Aiming for Continuous Flow

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Previous white papers were devoted to pulling materials to the jobsite (WP-1) and to underloading workers and equipment in order to increase their actual capacity to produce work (WP-2). This white paper is about structuring work processes, specifically about continuous flow processes (CFPs)—construction's 'assembly lines'.

TERMINOLOGY AND OBJECTIVES

A **continuous flow process** (CFP) is a type of production line through which work is advanced from station to station on a first-in-first-out basis. The idea is to approximately balance processing rates of the different stations so that all crews and equipment can perform productive work nearly uninterruptedly while only a modest amount of work-in-process (WIP) builds up in-between stations.

The objective of achieving continuous flow is maximizing the throughput of that part of the system while minimizing resource idle time and WIP. Just as pull techniques are limited by the relative size of supplier lead times and windows of reliability, not all work can be structured in CFPs. However, doing so where possible reduces the coordination burden on the 'central mind' and provides 'bubbles' of reliable work flow around which other work can be planned.

EXAMPLES OF CONTINUOUS FLOW PROCESSES

Consider the following examples of CFPs:

- interior wall rough-in
- finishing rooms of a hotel or hospital (painting, carpeting, etc. one unit after the other)
- excavating footings, placing formwork and rebar, then inspecting prior to placing concrete, and subsequently curing, stripping, and finishing
- excavation and shoring as in operations where lagging is placed in chunks of 6 feet or so in alternation with excavation
- setting, piping, wiring, and instrumenting process equipment

Key in these CFPs is that work gets done in small chunks. Each chunk is involved in one production task (or operation) and, once processed, is worked on in subsequent production tasks. In the mean time, the first tasks gets repeated, and so on.

In order to assess whether or not continuous flow is appropriate and then to achieve it, a number of steps must be taken. The steps in CFP design are: (1) data collection, (2) definition, (3) rough balancing, (4) team agreements, (5) fine balancing, and (6) change guidelines.

DATA COLLECTION

We need to know some things up front before we can design a CFP. We need information about the individual operations that are potentially involved in the CFP, and we need information on the relationships between those operations.

Individual operations are characterized by:

- work content
- method design (recognizing that this is precisely one thing that might be changed)
- setup time
- minimum resource unit (e.g., the minimum team for roughing in electrical overhead might be two workers with one scissor lift) (note that these may change with the redesign of operations)
- minimum process batch size (mostly determined by technical considerations such as having a room cleared for painting, but may vary with space needs)
- capacity (average installation rate) of the minimum resource unit with minimum process batches
- space and access need, protection requirements (e.g., spraying, noise, dust, etc.)
- variation in crew installation rate (note that variation can occur from processing error at the station, defective input from a supplier station or external supplier, differences in crew effort, differences in crew composition, or differences in the specific work to be done at a given time, the learning curve effect, and possibly other reasons)
- average and variation in installation rates for alternative process batches
- what materials are applied at the station? what are the batch sizes and space requirements for deliveries? what are the mean and standard deviation of on-time delivery rates for each type of materials?

While identifying the characteristics of individual operations, one needs to pay attention to available skill sets and equipment capabilities, yet not be misled by contractual or union boundaries, or other traditions that may constrain the view on operations.

Relationships between operations are characterized by:

- shared resources (e.g., crane or materials hoist, storage and work space, and access)
- buffer of WIP in-between them, prerequisite work in place

Figure 1 illustrates an operation with its crew, tools, and equipment needed to execute the method of choice. The production task also requires that prerequisite work be completed and that materials and directives be available. Figure 2 illustrates that there usually is a choice of pace at which the production task can be performed. This pace is set by the selection of a method and the associated resources.

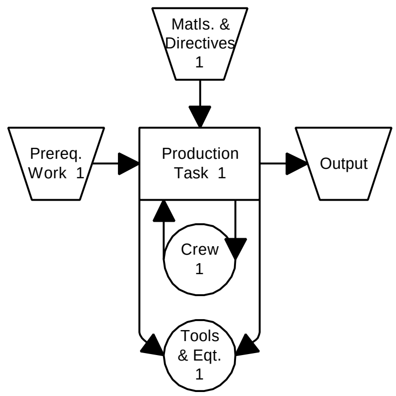

Figure 1: Single Production Task

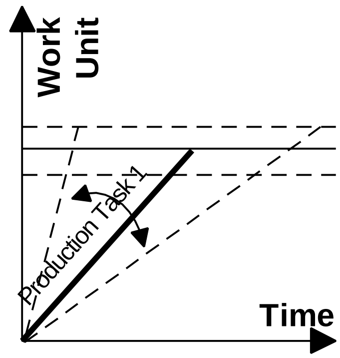

Figure 2: Pace of the Production Task

DEFINITION

Once descriptive data on individual production tasks and their alternatives is available, we can put different tasks together to form a system and see if it can be made into a CFP. Figure 3 illustrates a simple, linear sequence. This sequence is defined by output specifications (process dependencies), completion date, and possibly production rate (for coordination with downstream processes).

At first, production tasks will tend to be separated by buffers of inventory (Figure 3) and performed at different rates (Figure 4).

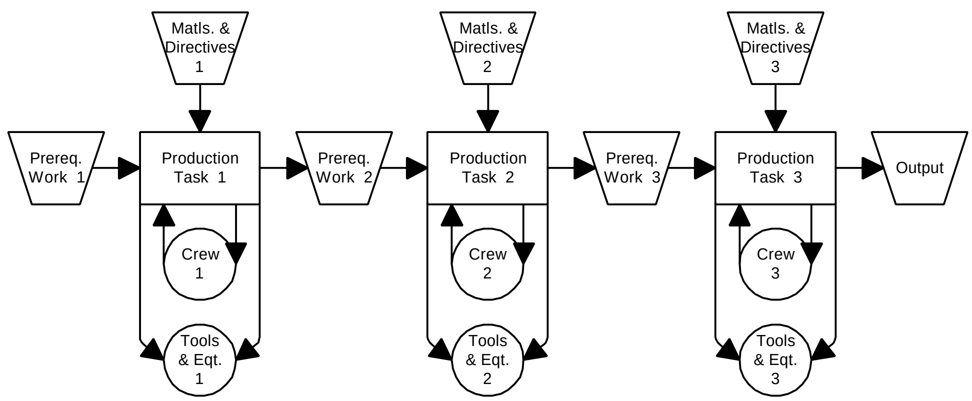

Figure 3: Sequence of Production Tasks

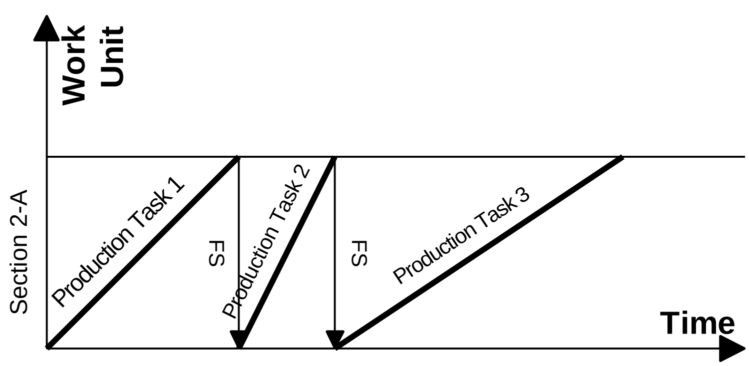

Figure 4: Sequence of Production Tasks Performed at their "Typical" Pace

The team must decide which parts will be made into continuous flow and which parts bill be decoupled by means of buffers. This decision is driven in part by the amount of flexibility that exists in the operation's design and the required resources. Technology might also be a driving factor (e.g., in order to avoid creating an excessive number of joints, concrete is typically batched and placed at a rapid pace, relative to the time it takes to place formwork and rebar. It does makes sense to build up an inventory of such formwork and rebar in place, prior to starting concrete work).

TEAM AGREEMENTS AND ROUGH BALANCING

The team must get together and define a strategy for moving through the building, recognizing that work content may vary from one location to the next. In the rough balancing stage, specific site constraints must be considered. For each production task:

- Create a project breakdown by area and component types.
- Select equipment and methods, identify those that will be shared.
- Define units of work (e.g., what will get done in a day) and identify work content per craft. Beware of craft jurisdictions!
- Size the crews to match the actual circumstances.
- Refine the methods design with actual crew in light of the site constraints.

These factors define the pace of the operations as work will progress to complete the project at hand. These decisions may yield a production schedule as illustrated in Figure 5.

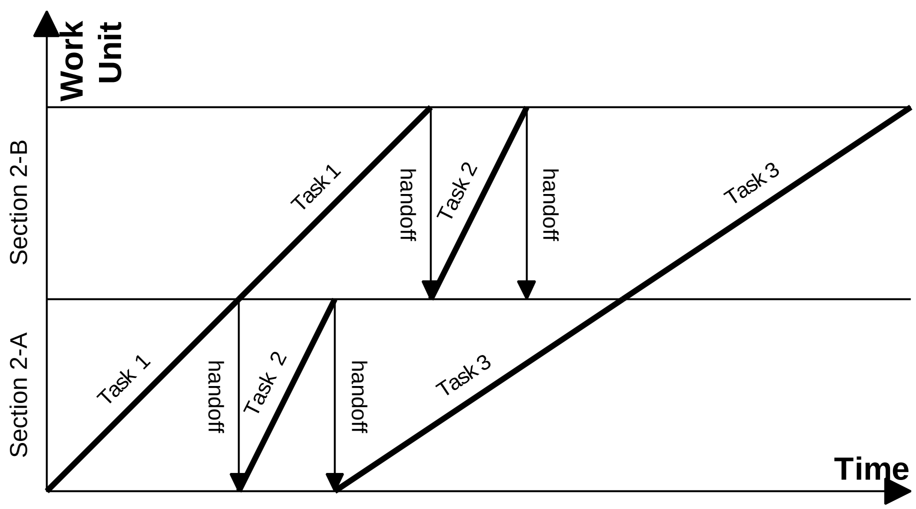

Figure 5: Production Schedule Based on Strategy for Moving through the Building

Questions to be addressed are:

- To what extent can the operations be balanced, after exploration of redistribution of tasks?
- Which is the bottleneck operation(s)?

The decision to be made is:

- Which operations will or will not be part of a CFP?

FINE BALANCING

Once a CFP has been identified, the next step is to balance it, recognizing that each operation has two sets of drivers: (1) crew capacity and method (incl. resources, that is equipment and work space constraints) and (2) stuff coming from others, including prerequisite work, materials, and directives such as drawings and specs. (Figure 1).

To balance the system, compare throughput for each operation. The tricky part here is the conversion of units from one operation to the next, depending on the trade (e.g., hanging drywall is done by panel whereas painting is measured per unit area or per room). The best unit may be "one day of work" but this remains to be investigated. A critical consideration is the setup and cleanup times needed at the start and end of each day.

Adjust the crew sizes jointly with equipment and methods, to work faster or more slowly, provided the chosen method is a good one. Another way to expedite the process may be to redesign the operation (e.g., to reduce setup and cleanup time) or to restructure it so that the same amount of work gets done faster.

Balancing a system to achieve continuous flow preferably is done by assigning capacities, but is ultimately achieved by a combination of techniques including mutual adjustment, inventory buffers, and capacity buffers (Figure 6). Questions to be addressed are:

- Where to locate and how to size in-line inventory buffers? For example, a bottleneck process in the first position should be allowed to produce an output inventory prior to initiating remaining operations so the latter can operate without interruption.
- Where to locate and how to size inventory buffers of delivered materials.
- Where to locate and how to size capacity buffers? For example, differences or variations in processing rates may best be managed by sizing capacity at stations to accommodate the upper limit, thus 'wasting' capacity when work flow is not at that limit.

Balancing assumes a relatively stable load on each station and a relatively stable process batch. The entire line is governed as a single unit toward objectives of end date and delivery rate. Work gets passed from one production unit to the next in a first-in-first out manner. This will significantly reduce the scheduling effort if the variability of output is limited (also see the "Parade Game" paper).

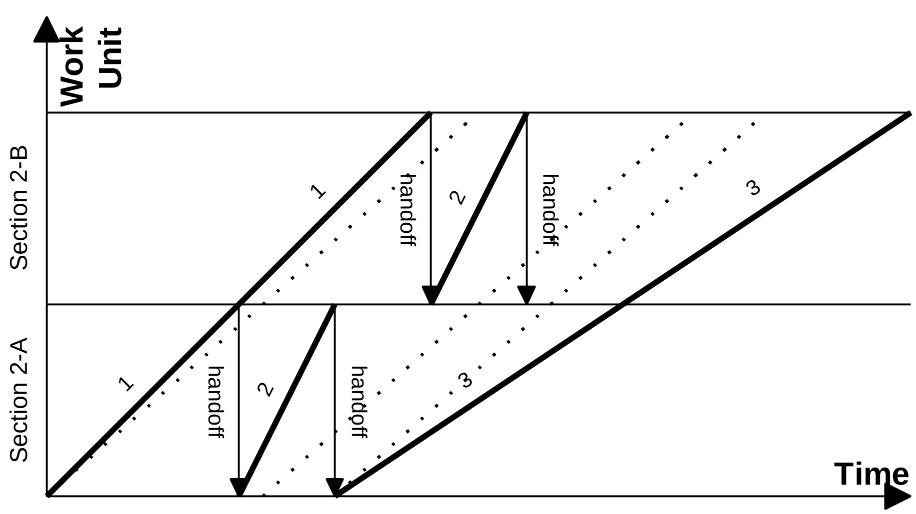

Figure 6: Aiming for Continuous Flow

CHANGE GUIDELINES

For self governance, the specialists operating at different stations in the line must agree on a division of operations, pacing or production rate, the size and quality characteristics of transfer batches (sometimes called "move batches" in the manufacturing literature), balancing techniques such as multi-skilling or rate adjustment, and strategies for adjusting to differences in load over time if unforeseen needs arise.

RESEARCH TASKS

- Suggest other example CFPs.
- Document work methods, variability and ranges in their production rate as well as setup/cleanup times.
- Describe how site conditions may affect the execution of those methods.
- Collect data on capacity for various crew sizes and delimitation of work and required skills.
- Understand trade jurisdiction for those work methods.

REFERENCES

"Parade Game: Impact of Work Flow Variability on Succeeding Trade Performance" by Iris D. Tommelein, David Riley, and Gregory A. Howell (1998) *Proc. Sixth Annual Conference of the International Group for Lean Construction*, IGLC-6, 13-15 August held in Guaruja, Brazil, 14 pp.