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LOOK-AHEAD PLANNING: SCREENING AND PULLING

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1. Levels and Functions of Planning

Planning consists of identifying activities and then selecting and ordering them so that they can be executed in the most efficient fashion. Identifying activities means that a project design must be understood in order to be broken down into manageable parts, where each part can be constructed separately yet tie into the project as a whole.

Presumably, the time and effort spent on planning will be offset by time gained in executing the planned work more efficiently. In principle, one could spend too much time on planning, but in the practice of construction engineering and management this seldom is the case. Resources engaged in performing construction work cost hundreds if not thousands of dollars per hour, so savings resulting from increased productivity through better planning easily offset costs associated with creating those plans. We simply do not plan enough. Better planning pays!

The goal of all planning is to make the construction process more manageable. We therefore use the term **production planning** to stress that a construction ***process*** as a whole is to be managed. Similarly, Melles and Wamelink (1993) talk about production control in construction. Production planning can be done at various levels of detail and we propose that at least three such levels be used:

1. Project Planning
2. Look-ahead Planning
3. Commitment Planning

While it is common practice to distinguish various levels of planning, the terms used here (especially look-ahead and commitment planning) refer specifically to planning methods that use lean construction techniques effectively.

1.1. Project Planning

For any one project, multiple interpretations of the design are possible. Multiple decompositions therefore exist, though, especially in more abstract plans, the division of work into parts is largely governed by the nature of the constituent components and their functional or structural role (e.g., concrete footings vs. structural steel). Prevailing industry practices regarding the division of work among specialty contractors (e.g., excavation, mechanical, electrical, vs. roofing) also help delimit the scope of activities. Activities may be further specified in terms of their duration (in project plans, these will be on the order of weeks or months) as well as major resources involved (e.g., pile-driving equipment, cranes). Project-level activities often relate to contract documents, for instance, work that is subcontracted out may be represented as a single activity with no further detail on resources needed.

The sequencing of project-level activities is driven to a large extent by technological constraints. For instance, if one element supports another, then the support is usually built first (Dzeng and Tommelein 1997 give a comprehensive list of such constraints).

In project-level planning, the critical-path method (CPM) is used to calculate the shortest project duration given a set of activities with duration and precedence relationships as input. The method performs a forward/backward pass calculation to compute schedule data including the earliest/latest start of each activity and also their float. Activities with no float are said to be critical.

A project-level plan may have a set start and finish date (e.g., ground breaking and the completion date of construction as defined by the owner who wants to move into the facility at that time). These dates define the maximum project duration, which may or may not correspond to the project duration calculated using CPM. When the calculated and the owner-defined project duration are not one and the same, alternatives to the original plan must be generated that meet the owner's objectives.

The schedule resulting from these CPM calculations is called a **master schedule**. It describes all work to be done on a project, albeit in abstract terms. At the master-schedule level, there is virtually no repetition of activities; all activities are one of a kind. Master schedules are tools for executive-level management to describe in a nutshell what type of construction activities will take place during project execution. They may support long-term coordination or specification of terms of payment. Since providing more detail on activities far into the future is difficult to do accurately for the entire duration of the project, no more detail is provided or desired at this level.

1.2. Look-ahead Planning

Because project-level plans are so abstract, they are not useful to field superintendents and foremen who plan which work will actually be performed in the next one or several weeks to come. Instead, they use bar charts reflecting work to be done in a look-ahead time frame, which often spans three or four weeks. This shorter time span means that fewer project-level activities will be included. In turn, look-ahead plan activities are detailed to describe the actual construction process that will be used (see for instance Odeh 1992 and Tommelein et al. 1994 for a description of integrated project- and process planning). This includes specifying methods and required resources (e.g., a crew of 3 iron workers, a 20 T crane, and structural steel for the first floor) so that **look-ahead plan activities describe assignable and controllable pieces of work**. Because project-level activities are broken down into smaller pieces, look-ahead plan activities tend to be more repetitive and they can be sequenced in several alternative ways. Note however that at this planning stage, **resources are characterized, but they are not specific yet**. The total quantity of resources available on the project, as well as capacity constraints are taken into account at this stage, but no individuals are named.

Look-ahead planning serves multiple purposes (Ballard 1997). First, it helps shape work flow in the best achievable sequence and at the fastest possible rate for meeting project objectives that are within the power of the organization at each point in time. Second, it makes the planner think through activities at a level of detail at which labor and related resources can be made to match work flow and work can be assigned to crews. Third, it helps identify long enough in advance which resources must be available at the site or arrive in the near future for that work to be executable. Using the proper screening procedures, this results in a regularly updated backlog of assignments for each frontline supervisor and crew. Fourth, it allows for highly interdependent work to be grouped together, so the work method can be planned for the whole operation. Fifth, it helps identify operations that must be planned jointly by multiple trades.

To understand the use of the look-ahead time frame, consider the day at which the production plan is updated. If an activity is scheduled to take place in four weeks from that day and it is unlikely or unknown that all its required resources will be available at its scheduled time, then that activity should be moved back in the schedule. It should not be allowed to advance into the third week of the updated look-ahead schedule because there is only a slim chance that it will constitute a workable assignment two weeks later, when it will appear in the first week of the then-current look-ahead. Alternatively, the planner may inquire about resource availability and possibly start pulling (i.e., actively expediting) the resource to make sure it will arrive in time to meet the activity's need. Deciding which activities should be allowed into the four-week look-ahead schedule, and which ones should be allowed to move forward in that schedule, is called **screening** (explained in more detail later).

Most practitioners using look-ahead schedules today will allow activities to advance in the schedule unless there is positive knowledge that it ***cannot*** be done. In contrast to current practice, we are advocating that nothing be allowed to advance unless there is positive knowledge that it ***can*** be done. These two are not complementary. In our approach, the look-ahead time frame helps focus attention on all that will be needed and does so long enough in advance, so that the planner has time to take corrective action if needed and desirable.

Taking corrective action could mean **pulling** resources (explained in more detail later) but it could also mean **rescheduling** activities. In either case, actions pertain to activities that are scheduled four or five weeks out, while there is time to have a positive impact on them. Pulling usually does not instantaneously remedy a problem, as time must be allowed for the pulled resource to work its way through the supply chain from the point of pull to the point of demand. Similarly, rescheduling means that the plan will change. The culprit activity gets delayed but other activities may be re-sequenced and some even move forward in time. If that is the case, time must be allowed to check the new resource needs against availability and start pulling if necessary. The appropriate span of the look-ahead time frame will thus depend on how responsive the supply system is, which is a function of the nature of construction being performed and the players involved. System characteristics may be determined by asking questions such as "How easy vs. costly is it to expedite materials?", "Are materials substitutable by others or are they custom made?", "To what degree can activities be reshuffled in the plan?", and "Does the crew have a large workable backlog?".

Look-ahead planning is thus characterized by a look-ahead time frame combined with screening. When activities are rejected because they fail to meet quality criteria, rescheduling and pull mechanisms come into play. These will be elaborated on later in this paper. A look-ahead schedule is to be updated every week: its first week will then be removed from the plan to become the weekly work plan (see commitment planning) and a week added at the end.

1.3 Commitment Planning

The third level of planning involves assigning specific work to production units (such as individual crews or named workers as appropriate), determining where exactly they will perform their work, and allocating materials and equipment to them as needed. This is done using a **weekly work plan**, prepared a few days prior to the start of the corresponding week. The weekly work plan may also be complemented by a **dynamic layout plan** to depict which crew, materials, and equipment will be where at what time (Tommelein and Zouein 1993).

Ballard termed this assignment task **commitment planning** in deliberate contradiction to the belief that commitments are made at the master schedule and contract level (Ballard and Howell 1994). In current practice, it is all too often the case that managers assign crews to do work that simply cannot be done for various reasons (e.g., incomplete prerequisite work, lack of materials, unavailability of needed equipment). This results in a low rate of completing work as planned. Productivity is hampered because crews are forced to be idle and work gets done out of sequence, and this, of course, defeats the very purpose of planning.

1 WEEK PLAN

PROJECT: Pilot — **FOREMAN: PHILLIP** — **DATE: 9/20/96**

ACTIVITY	Est	Act	Mon	Tu	Wed	Thurs	Fri	Sat	Sun	PPC	REASON FOR VARIANCES
Gas/F.O. hangers O/H "K" (48 hangers)			xxxx Sylvano, Modesto, Terry	xxxx						0%	Owner stopped work (changing elevations)
Gas/F.O. risers to O/H "K" (3 risers)					xxxx Sylvano, Mdesto, Terry	xxxx	xxxx	xxxx		0%	Same as above-worked on backlog & boiler blowdown
36" cond water "K" 42' 2-45 deg 1-90 deg			xxxx Charlie, Rick, Ben	xxxx	xxxx					100%	
Chiller risers (2 chillers wk.)						xxxx Charlie, Rick, Ben	xxxx	xxxx		20%	Matl from shop rcvd late Thurs. Grooved couplings shipped late.
Hang H/W O/H "J" (240'-14")			xxxx Mark M., Mike	xxxx	xxxx	xxxx	xxxx	xxxx		100%	
Cooling Tower 10" tie-ins (steel) (2 towers per day)			xxxx Steve, Chris, Mark W.	xxxx	xxxx	xxxx	xxxx	xxxx		70%	Some work in next week's sched. was included this week.
Weld out CHW pump headers "J" mezz. (18)			xxxx Luke	xxxx	xxxx	xxxx	xxxx	xxxx		100%	
Weld out cooling towers (12 towers)			xxxx Jeff	xxxx	xxxx	xxxx	xxxx	xxxx		60%	Eye injury. Lost 2 days welding time
F.R.P. tie-in to E.T. (9 towers) 50%			xxxx Firt, Packy, Tom	xxxx	xxxx	xxxx	xxxx	xxxx		100%	
WORKABLE BACKLOG Boiler blowdown-gas vents -rupture disks											

Figure 1: 9/20/96 Weekly Work Plan

Commitments by production units to specific activities and tasks are often made weekly. Weekly work plans are effective when they meet specific quality requirements for definition, soundness, sequence, size, and learning.

1. **Definition:** Are assignments specific enough so 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 has been completed?
2. **Soundness:** Are all assignments workable? Are all materials on hand? Is design complete? Is prerequisite work complete? Note that some make-ready work will remain for the foreman to do during the week, e.g., coordination with trades working in the same area, movement of materials to the point of installation, etc. Nonetheless, the intent is to do whatever can be done to get the work ready *before* the week in which it is to be done.
3. **Sequence:** Are assignments selected from those that are sound in priority order and in constructability order? Are additional, lower-priority assignments identified

as workable backlog, that is, are additional quality tasks available in case assignments fail or productivity exceeds expectations?

4. **Size:** Are assignments sized to the productive capability of each crew or subcrew, while still being achievable within the plan period?
5. **Learning:** Are assignments that are not completed within the week tracked and reasons identified?

Quality assignments shield production from work-flow uncertainty. Failure to make quality assignments exposes production units to delays looking or waiting for resources, to multiple stops and starts, and to inefficient construction sequences. Even more destructive to productivity is failure to match work load to labor capacity, which is consistently possibly only by managing work flow through matching resources with production tasks that are otherwise ready. The principles for shielding production from uncertainty were described more fully in Ballard's presentation titled "Shielding Production" and are therefore not further elaborated on here.

2. LOOK-AHEAD PLANS IN THE SUPPLY CHAIN

Look-ahead planning can be performed by any production unit, i.e., any resource that sets a pace for production (e.g., a crew or a machine operator). To illustrate how look-ahead plans of several production units along a supply chain relate to one another, consider the process of constructing an industrial process facility, such as an oil refinery, that involves installing thousands of unique pipe spools. This process is here characterized as comprising two chains of activities: pipe spools are designed and fabricated off-site while work areas are prepared on site. After spools have been shipped to the site, these chains merge upon the installation of spools in their designated areas.

Pipe spools are fabricated off-site according to the availability of design information, the fabricator's plant production capacity, etc. Individual tags denote that each spool has unique properties and each has a designated destination in the facility under construction as shown in the project documents. Spools are subject to inspection before leaving the fabricator's plant. The outcome of the inspection activity is that a spool will be found fit-for-installation with x% likelihood, and, thus, that there will be a problem with 1 - x% of them. In the latter case, the fabricator must rework this spool to rectify the problem, prior to shipping it to the project site.

Concurrently with this off-site materials handling process, construction is under way on site. Crews of various trades must complete their work in each area where spools are to be hung, prior to spool installation. When a specific set of ready-for-installation spools is available on site, and all prerequisite work in the matching area has been completed, the spools can be installed. This yields an area completed, ready for another trade to move into.

Key to understanding the complexity of managing this kind of construction work is realizing that materials are to be installed in matching sets. It is assumed here that tens of spools are needed in each area and that each spool is unique: if one is missing, no other one can be used instead. This management task is made more difficult due to the possible manifestation of uncertainty, here modeled in terms of variability in the duration of fabrication and transportation, and the occurrence of rework.

Figure 2 illustrates a process model for this scenario. The symbols used are those from the STROBOSCOPE computer system for discrete-event simulation (Martinez 1996). Details of the model have been omitted here but they are given by Tommelein (1997a, b, c).

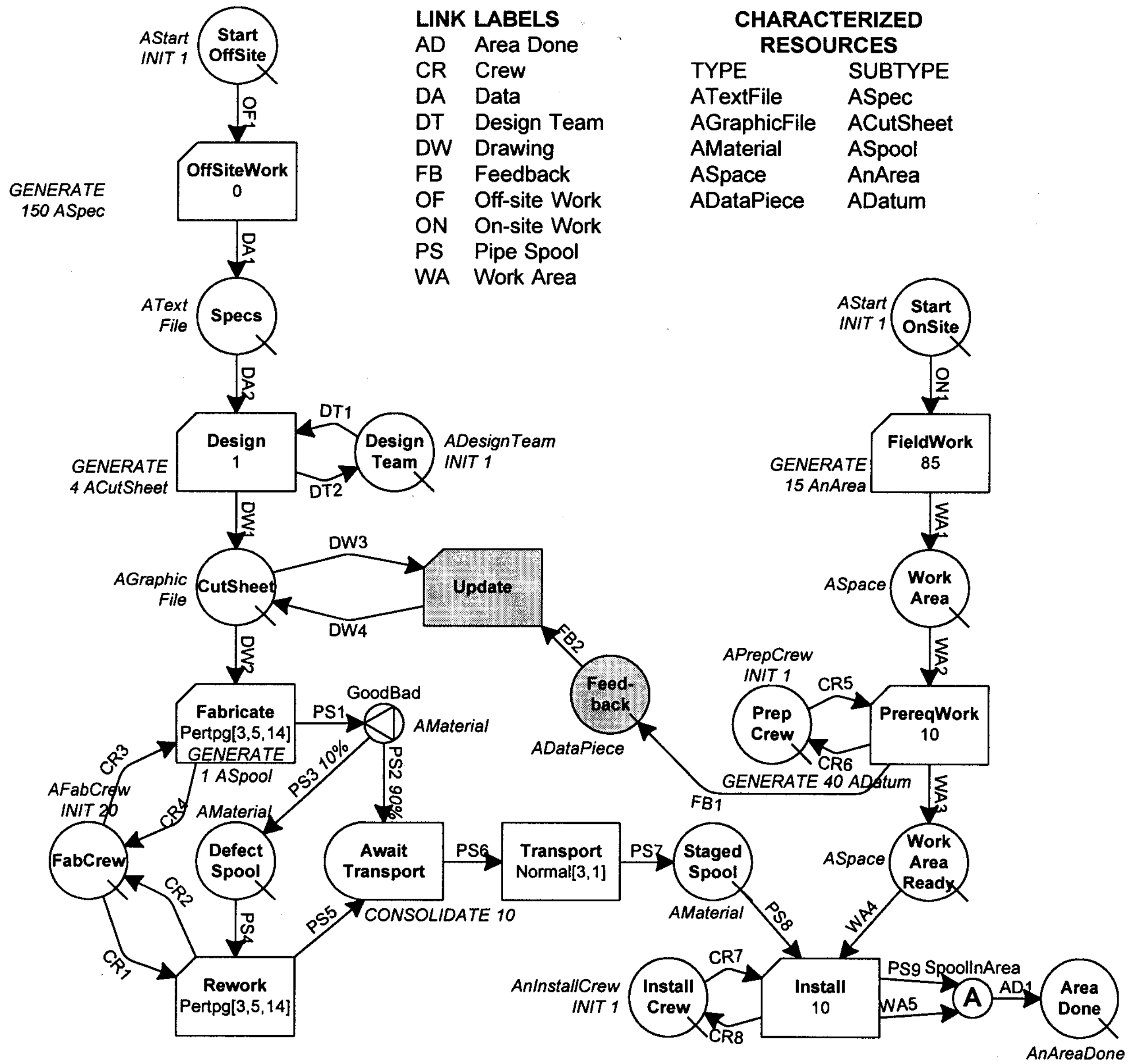

Figure 2: Pipe-spool Process Model

The off-site supply chain shows design, fabrication, and transportation in sequence, followed by on-site installation of pipe spools. Assuming that the designer (Design Team), fabricator (Fab Crew), and installation crew (Install Crew) all create look-ahead plans, Figure 3 illustrates what the relationship among those plans might be. The creation of design documents for an assigned set of spools might be scheduled one week out on the designer's look-ahead plan and be estimated to take 2 days. Fabrication of that same set of spools might be scheduled at the end of the second week out on the fabricator's look-ahead plan, estimated to take 4 days. Finally, installation of those spools might be scheduled in week 4 on the installation crew's look-ahead plan, estimated to take 8 days. The flow of assignments from one production unit to the next along the chain is also shown.

This example assumes that other assignments are performed with different priorities by each production unit along the supply chain. This typically is the case for production units that serve multiple projects simultaneously. Thus, it may not be possible for the assigned set of spools to flow through the entire sequence at its fastest possible rate. In addition, uncertainty about the duration for completing an assignment by one unit may cause the next unit to add a time buffer between the anticipated completion of the assignment by the first and the scheduled start by the second. This reduces the likelihood of the second being delayed due to delay of the first—it is shielded from uncertainty—and in effect makes the two processes more independent, (Howell et al. 1993).

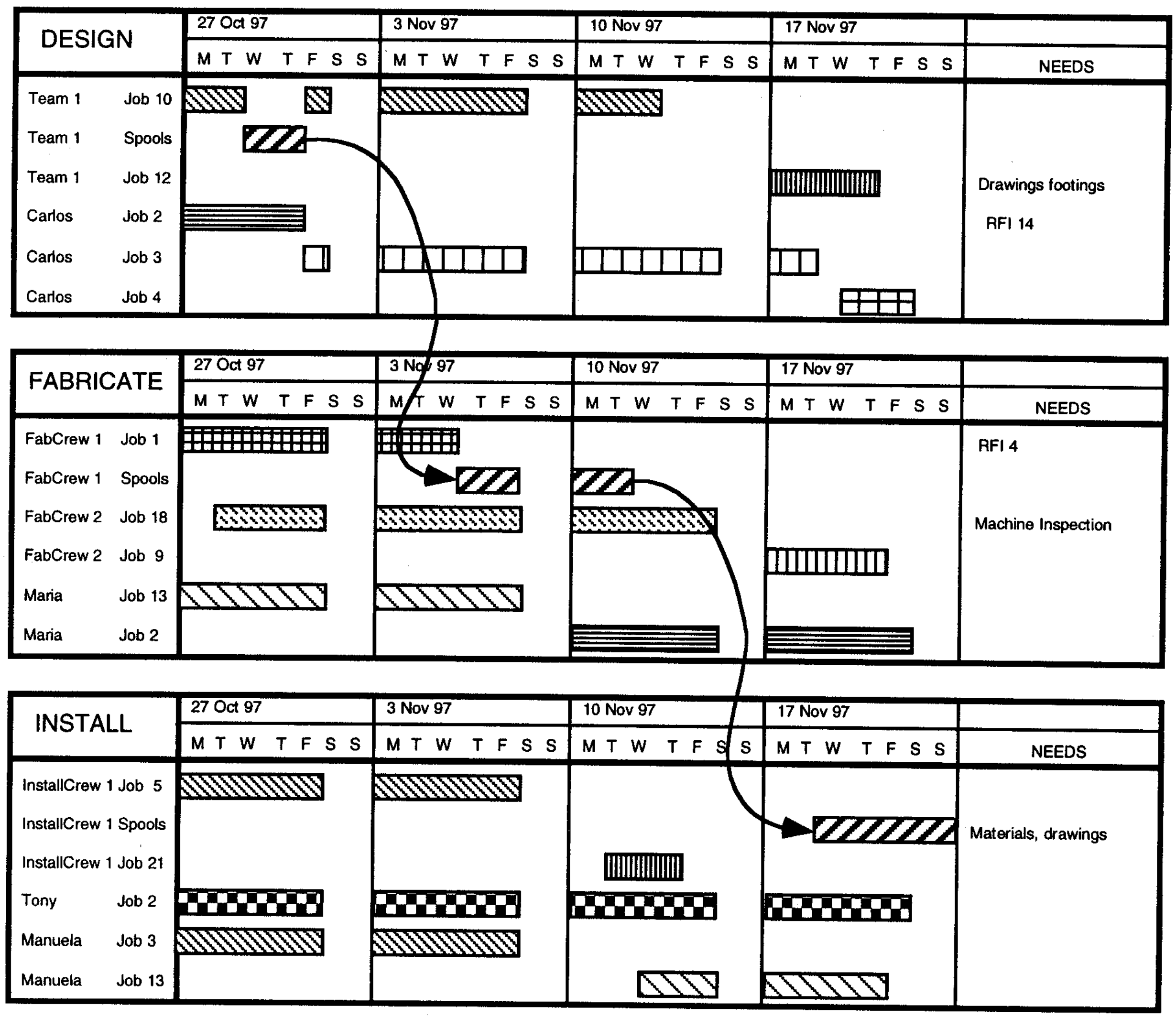

Figure 3: Look-ahead Plans for a Sequence of Supply-chain Production Units

3. SCREENING FUNCTION IN LOOK-AHEAD PLANNING

As mentioned previously, **screening** refers to decision criteria that determine which activities should be allowed into the look-ahead time frame and which ones should be allowed to move up in time within that time frame. The quality criteria for shielding production from uncertainty at the commitment-planning level apply just the same to look-ahead planning, and they will help in screening. When this is done successfully, look-ahead planning produces and maintains an inventory of quality assignments, so less shielding will be needed during weekly work planning. However, several practical questions arise in this regard and further research is needed to provide more insight.

Based on data collected to date, there appears to be a lot of uncertainty pertaining to the definition of activities. Planners may not fully appreciate the complexity and scope of work they are planning when they compose networks of activities three and four weeks out from the planning date, so activities are overlooked. Definition may be amended by revelation of some previously undetected prerequisite work or item of material, sizing may change accordingly, etc. In addition, unforeseen changes due to outside factors (e.g., an owner changing the design) may make some activities obsolete while forcing others to be included in the plan, thereby causing the look-ahead schedule to get fouled up. The rarity of 100% PPC suggests caution on this point. However, many of the failures may be the result of not trying to do detailed planning until faced with the grim reality of having to do the task next week or tomorrow. Accordingly, experimentation is under way with doing first-run studies in the third week of look-ahead schedules.

4. Pull Mechanism in Look-ahead Planning

Upon execution of a schedule, it is traditionally assumed that all resources required to perform an activity that is about to start will indeed be available at that activity's early-start time. In this so-called **push-driven** approach, each activity passively waits for its resources to become available and prerequisites to be completed. When some have become available but others needed at the same time have not, those available will wait in a queue or buffer for the combination of resources—the set of matching parts—in its entirety to be ready. While it may be possible to start work with an incomplete set of resources, chances are this will negatively affect productivity (e.g., Thomas et al. 1989, Howell et al. 1993).

Unfortunately, because of uncertainty in duration as well as variation in execution quality and dependency logic of activities, schedule delays are bound to occur as construction progresses. The actual manifestation of that uncertainty will be known only upon plan execution and therefore must thus be dealt with in real time. At that point, rigorously adhering to the initial plan may not be the best approach for successful project completion as network characteristics and resource availability will deviate from those assumed during planning.

In contrast to the push-driven approach, a **pull-driven** approach supports the urge to finish partially completed work in the system. Keeping busy by processing just any one of the resources in the input queue of an activity requiring a combination of resources is insufficient. To pull means that resources must be selectively drawn from queues—so the activity that processes them will be busy just the same—but chosen so that the activity's output is a product needed further downstream in the process, and needed more so than its output using other resources in the queue would have been.

To implement a pull mechanism, individual resources must have been specified in the schedule, so that missing ones can be identified early on when schedule delays can still be prevented. Traditional schedules usually do not show such detail on individual resources but look-ahead schedules do require it for quality criteria to be applicable to assignments.

In addition, pull mechanisms require selective control over which resources to draw for any given activity. This selection is driven by information not solely about resources in the queues immediately preceding the activity under consideration, but also about work-in-progress and resources downstream (successor activities and queues) in the process. Resources get priority over others in the queue if they are known to match up with resources already available in queues further downstream in the process. This way, those available resources will not unduly await their match and be in process for any time longer than needed.

The following illustration of a pull mechanism is based on the pipe-spool supply-chain model that was presented in section 2. The effect of pulling (Case 3) is contrasted with two alternative models (Case A and Case B) that use random and predetermined sequencing of spools, respectively (Table 1).

Table 1: Alternative Sequencing Strategies

CASE	DESCRIPTION	CutSheet DRAW SEQUENCE	WorkArea DRAW SEQUENCE
A	Random Sequencing	Random	FIFO
B	Coordinated Sequencing	FIFO	FIFO
C	Pull-driven Sequencing	Priority to spools that match area(s) ready	FIFO

The three models were derived from the same basic template that was crafted to illustrate the occurrence of various kinds of uncertainty in construction processes. Some industry data was obtained to estimate orders of magnitude for activity durations and percent rework (Howell and Ballard 1995). Some uncertainty was not modeled (OffSiteWork is assumed to be complete and thus all Specs are available at time 0; FieldWork results in all WorkAreas being available at time 85) so as to not complicate interpretation of the simulation results. Obviously, modeling uncertainties further upstream in the off- or on-site activity chains and including those regarding Design, PrereqWork, and Install will further exacerbate the effects described below. The basic model simulates the installation of 600 pipe spools in 15 areas; 40 spools are designated to each area.

The models differ from one another in two ways: (1) they use a different order in which to draw resources from the CutSheet queue (see Table 1), and (2) only Case C includes the Feedback queue, the Update activity, and links FB1, FB2, DW3, and DW4 (see Figure 2). Other draw sequences could have been implemented and their impact studied on productivity, project completion, etc. Readers interested in reproducing the outputs presented here or running other scenarios can obtain the source code from the authors.

Cases A and B reflect two extremes in degree of pre-construction planning. Figure 4 illustrates the results of their computer-based simulation. **Case A** reflects total lack of coordination. CutSheets (or Spools) and WorkAreas are processed in an order independent of one another. Thus, the likelihood for mismatches to occur at installation time is high. This leads to a huge build-up of spools on site waiting for the areas where they are to be installed to open up, and vice versa. However, when installation finally starts, it progresses at its fastest possible rate.

Case B describes perfect coordination. It is an idealized case, which, for many reasons will be impossible to achieve in reality. CutSheets 1 through 40 go to fabrication before 41 through 80, etc. Similarly, Area 1's prerequisite work is performed prior to Area 2's, etc. This results in minimal space needed to stage spools on site, though some spools will accumulate due to asynchrony of the two activity sequences, and uncertainty and defects in their activities.

Case C augments Case A with a pull mechanism. CutSheets are first processed in random order relative to work areas, but as soon as areas are ready for spool installation, the CutSheet's priorities are updated with that feedback and *pulled* to the site. Here, again, relatively few spools accumulate on site and the project duration remains fairly short. However, there is a penalty in terms of field productivity. Fortunately, this can be improved by ordering the crew to start later, when more spools are on site, so they can work at their fastest possible rate.

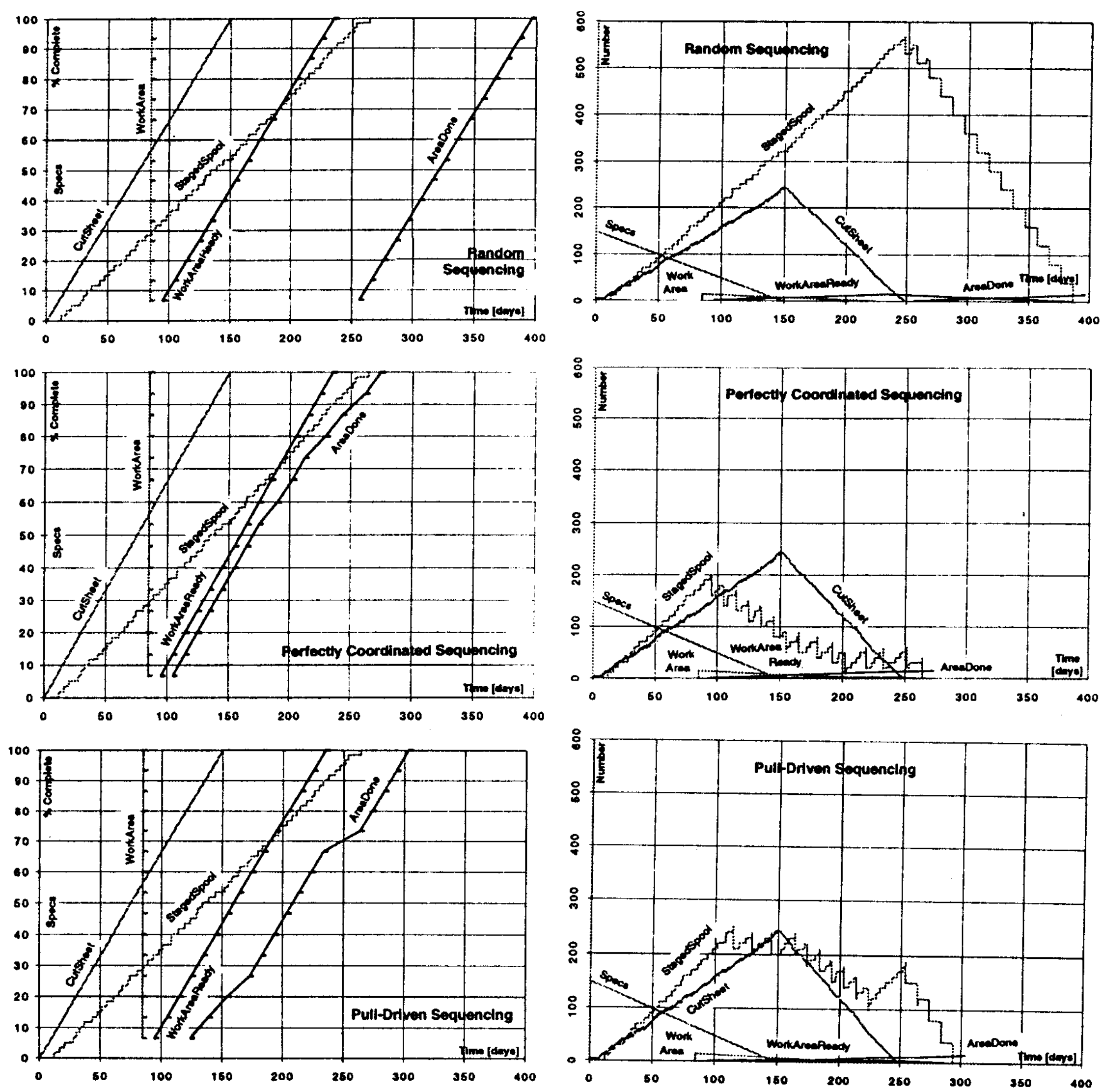

Figure 4: Percent Complete vs. Time and Number of Resources vs. Time for Specs, WorkArea, CutSheet, StagedSpool, WorkAreaReady, and AreaDone Queues for Random, Coordinated, and Pull-driven Sequencing

The effects of pulling on the number of spools accumulating at the site and on the completion time of the project are indeed quite dramatic. Note that the pull mechanism presented here is not even the most optimal one for this system. As shown, feedback on the completion of work areas is relayed only after those areas have been completed and are ready for installation work. Instead, feedback could have been relayed earlier on in anticipation of area completion while also taking into account the time it will then take the pulled spools to be fabricated and shipped to the site. Additional pull links could be included, relaying progress data from on-site to off-site and vice versa. Determining the proper pull mechanisms is a key function of production system design. As the example has illustrated, system design can be aided by computer-based simulation of the construction process.

5. SUMMARY

This paper presented three levels of production planning of which two, namely look-ahead planning and commitment planning, use lean construction techniques effectively. The paper's specific focus was on look-ahead planning, which involves planning based on a four-to-five week time horizon using screening, pulling, and rescheduling. A computer-based simulation of an example pull mechanism was included.

While pulling is an effective technique to expedite resources, the need for it can be minimized when one succeeds in setting up an integrated, real time, and transparent production planning system. This would allow upstream suppliers to adjust their schedules to downstream needs, without having to wait for a pull signal. In turn, this would allow suppliers to get a jump on demand, so they would be better prepared to respond to pull signals when they do arrive. Pull signals could be like kanban cards that say "deliver me x". In construction, we are still far removed from having such systems in place but establishing them would serve our industry well in its goal to achieve lean production.

6. ACKNOWLEDGMENTS

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