Design of Construction Operations

LCI White Paper-4

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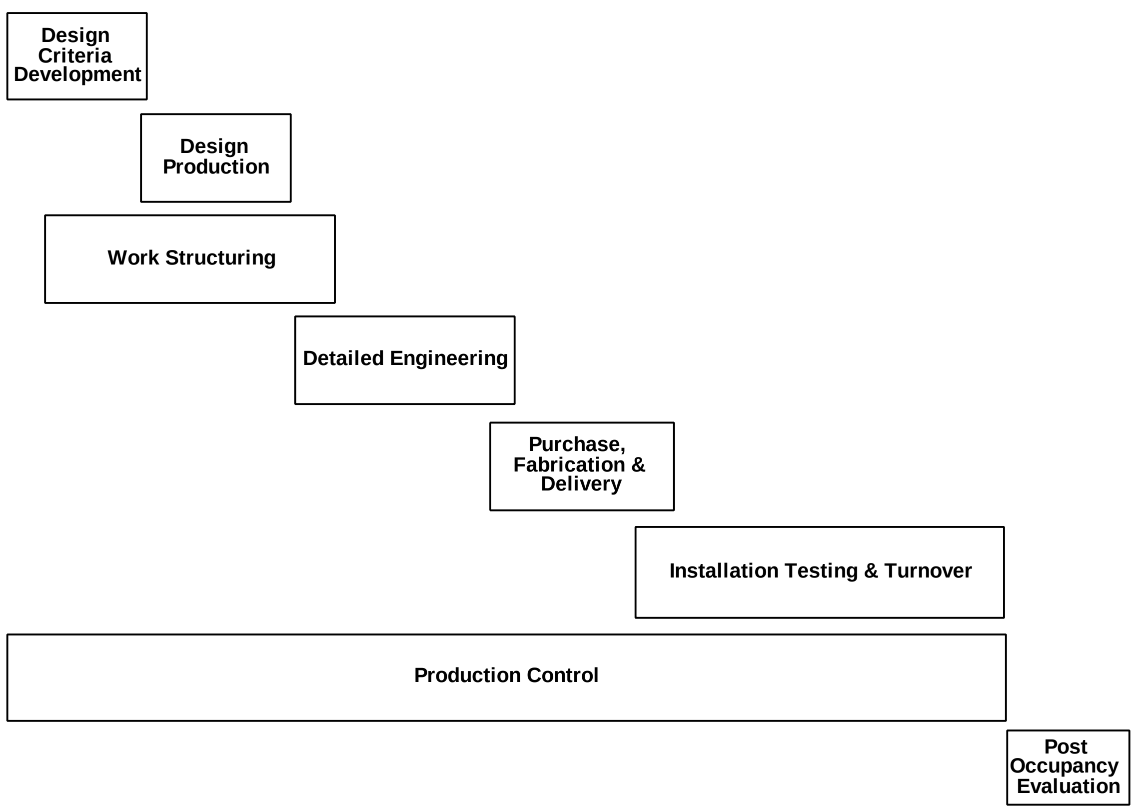
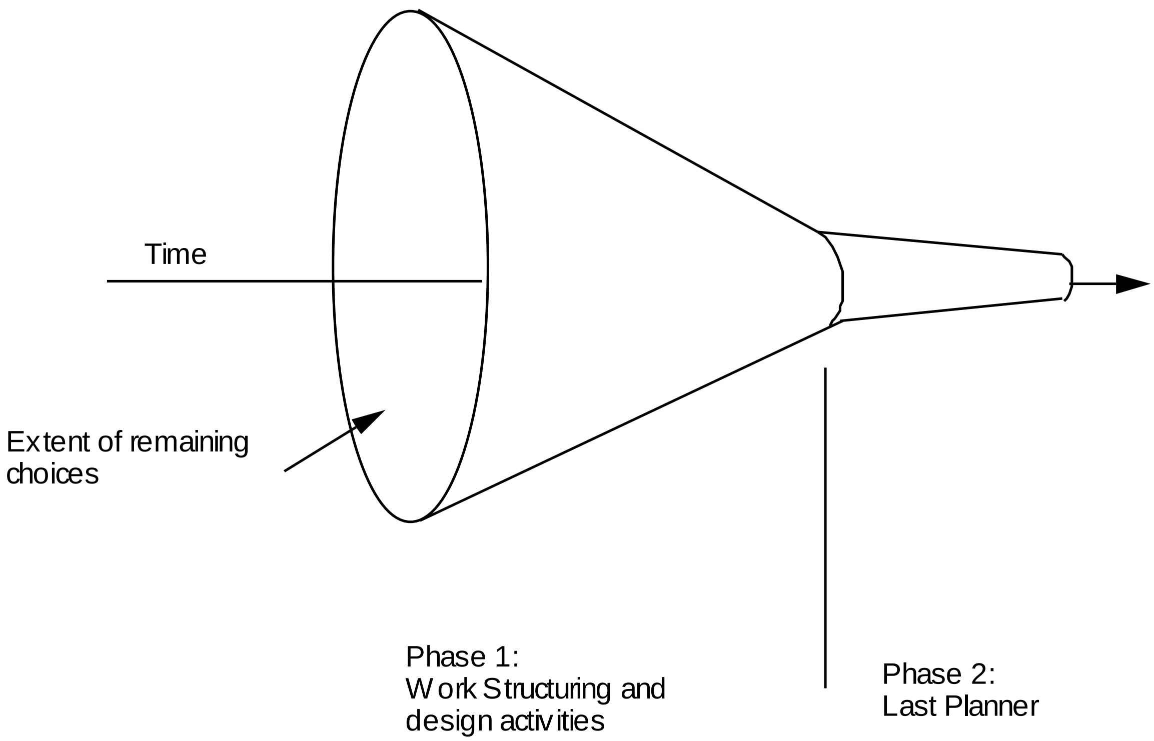
Construction operations, also called "work methods", are the way the crew uses what they have to do work. Work methods appear simple enough as represented in the estimate: form, place, and strip. But within those cycles design is seldom detailed or explicit at the step or subcycle level. Under lean construction, the design of the product and the process occurs at the same time so factors affecting operations are considered from the first. Our aim is to make the design of the operation explicit and to assure the issues affecting the operation are considered at the most appropriate time.

Moving from the current state where the operation receives little attention to a full implementation of lean construction will require better understanding of how operations are designed today and then working to improve that process. For these purposes we can start by considering work method design in two phases. The first begins in product design and work structuring and continues until consideration by the last planner. The second phase carries forward from last planner consideration until the operation is completed.



In the first phase, which begins in design production and work structuring, decisions about the selection of materials, their joining, and configuration on site constrain the work method. For example, the choice of tilt up panels over masonry limits downstream choices about the work method. We have been tinkering with the idea that the first phase can be understood as a funnel where the surface of the funnel are the time, cost and quality boundaries. The opening of the funnel is the range of solutions left. It decreases as time moves forward and decisions are made. In this image, downstream planners are progressively constrained while upstream managers hope that at least one acceptable solution remains within bounds .

The extent of choices on the design of operations



Confidence that a solution does exist increases through use of 3D CAD because it gives a clearer view of how the pieces might be assembled. The interdependence between product and process can be explored using computer models of the design so that work can be structured to best meet project objectives. Issues to be considered during this phase include:

- the design of the product itself,
- available technology and equipment,
- site layout and logistics,
- the size of work packages released to the crews,
- the size of work packages to be released to downstream crews,
- potential site environment factors (temperature winds etc),
- safety,
- the expected experience and skills of craft workers and supervisors,
- craft traditions or union work rules (to name but a few).

CAD cannot reveal factors such as the reliability of the planning system and the accuracy of early capacity allocation decisions that can affect the way work is done. For example, a pipe spool can be fabricated in a shop or on site. Site work may be required if inadequate shop capacity is available but may cost more. Marketing plans, proposals and cost estimates rest on assumptions about the way capacity will be allocated and the work will finally be done, even though the determining details are far from resolved.

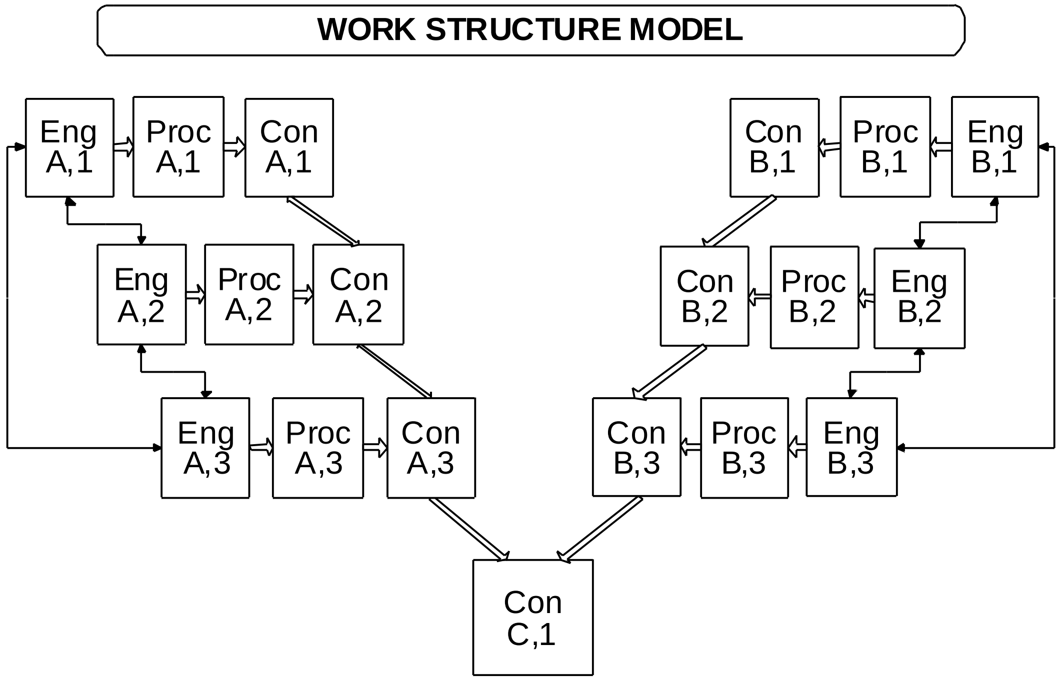
The funnel metaphor appears intuitively correct because all of the details are rarely resolved before the activity begins and most operations continue to evolve once underway. Process design, like product design, proceeds through examination and selection of options, moving from less to more detail. There is always some risk that progressive detailing will reveal impossible combinations of elements. The hope is that there will be some possible combination of elements that at least minimally satisfies design requirements. This image contradicts the view that there is one right or standard way to do work and suggests two strategies at the extreme. One is to leave as much flexibility as possible for the last planner. The opposite strategy would be to completely prescribe all details in advance and then assure that the planned for circumstance happens. (This may be another essential difference between the production phases of construction and manufacturing. In so far as construction is a prototyping process, the design of the operation will evolve. Once that stage is passed in manufacturing the details of the operation appear to be almost completely resolved. But of course Shingo teaches they are not – but the evolution takes years.)

There are obvious problems with designing construction operations under either strategy. Under the first, total flexibility makes planning and coordination with others difficult, and projections of cost or completion unreliable. In the second, early prescription ignores late developments. Although, following procedures established early and supported by intermediate planning might improve the reliability of workflow. We want to maintain as many acceptable options as possible within the constraints of facility type, location, stakeholder demands, applicable requirements, and customer needs. Just as with product design options, process design options progressively disappear as we move forward through time because we have overrun the lead times of suppliers. For example, there are lead times for acquiring construction equipment, labor, permits, etc. A cost-superior alternative may not be feasible after a certain date because we can't acquire what's needed to implement that alternative and still meet the end date for the project. In addition to overrunning lead times of suppliers, we also may eliminate options by examination. We may not be able to use a certain forming technology because no local contractors have that skill or because it just doesn't make sense for the type of walls we're building. In fact, we may be able to specify the design for each operation in front end planning, but even so, there is more design work to be done within the detailed engineering phase (identification of steps, sequence, and resource requirements) and within the lookahead process (pace, batching, transfer requirements, buffer location and sizing, space management, etc.). And yet more design work to be done once the work package is released to the crew "Who's getting the sand? Mike, you, and Ben do the prep work."

This discussion raises related questions:

1. How should early decisions be made to maintain needed downstream flexibility or to assure planned circumstances occur?
2. In what circumstances and with what information should such consideration occur?
3. When should the details of the operation be considered?

LCI proposes that explicit consideration of the details of the operation occur in the lookahead process. Since method design is a reductive process the concept of last responsible moment should be employed so design issues requiring longer response times will be considered, and that the timing for other issues be set so that essential factors driving the operation are still open. We suggest that First Run Studies be a routine part of planning prior to the start of new operations.



FRS conducted at this time may reveal that the last responsible moment has passed, or that all of the factors involved are not yet stable enough to support a complete plan. Both findings are important, the first for future planning, the second for completing the plan at hand.

Implementation of FRS moves forward the beginning of the 2nd design of operation phase, consideration by those directly involved. In the more typical circumstance, a foreman is assigned work and then confronts the circumstance on the ground. Most of the leverage is lost and planning for work can become coping with things missing or in the way.

The FRS planning meeting should occur 3-6 weeks before the start of a significant operation or class of work such as duct work, or stainless piping or plumbing trees. The meeting should include at least the lead worker, immediate supervisors and support. The meeting should produce a plan for how the work will be completed. The plan should be in sufficient detail to serve as a control document for the operation. The following check list can be used. The design process may be iterative so you can expect to revisit issues or take them in a different order. In any case, planning the way work will be done at the level of the steps or subcycle {shouldn't subcycle be one word?}often results in a significant reconsideration of the way the operation will be completed and the effective capacity of the crew. In one example a crew placing 80 feet per day of 36" diameter reinforced concrete pipe improved their performance to 300 feet per day after 2 meetings. They removed the obstacles built into the way they were doing the work.

You may find much either has or should have been considered earlier or will or should be considered closer to the start of work. These findings should adjust your planning process. From a research perspective, these experiences will help us understand when is the best time to begin planning different aspects of the work.

Are we designing an operation at a workstation or a series of operations moving through multiple workstations? I.e., are we designing the installation of wall rebar or the process of building walls? Is the operation part of a continuous flow process, so that we must keep pace with others and are immediately dependent on an upstream station for prerequisite work; i.e., the key issue is balancing interdependent subcycles. Or, is the operation either independent or can be decoupled from providers of prerequisite work? The strategy for evolving operation designs presented later fits nicely here. Streamline each operation within a continuous flow process in order to 'reveal' latent capacity, then balance; as opposed to trying to balance flow across multiple workstations using historical data on capacity/productivity. In the process of streamlining, understand and minimize processing variability at each station, then incorporate either inventory or capacity buffers to accommodate remaining variability.

Turning from installation flow to supply flow: What variability exists in supply flows of materials and design information? To what extent can we act in the time available to reduce variability, and to what extent must we shield ourselves from remaining variability?

FRS/operations design is not limited to repetitive operations. Indeed, we recommend that <u>all</u> operations be subjected to FRS on <u>each</u> project. If selection is necessary for some reason, consider selecting critical, hazardous, and new operations for detailed planning and improvement in addition to repetitive operations. Repetitive operations obviously offer payback, but also most resist planning because everyone 'knows' how to do them already, unless they also fall under one of the other categories. Critical operations like heavy lifts have traditionally been planned to the gnat's ass. Hazardous operations like enclosed space work have been planned somewhat, tho' too little attention has been given to the actual steps to be performed as distinct from provision of pretest and safety gear. New operations obviously warrant planning because we can't rely on what's been done in the past.

First Run Study Check List

1) Requirements: What has to be done?
    a) Quantity & description
    b) Completion Date and Duration
    c) Budget
    d) Contract & specifications
        i) Inspection Criteria
2) Status of operation: What is the state of things?
    a) Plans to date - what is in place for the operation?
        i) Experiences from previous projects?
    b) Design Issues
        i) Is design clear and stable?
        ii) Reviewed for conflicts
        iii) Are there any questions or changes on the horizon?
        iv) Constructability - has the operation been considered for design changes to improve installation?
    c) Materials - available? familiar?
    d) Prerequisite work
    e) Space
        i) Access permits

- ii) Storage
- iii) Installation
- iv) Environmental control
- v) Other activities?

f) People
- i) Skills
- ii) Motivations

g) Tools & Equipment (You may find far fewer tools are needed as the plan becomes more considered and in detail.)
- i) Energy sources

h) Safety - to be provided for by others or beyond installation crew?

i) Coordination with others - what is the status?

3) Sequence: How will the work proceed?

a) How many work fronts will be opened?

b) Where will the operation start?

c) Direction of progress?

d) Critical coordination issues or obstacles
- i) Decision hold/points
- ii) Alternates

e) Work release criteria for next step or operation?

4) Detail operation plan; Who stands where? Do we bolt pieces up and then lift, or lift then bolt?

a) Flow chart

b) Extent of prefabrication/pre-assembly

c) Safety concerns

d) Interactions (may be covered in other areas)
- i) Intermediate inventories
  - (1) Size and purpose
- ii) Shared resources

e) Tools and equipment

f) Crew balance

g) Number of workers
- i) Special skills

h) Pacing and control tools
- i) Linear schedules or? {may want to distinguish a la Vorster between line of balance and linear}

i) Learning/evolution

j) Internal Flexibility

k) Hold points

l) Potential interferences/obstacles/impacts

m) Supervision plan concerns - what will they be looking for? monitoring progress?

n) Alternate work processes for special areas (how do we fit it in the corner?)

Once the operation is underway, the first few cycles should be observed closely and considered against the plan. Still photos of each step and video of the process are useful for analysis. Cycle times should be recorded and any interference or deviations from the original plan noted (although in early studies such deviations are almost as likely to be errors in the plan as in the work). The resulting document should accurately describe the operation in a way the workers and lead hand can understand while providing enough detail and data to support business decisions for improvement. Typical studies include process, crew balance and flow charts. {I always require also a 'flow diagram', meaning a diagram showing how things move through space. I think we should stress here the importance of measuring and understanding variability in processing durations and arrival rates of inputs.}

Thoughts on the Evolution of Operations

Construction operations usually begin with significant uncertainty but implementation of FRS will reduce it. The product may be well defined (but it isn't always) and all resources may be on hand and well organized (but they rarely are). The crew, with some guidance from senior supervisors and inspectors, works out the details of each sub cycle or step. The flow of work through an operation is often jerky and hesitant because people are learning as they go, the supply of resources is erratic, and the duration of sub cycles varies. On some sites, problems with resources so disrupt the operation that the crew simply works as each piece of work comes available. In this case there is little reason to improve or strive for any particular level of performance. Instead the operation unfolds in response to changing circumstances and developing skills instead of being actively designed.

Work methods appear to evolve in two dimensions along a predictable path. The human dimension is how well the crew understands the operation. The interaction between sub cycles is the primary technical issue. For example, interaction is high if the second step must wait on the first. Or interaction may be high if sub cycles share a common resource such as a ladder. Reducing interaction is one key to improving performance.[1]

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[1] Howell, G., Laufer, A., Ballard, G. "Interaction Between Subcycles: One Key to Improved Methods." ASCE *Journal of Construction Engineering and Management*, Vol. 119, No. 4, December, 1993

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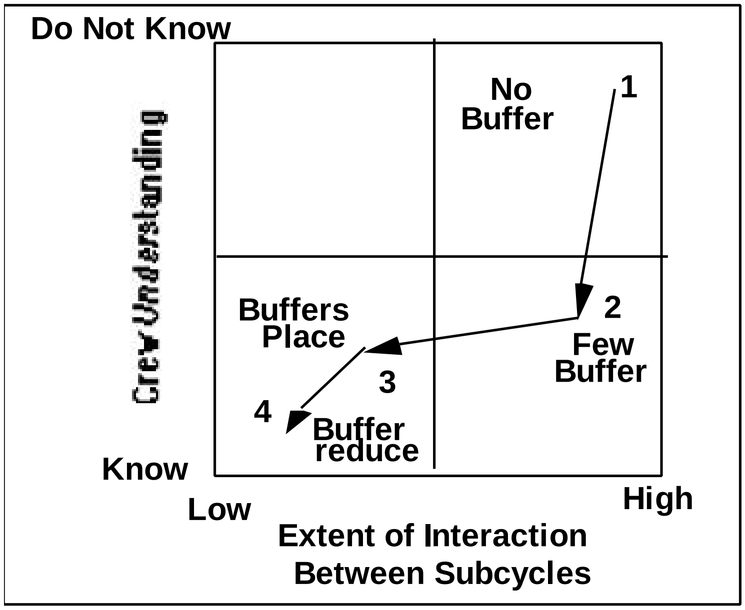

Evolution of Construction Operations

This might be accomplished by inserting a surge pile or intermediate inventories between the steps or by providing two ladders so sub cycles can proceed independently. Low interaction means both sub cycles can continue without interruption from the other. (In a sense the Last Planner system of drawing assignments from workable backlog is built on the same principle. Here the workable backlog buffers installing work from variations in organizing the resources to do the work.)

The operation begins at point 1 because the crew does not completely understand all of the details of the work, and interactions between sub cycles are usually high, and throughput low. This does not mean the crew is untrained, rather that immediate circumstances such as the location of materials, the number and condition of tools, the skills and strengths of the crew must be considered as the method develops. The extent of interaction is related to the lack of familiarity of the crew with the operation and the fact that the inventory of work in progress has not accumulated at intermediate points. So the crew does one step at a time. While this may be slow, it is a prudent strategy which minimizes rework as the crew is less likely to embed errors if they move one item through all steps in the operation before breaking the crew into sub units. For example consider the impact of a crew unpacking and incorrectly assembling several hundred light fixtures. Errors are usually discovered when the product of one sub cycle or operation must be joined to another. It may be wise to assure the crew really is aware of potential errors before rushing into high production.

At the end of a few repetitions, point 2, the crew is much more familiar with operation and has sorted out most of the technical details. They may have installed a few intermediate inventories to reduce the need to transport materials. Thus the movement from point 1 to 2 is based primarily on learning.

But the sub cycles still interact to limit performance. The operation can be dramatically improved at this point if someone provides needed resources (ladders or s) and the permission to change the operation. Unfortunately this is rare as the pressure to produce the next unit locks the crew into the method at hand. This is an important factor in the development of operations. If the crew is under constant pressure to produce the next unit, they will never be able to reorganize the operation and develop the intermediate inventories needed to reduce interaction. In many cases the pressure to complete arises from efforts to show progress for the control system or to release some small amount of work to the next crew.

Point 2 is the time to reorganize the operation to efficiently produce the last unit by breaking the operation into concurrent steps that do not interact. (This point may be reached far more quickly if the design and learning process follows the FRS pattern.) This causes the movement from point 2 to 3. At point 3 intermediate inventories have been installed but are only roughly sized to allow variations in sub cycle completion.

Movement to from point 3 to 4 is rare. Runs do tend to be short and often most of the repetitions are complete before point 3. Engineering information is the key to moving from 3 to 4 because it is only possible to optimize the operation when the unimpeded cycle times that determine the real capacity are known. It is then possible to reduce the intermediate inventories and move back to a tightly coupled state while still maintaining low interactions. Tight coupling and low levels of interaction mean rapid completion as throughput is high.

First Run Studies run studies speed the evolution of an operation as the movement between stages is not left to chance. The crew and entire production team comes to grips with the details of the operation in planning before mobilizing in the field. Areas of uncertainty can be identified in advance and decisions made on the coping and learning process to be employed. Often the crew can reduce the time spent in the initial learning phase of the operation by thinking through the details in an open discussion aided by simple graphics. The idea of interaction can be added to the study by drawing a process chart showing sub cycles and then exploring where intermediate inventories might be placed at the outset without risking quality. Raising the issue of intermediate inventories often changes how lead workers conceive work methods and increases their foresight. In most First Run Studies, the crew asks "How many of these cycles do we have to do?" This question is rarely asked when the operation is designed in the field as the apparent problem is completing the next sub cycle.

Planning helps the crew move from point 1 to point 2 and opens the possibility that the operation can be continuously modified to improve performance by moving from 2 to 3 and so on. In part this improvement occurs because the planning meeting allows people inside the crew and out a chance to offer their experience and insight. The response from the crews is usually enthusiastic. Their brains are engaged and they learn general principles that can be applied in future operations. As one worker said, "Before, no one ever asked us how we would do it right." An additional benefit of First Run Studies comes with involving safety and quality control in the design of the operation instead of trying to inspect it in later. The documentation prepared in the course of completing a First Run Study provides a way to capture best practices and "remember" them for future projects.