria can be known beforehand, designers and engineers can make preparations for doing specific tasks and consequently can do them better and more efficiently.

2 PRECONDITIONS FOR PULLING

The fundamental prerequisite for pulling is a window of reliability greater than supplier lead time (Ballard, 1998). The "window of reliability" is that amount of time in advance that we can accurately predict future events. If an architectural or engineering firm only completes 70% of items on its weekly work plan, and if those plans are formed at the end of the prior week, their predictability of future events is only 70% one week ahead.

"Supplier lead time" is the time from issuing an order to delivery of that order. If it takes two weeks to fabricate and deliver a pipe spool once an order is issued to the fabricator, the lead time is two weeks. When supplier lead time exceeds the relevant window of reliability, supplier processes are divided into parts and inventory buffers are placed within the window of reliability.

Although not ideal, this is an acceptable solution for standard components. It is not ideal because of the risk of damage, increased handling costs, and cash tied up in inventories. It is acceptable when there is no better alternative and because standard components are almost certain to be needed and used, even if not immediately.

It is quite otherwise for custom products. Stockpiling them in advance clearly runs some risk of design obsolescence, in addition to the issues listed above for standard components. However, the far greater problem is the waste of overproduction (Ohno, 1988); i.e., the use of capacity to produce something not needed as opposed to something that is. Pulling is the technique for insuring that capacity is used to do the work that maximally progresses a project toward its goals, given the actual state of the project and of its production systems.

3 OBSTACLES TO PULLING IN DESIGN

One obstacle to the application of pull techniques to design appears to be the nature of the design process itself. Design criteria and possible design solutions are reciprocally interdependent, each evolving from the other as design progresses (Roozenburg and Eekels, 1995; Chandrasekaran, 1992; see also Austin, et al., 1998, for a description of detailed design and its complexity). As a result, it is difficult to know very far in advance about process logic and predescessors because that is developed as each step is taken.

It could then be claimed that, *aside from the physical production tasks of design, such as production of drawings, design tasks cannot be fully understood in advance of their execution, and so cannot be made ready through pulling. As a result, such assignments cannot be evaluated against quality criteria of soundness because the inputs necessary to their completion cannot be identified before accepting and initiating the assignment. On the other hand, experience of previous tasks can serve as a rough cut guide to estimating durations. Over multiple tasks, such averages approximate actuals, especially since the design process can be truncated when necessary by accepting a solution in hand and not continuing to pursue superior solutions. Consequently, the type of control appropriate to design is not the same as the type of control appropriate to construction. In design, we should push designers through a sequence of tasks constrained by target dates for issuing deliverables, truncating the search for superior solutions when necessary in order to hold the design budget and schedule.*

Consider the task of producing a piping isometric drawing versus the task of doing a piping layout for a given area. 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.

This claim is for the adequacy of push-only systems of design production control. In contrast, consider the following hypothesis*: If the designer knows what work is upcoming, he/she (or others) can prepare for it: better understand the task, make ready: pull prerequisites, resolve conflicting directives, collect information. Also, design managers can better match capacity to load, reducing idle resource time and overproduction, and can avoid having too many or too few specific skill sets to do the available work.* There are obviously significant benefits to be gained by resisting a push-only system.

But there is yet another obstacle to the application of pull techniques in design; i.e., the way design has come to be managed and the associated habits of thought and action. For the most part, project management concepts and techniques such as CPM scheduling and earned value analysis have been applied to design management (Diekmann and Thrush, 1986; Gray, et al., 1994). These project management tools tend to neglect flow and value and focus entirely on conversion processes (Koskela and Huovila, 1997). Their ineffectiveness in design management has been recorded by Koskela et al., 1997; and also by Tommelein and Ballard (1997a).

Lacking contrary evidence, it may well be true that pull techniques are inapplicable to design management. But it is clear that their absence results in considerable waste and inefficiency, making it important for us to seek ways to overcome these obstacles. Part of the solution will be concepts and tools that facilitate the management of work flow and value generation in the design process. Some attempts have previously been reported under the banner of the Last Planner system of production control (Ballard, 1997; Koskela et al, 1997; Ballard and Koskela, 1998; Miles, 1998.) The next section provides a brief history of Last Planner. Following that is a previously unpublished case, the results of which are pertinent to this paper.

4 A BRIEF HISTORY OF THE LAST PLANNER SYSTEM OF PRODUCTION CONTROL

The functions of production management systems are planning and control. Planning establishes goals and a desired sequence of events for achieving goals. Control causes events to approximate the desired sequence, initiates replanning when the established sequence is either no longer feasible or no longer desirable, and initiates learning when events fail to conform to plan (Ballard, 1998). When environments are dynamic and the production system is uncertain and variable, reliable planning cannot be performed in detail much before the events being planned. Consequently, deciding what and how much work is to be done next by a design squad or a construction crew is rarely a matter of simply following a master schedule established at the beginning of the project. How are such decisions made and can they be made better? These questions were the drivers of initial research in the area of production unit level planning and control under the title of the "Last Planner System", a summary report of which is included in Ballard and Howell (1997).

A key early finding was that only about half of the assignments made to construction crews at the beginning of a week were completed when planned. Experiments confirmed the hypothesis that failures were in large part a result of lack of adequate work selection rules (these might also be called work release rules). Quality criteria were proposed for assignments regarding definition, sequence, soundness, and size. In addition, the percentage of assignments completed was tracked (PPC: percent plan complete) and reasons for noncompletion were identified, which amounted to a requirement that learning be incorporated in the control process.

- Definition: Are assignments specific enough that the right type and amount of materials can be collected, work can be coordinated with other trades, and it is possible to tell at the end of the week if the assignment was completed?
- Soundness: Are all assignments sound, that is: Are all materials on hand? Is design complete? Is prerequisite work complete? Note: During the plan week, the foreman will have additional tasks to perform in order to make assignments ready to be executed, e.g., coordination with trades working in the same area, movement of materials to the point of installation, etc. However, the intent is to do whatever can be done to get the work ready before the week in which it is to be done.
- Sequence: Are assignments selected from those that are sound in the constructability order needed by the production unit itself and in the order

needed by customer processes? Are additional, lower priority assignments identified as workable backlog, i.e., additional quality tasks available in case assignments fail or productivity exceeds expectations?

- Size: Are assignments sized to the productive capability of each crew or subcrew, while still being achievable within the plan period? Does the assignment produce work for the next production unit in the size and format required?
- Learning: Are assignments that are not completed within the week tracked and reasons identified?

As a result of applying these criteria, plan reliability (the percentage of assignments completed) increased, and with it, crew productivity also increased. (Ballard and Howell, 1997)

The use of explicit work selection rules and quality criteria for assignments was termed “shielding production from upstream uncertainty and variation.” (Ballard and Howell 1994) Such shielding assures to a large degree that productive capacity is not wasted waiting for or looking for materials and such. However, because of its short term nature, shielding cannot avoid underloading resources when work flow is out of sequence or insufficient in quantity. Further, reasons for failing to complete planned assignments were dominated in most cases by materials-related problems. Consequently, a second element of the Last Planner System was created upstream of weekly work planning to control work flow and to make assignments ready by proactively acquiring the materials and design information needed, and by expediting and monitoring the completion of prerequisite work (Ballard, 1997).

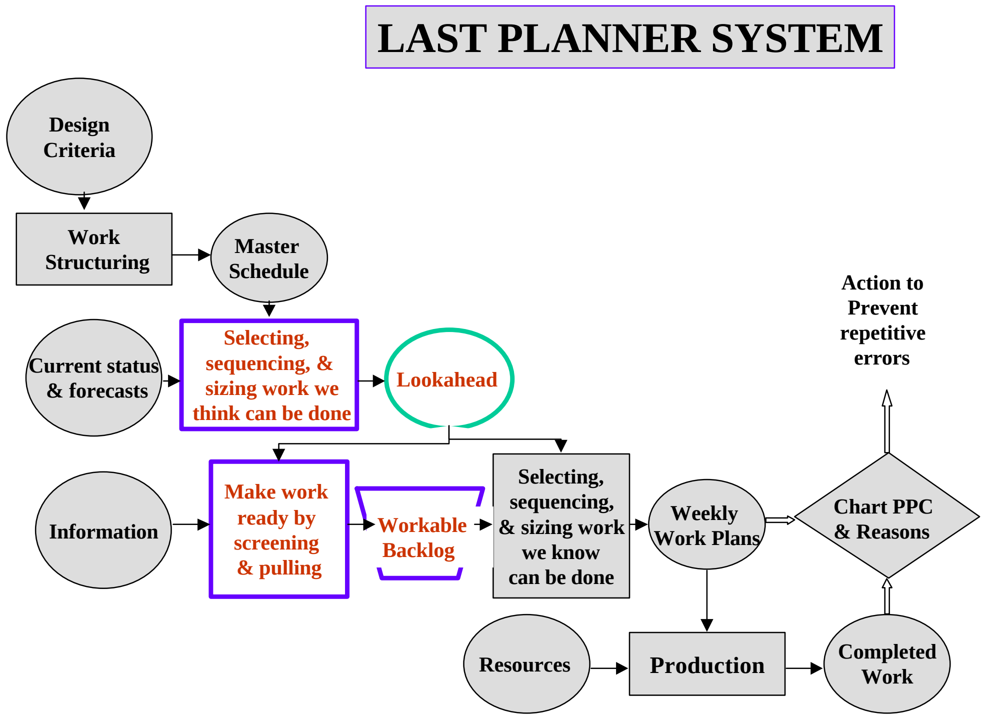

Figure 1-Last Planner System: Work Flow Control

The tool for work flow control was lookahead schedules. The construction industry commonly uses lookahead schedules to focus supervisors' attention on what work is supposed to be done in the near future. Experiments in work flow control were performed using lookahead schedules in a very different way than had been traditional. A set of rules was proposed for allowing scheduled activities to remain or enter into each of the three primary hierarchical 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 to be successfully executed.

In addition, a set of objectives was proposed for the lookahead process:

- 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

Lookahead windows are structured such that week 1 is next week, the week for which a weekly work plan is being produced. Week 2 is two weeks in the future. Week 3 is three weeks in the future, and so on. Early data indicated that plans as close to scheduled execution as Week 2 only contained about half the assignments that later appeared on the weekly work plans for that week.

PROJECT: Pilot **5 WK LOOKAHEAD**

ACTIVITY	1/13/97						1/20/97						1/27/97						2/3/97						NEEDS
	M	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	M	T	W	T	F	S	
Scott's crew																									
"CUP" AHUs-10 CHW, 2 HW	X	X	X	X	X		X	X	X	X	X		X	X	X	X	X								CHW delivers 1-8-97 thru 1-13.HW delivers 1-20.
Punch, label, & tag AHUs															x	x	x								Materials on site
Ron's crew																									
DI Steam to Humidifier			x	x	x																				Materials on site
DI Steam Blowdown	x	x																							Check material
DI Steam Cond. to coolers (13)							x	x	x	x	x		x	x	x	x	x		x	x	x				Material on site
Charles' crew																									
200 deg HW 1-"H"	x	x	x																						Matl delivery 1-8-97
200 deg HW 1-"B" & 1-"D"							x	x	x	x	x		x	x	x	x	x								Release matl for 1-15-97
1st flr 200 deg HW guides & anchors	x	x	x	x	x								x	x	x	x	x								Material on site. Need West Wing flr covered.
Richard's crew																									
2-"A" HW & CHW	x	x	x	x	x																				Control valves for added VAV coils
CHW in C-E-G tunnels	x	x	x	x	x		x	x	x	x	x		x	x	x	x	x								Need tunnels painted & release materials
Misc FCUs & cond. drains in "I", "J", & "K" 1st flr							x	x	x	x	x		x	x	x	x	x								Take off & order materials
Punch, label & tag							x	x	x	x	x		x	x	x	x	x								Material on site

Figure 2 - Lookahead Schedule

Week 3's percentage was only 40% (Ballard, 1997). Failures to anticipate assignments appear to result in large part from lack of detailed operations design and consequently could be remedied by incorporating detailed operations design into the lookahead process.

5 CASE STUDY: THEATER PROJECT

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.

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

Table 1: Reasons for Noncompletion

The percentage of action items completed was tracked and published biweekly. The columns in Figure 5.1 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	85%

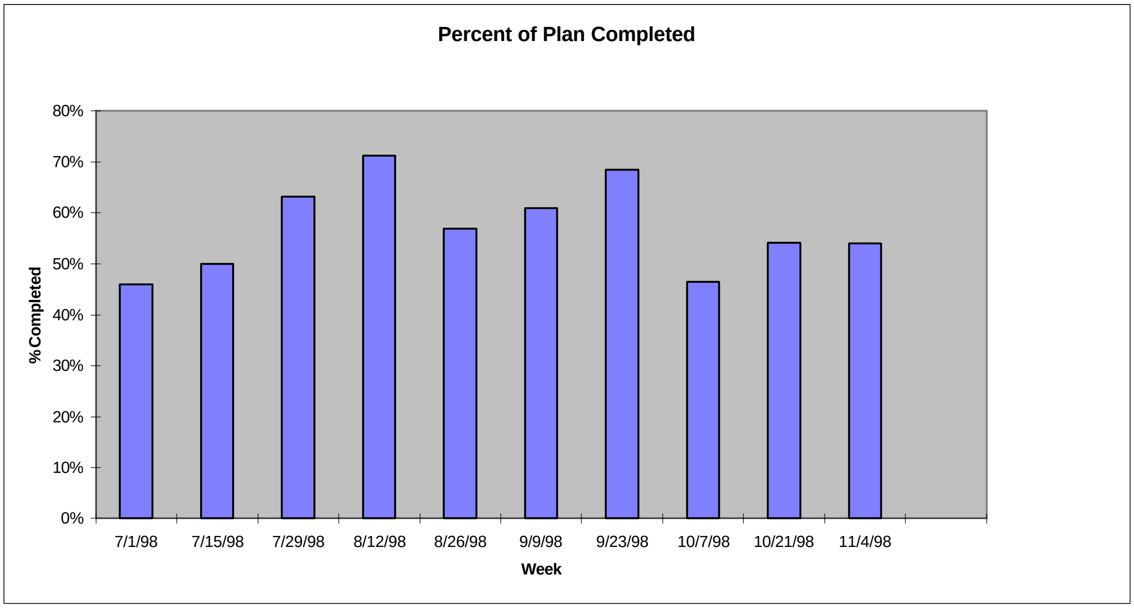

Figure 3 - Percent Plan Complete (PPC)

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?)?

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 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 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. Secondly, 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.

6 ACTIVITY DEFINITION MODEL

As previously noted, the precondition for effective use of pull techniques is a window of reliability greater than supplier lead times. 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 and Huovila, 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.

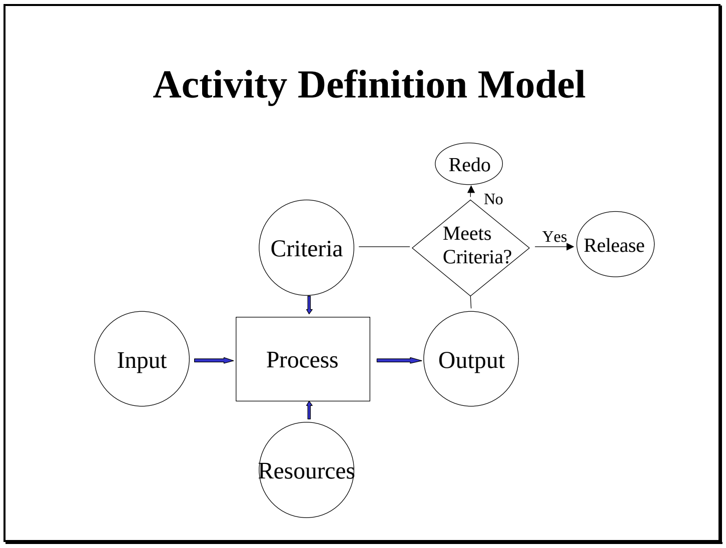

Figure 4 - Activity Definition Model

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 activity is the Output desired. Criteria for that output are specified or actions to specify/clarify are listed. Prerequisite information (Inputs) are noted or actions to request or obtain them 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.

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 both 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.

7 CONCLUSION

It has been proposed that pull techniques can be applied to the management of design. Key to that application is improving plan reliability, for which is proposed use of the Last Planner system of production control. Pulling is an integral part of the Last Planner system, and is facilitated by use of the Activity Definition Model to decompose master schedule design activities into actionable components.

The potential benefits are more reliable work flow across the various 'workstations' found in design, supply, and installation. In addition, pull techniques promise improvement in design productivity, which can be realized in quality improvements or reductions in time or cost.

The primary obstacles to application of pull techniques to design are the developmental nature of the design process and the tradition of managing design with push techniques. Delaying decomposition of design activities until near in time to their scheduled execution is a response to the first obstacle. The second obstacle is to be overcome by demonstrating the effectiveness of combining pull with push. Experimental applications are needed of these concepts and techniques, from which further refinements will inevitably emerge.

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