Tommelein, I. D., & Lerche, J. (2023). Comparison of takt planning methods used on projects of different types. *Proceedings of the 31st Annual Conference of the International Group for Lean Construction (IGLC31),* 1605–1616. doi.org/10.24928/2023/0255

# COMPARISON OF TAKT PLANNING METHODS USED ON PROJECTS OF DIFFERENT TYPES

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## ABSTRACT

Takt planning has been used to deliver projects of different types and in different industry sectors. We presuppose here that the methods used to develop project takt plans therefore must vary. To test whether this presupposition holds we consider two different project types (wind turbines and healthcare facilities) and compare sample projects of these types in terms of the rationale that was applied when developing their takt plans. We show that the rationale takes into account the relative cycle times and associated resource costs of individual steps in their production processes, considering the dependencies between those steps and between processes. Little has been written in the literature to date about the relative costs of process steps in takt plans, and how these costs affect the opportunities planners have and choices they make when leveling workloads to determine the so-called "operable" takt time. That is done here. This paper contributes to the literature on takt production used to deliver construction projects by describing theoretical concepts that help to differentiate takt planning methods used to plan projects of different types.

## KEYWORDS

Production system design, takt production, takt planning, work structuring, flow, complexity, cycle time, cost, Critical Chain, Theory of Constraints

## INTRODUCTION

Takt planning has been used to deliver construction projects and phases of work within projects of different types and in different industry sectors, such as multi-family housing, healthcare, and manufacturing plants. Project types can be differentiated based on characteristics such as their complexity, size, spatial features (e.g., location, horizontal vs. multi-story, onshore vs. offshore), and supply chain ecosystem (e.g., supplier and subcontractor availability and capability), and phase types can be differentiated likewise within projects. Recognizing variation by project- or phase type, one might expect that methods used to develop project takt plans will vary. This expectation is in line with Shenhar's (2001) argument that "one size does not fit all projects," i.e., that different types of projects should be managed in different ways. While Shenhar (2011 Table 1) labels all construction projects as "build to print" and lumps them together in the Low-Tech bin, within this bin further distinctions can certainly be made. With this in mind, we start this paper from the presupposition that the methods used to develop project (takt) plans therefore must vary.

To test whether this presupposition holds we consider two different project types, namely wind turbines and healthcare facilities, and compare sample projects of these types in terms of

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the rationale that was applied when developing their takt plans. The rationale is based on relative cycle times and associated resource costs of individual steps in their production processes, considering the dependencies between those steps and between processes. To ground this paper's contribution in prior work, we next review literature related to takt production used to deliver construction projects, and scheduling-related topics including the Critical Chain method (CC) based on the Theory of Constraints (ToC). We then explain the perspective we adopted for our analysis, that considers the relative costs of process steps in takt plans, and how these costs affect the opportunities planners have and choices they make when leveling workloads to determine the so-called "operable" takt time. That section is followed by the presentation of Project Type 1, a wind farm infrastructure project, and Project Type 2, a healthcare facility project. Each one includes a description of the rationale applied in planning these projects. The paper ends with a discussion and conclusions.

# LITERATURE REVIEW

## PROCESS STEP DEPENDENCIES AND INTER-PROCESS NETWORK DEPENDENCIES

Before talking about process steps in takt plans, it is worth separating the functions of planning and scheduling. According to Kelley & Walker (1959), planning is defining what activities have to occur and their order of occurrence based on technical or logical relationships (the topology of the network); scheduling further adds the dimensions of time and cost to these activities (the geometry of the network). The critical path method (CPM) highlights the sequence(s) of activities having the longest duration. A CPM schedule does not depict the possible occurrence of variation in duration or timing of activities, or the existence of alternative activities. A manifestation of variability (e.g., uncontrolled stoppages) may result in delaying the project.

Since the inception of CPM, a variety of other and often-times related network scheduling methods have been developed (e.g., Russell & Wong 1993). Location based scheduling (LBS) explicitly depicted location-dependent logic (Willis 1998, Harris & Ioannou 1998, Kenley & Seppänen 2010, Lerche et al. 2019). Takt planning further introduced into the plan a given beat (the takt) and the direction of the flow of work, as will be elaborated on in the next section. The Critical Chain (CC) method with its drum-buffer-rope concept defined the slowest process step as the drum and based on that drum paced the other process steps (Goldratt 1999).

Whether to use CPM, LBS, Takt, or CC as methods for planning needs to be decided judiciously in order to match the project requirements and opportunities provided by their context. Any one or several of these methods can be used within the Last Planner® System (LPS), where the work structuring of activities is based on principles applied to logical layers of planning (Ballard 2000, Ballard & Tommelein 2021). LPS focuses on how to plan in light of what to accomplish with the plan, rather than on the specifics of what a plan consists of (Lerche et al. 2020b). The LPS does not single out the use of any method in particular.

When scheduling, activities are aligned according to their technical or logical relations. Howell et al. (1993) defined these as degrees of linkage (from loose to tight) between processes. Hopp and Spearman (1996) found these linkages to have dependent or independent demands. Bølviken et al. (2015) defined relationships between processes as dependencies that can turn into constraints, either physical or non-physical. For example, a physical constraint arises when a component or prefabricated unit's physical characteristics (weight, dimensions, etc.) exceed the crane capacity (e.g., Taghaddos et al. 2018). Protecting the schedule (or production plan) from variability requires the discipline of actively removing or limiting such constraints (e.g., through work structuring and make-ready planning when using the LPS).

Using CPM, buffers may be introduced within and between activities to allow time or resources to mitigate the risks of being delayed from such constraints. LBS further allows for location buffers, and CC looks to create a buffer of inputs needed by the drum. Goldratt (1999) defines a system constraint as what prohibits the system from achieving higher performance, something that is not an act of God and can therefore be handled. This could be true for example in case of the crane, but then raises the questions "What are the tradeoffs?" and "At what cost?"

## TAKT PLANNING

Researchers have described theoretical constructs and applications of takt planning or, more generally speaking, takt production (e.g., Frandson et al. 2013, Linnik et al. 2013, Binninger et al. 2019, Gadbois et al. 2018, Lehtovaara et al. 2020, Jabbari et al. 2020). As is presupposed here, takt planning methods will differ as the project types differ but research in this area is lacking. Barring exceptions such as Tommelein's (2022) detailing of the Work Density Method (WDM), we have found few papers that actually spell out the specifics of any method used to develop the takt plan. Nevertheless, at heart the methods include the following procedural steps:

1. Identify a sequence of steps that make up a linear process. Alternatively, linearize a process that has concurrent steps by sequencing its steps so that they have a one-on-one finish-to-start relationship with at most one other step, or by performing concurrent steps off-takt, that is, removing them from the process under consideration. To illustrate, each square in Figure 1 represents a process step and its color refers to a specific trade. One trade may perform different steps in the process either with the same crew or with different crews.

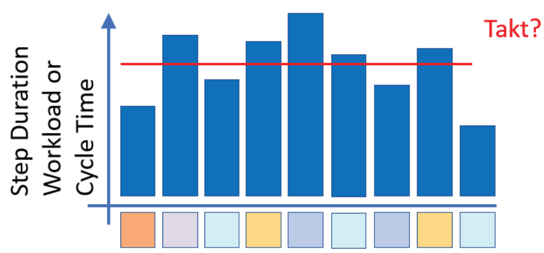


Figure 1: Workload histogram for a linear process
(aka. cycle time histogram or Yamazumi chart)

2. Based on the demand for the process deliverable, calculate what the takt should be (shown by the red line in Figure 1). "Takt Time [is] the pace that exactly meets customer demand given available production time. This is a customer-focused metric" (Moran 2022).
3. Determine the duration of each step. This duration is called the workload or cycle time. It is shown in Figure 1 by a blue vertical bar for each step.
4. The peak of all steps' cycle times must fall below the takt or the process will not be able to fulfil its customer's demand. That peak defines the "Operable Takt Time [which is] the pace you can actually achieve with your current process and equipment. This is a manufacturing-focused metric."[3] (Moran 2022).
5. If the operable takt exceeds the customer's takt, then lower the blue vertical bars until they all fall below the takt (red line). The difference between the two serves as a capacity buffer needed to absorb duration variability. Protecting the takt plan from variability is commonly done by underloading resources (i.e., creating a capacity buffer) or by allocating time- or space buffers (Frandson et al. 2015).

[3] Jabbari et al. (2020) used the notation T(Z) to refer to the peak workload in a workload histogram. This peak defines the operable takt time of a process, although they did not use that term. Z is the number of zones (locations where work is done) into which the work space is divided. T(Z) is a function of Z because the operable takt depends on how the workspace is divided into zones due to the fact that workloads may vary by trade and by zone.

A blue vertical bar (including the tallest one called the peak workload that defines the operable takt) can be lowered by adjusting one or several "throttles" or "adjustment mechanisms" (Binninger et al. 2017) available to planners in general, namely: (1) Modification of product- and component characteristics, (2) Use of alternative breakdowns of the scope of work, (3) Resequencing of work and addition or removal of work from a process sequence, (4) Selection of alternative means and methods used by a trade, and (5) Development of worker- and crew trade skills, and selection of the number of trade resources that can be assigned.

Such throttling can make use of lean methods, such as:

- Single Minute Exchange of Die (SMED): a method to reduce changeover and exchange times between different components in a manufacturing setting. Some people spell out this abbreviation as Simplify, Move, Eliminate, or Delegate.
- Sort, Straighten, Shine, Standardize, and Sustain (5S): a method to increase work space efficiency.
- Plan Do Check Act (PDCA) aka. the Shewhart- or Deming cycle: a method for action learning, which in this context may be used to understand the conditions of process steps relative to each other. Workload leveling between process steps while aiming to achieve the takt (as is illustrated in Figure 1 with the red line) will require changes in cycle times: some will need to be reduced whereas others could be increased and still fall below the takt.

## THEORY OF CONSTRAINTS

An alternative to using a method for takt planning is to apply the Critical Chain (CC) method based on the Theory of Constraints (ToC) (Goldratt 1999). The ToC starts by recognizing the slowest step (bottleneck) in a process. The bottleneck is designated as the drum or pacesetter for the process. Steps upstream of this bottleneck are paced using a pull mechanism called a rope that is tied to the drum. A buffer is intentionally built up before the bottleneck to prevent that bottleneck from starving. This explains the drum-buffer-rope method.

The drum-buffer-rope method can be applied to construction settings. However, its shortcomings must be addressed as well. Roser (2014) mentioned two. First, the rope ties the steps upstream of the bottleneck to that bottleneck, but the ToC is silent about how to manage the steps downstream. These downstream steps—like all other steps in the process—must be considered in any production system's design. Second, a process may have, not one, but multiple bottlenecks and those may shift over time (Roser et al. 2002).

Lerche et al. (2022a) illustrated how a combination of takt and kanban thinking could be applied to protect the process steps deemed bottlenecks. The kanban (like the rope in the ToC) adds a pull link between process steps in the takt plan to prevent any process step from commencing when its preconditions are not met, or the previous task is not finished.

## COST

As mentioned, an objective in takt planning is to make the operable takt less than the customer's takt and this is done by lowering workload peaks or using other throttles. An issue not previously discussed is that the application of a throttle has not only cycle time- but also cost implications. When looking at only direct costs, in certain situations it may be reasonable to claim that there is no extra cost for using the throttle of speeding up or slowing down work. For example, assume that the cost to perform a step with a certain quantity of work (e.g., 60 units in a zone) can be computed by multiplying a production rate (e.g., one worker can install 5 units/hour) by the number of resources at their cost rate (e.g., a worker is paid $100/hour) (or some other function, but ignoring any non-linearities in the cost function that may arise for example from overcrowding). Using these example numbers, the duration of the step when performed by one worker is 60 units / (5 units/hour) or 12 hours and thus the cost of the step in this zone is $1,200. Using two workers, the duration is cut in half to 6 hours but the cost is still

$1,200. Other considerations come into play in the throttling process especially when considering cost, such as:

- A cost penalty will be incurred when the workload is highly variable and unevenly distributed from one zone to another, as this makes it difficult for a trade to maintain a constant crew size. This is not to say that crew sizes cannot change over time, but it is the case that keeping people working together for a longer time results in better performance.
- Some workload variability could be absorbed by engaging multi-skilled workers, but they are likely paid more than less-skilled workers.
- Some resources are very expensive compared to others and may be available only in limited numbers. Throttling up may therefore be cost prohibitive or impossible altogether.

## RESEARCH PERSPECTIVE

The research method follows a case study approach with multiple embedded units of analysis. The first unit of analysis is the case description in terms of context, process, and cost drivers. The second unit of analysis investigates the takt planning method as previously described with procedural steps 1 through 5.

## PROJECT TYPE 1: WIND FARM INFRASTRUCTURE

### PROJECT SCOPE

The construction of wind farm infrastructure combines multiple technical modules, to result in a power plant with a life time exceeding 20 years based on the turbines' end-of-life expectancy. Wind farms are often divided in two systems: (1) the transmission system (housing of electrical power transmission equipment or cabling) connecting the power plant with a national grid, and (2) the power generating system (cable connections, wind turbine generator structures) harvesting the wind's energy. The module assembly strategy follows what Peltokorpi et al. (2018) calls "sectional," leading to interfaces having clear technical dependencies.

### PROCESS

As the wind energy industry is rapidly developing both onshore and offshore, modules are increasing in power output capacity and physical size (Enevoldsen and Xydois 2019). At the highest level, a wind farm can be broken up into separate packages, pertaining to grid connection points, cables, transformer stations, foundations, and wind turbines. Each of these packages then contains sub-systems or modules, e.g., the wind turbines package consists of the tower, nacelle, and blades. Lerche et al. (2022) revealed how the process time for an offshore cable termination is related to the design choices made not only for the cable itself but also for its support structures. They reported how the offshore wind farm infrastructure is assembled in accordance with its technical dependencies, and noted that technical dependencies appear to make the ordering of processes predictable and replicable. This is the case especially for installation processes that require equipment (e.g., cranes, purpose-built vessels, or underwater robotics) (Barlow et al. 2018), which might explain why offshore installation in particular has been planned using CPM (Lerche 2020). When a technical dependency is broken, schedule adjustments can be made, e.g., if a foundation is installed but cabling is not complete, the turbine can be installed but not commissioned, and temporary power generators would be required to sustain its product integrity (lifetime expectancy) until the cabling is completed.

### COST

The tradeoffs made by the infrastructure developers are related to the cost of installation versus the cost of maintaining power production, while accounting for the financial incentives for finishing early or at least on time that stem from the opportunity to start generating power and earn revenue (opportunity cost). Sovacool et al. (2017) described the difference between onshore and offshore in terms of the risk associated with the cost of the equipment, in particular purpose-built vessels used for offshore installation (Barlow et al. 2014). Installation vessels being the main cost driver, with an average rate of €250,000/day, has made both developers of offshore infrastructure and their supplier pool of manufacturers (cables, transformer stations, foundations, and turbines) conscious of vessel capacities and costs. Consequently, they have shifted their focus to limiting the time spent offshore (Lacal-Arántegui et al. 2018; Lerche et al. 2020, 2022). Although onshore wind farm infrastructure development and project execution use less expensive equipment, the relative cost of equipment is still considerable.

## DEFINING THE TAKT

The technical dependencies provide clear direction for the linearity of process steps between trades. Wind farm infrastructure installation requires only a few trades, electrical and mechanical trades being the primary ones, where specialized resources for specific process steps are seen as 'off-takt'. Lerche et al. (2020, 2022) defined process steps according to module type and trade required (Figure 2):

1. For the main module process steps where the use of highly specialized equipment is essential (e.g., a crane with exceptionally large reach or hoisting capacity), these can be determined by contractual terms for either the equipment or for the assembly crew. It could also be determined by what durations to handle given modules are practically feasible for the equipment. Process steps preceding and succeeding these then either align with the drum (as mentioned in the ToC) or planned to a different takt. For process steps without such equipment requirements, the durations could be organized according to location or trade as is the case when developing a (takt) plan for building construction (Lehtovaara et al. 2020).
2. Considering large equipment for handling the modules (installation processes here) to be the drum, this sets the takt for up- and down-stream process steps. The takt is then calculated according to the beat of procedural step 2. Lerche et al. (2020) found that installation vessels set the beat, providing pre-assemblies with a turnaround rate that could be divided by the number of modules in a batch. Such a calculation would also apply in case additional units of large equipment (e.g., purpose-built vessels) are introduced.

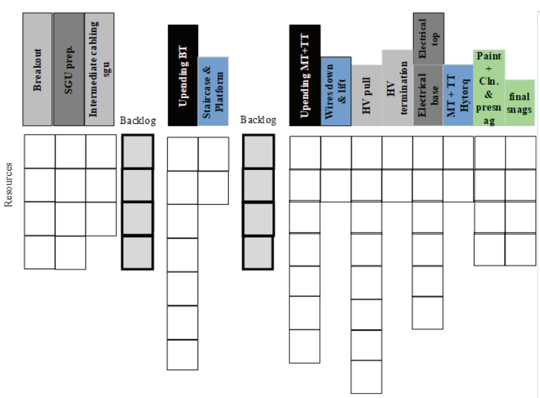


Figure 2: Process steps with resource requirements (Lerche et al. 2022)

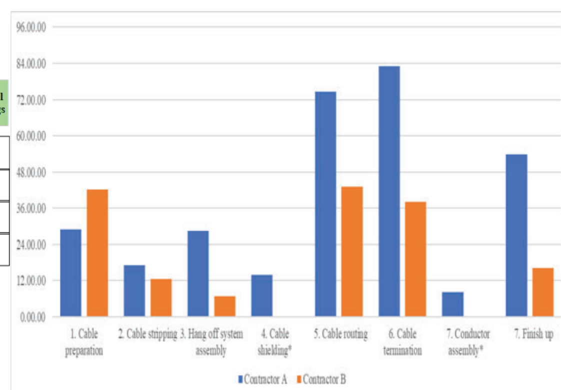


Figure 3: Comparison of process step durations between two contractors (Lerche et al. 2022)

3. Capacity buffering with resources allows for leveling the process steps durations, those process steps with high technical dependencies or equipment constraints require alternative solutions as design changes, or capacity improvements to the equipment. Simultaneous work of different trades is commonly used for offshore commissioning, allowing the trade to finish a location one at the time.

# PROJECT TYPE 2: HEALTHCARE FACILITIES

## PROJECT SCOPE

The construction of a healthcare facility comprises multiple project phases pertaining to the building's core-and-shell and fit it out (site work, foundations, structure, exterior cladding, interior rough-in, finishes, commissioning). Healthcare projects require the installation and commissioning of complex mechanical-, piping-, electrical-, fire-life-safety- and other systems each of which must meet stringent performance requirements (seismic safety, sustainability requirements, etc.), and all are packed together in a limited amount of building space designated to utilities. Therefore, these projects are considered complex when compared to commercial building or housing projects, for example.

Here, we focus specifically on a later phase of project delivery, namely interior work (rough-in and finishes), during which many trade specialists are involved. Because of interdependence between the trades' work, judicious coordination of that work can significantly help to speed it up. Therefore, not surprisingly, in healthcare- and laboratory projects such work appears to have been planned more often using takt (e.g., Linnik et al. 2013, Frandson and Tommelein 2014, Gadbois et al. 2018) than has been the case for earlier work (e.g., foundations).

## PROCESS

Interior work is typically not dependent on a single, pacing resource (in contrast, e.g., structural steel erection may be paced by a tower crane). Due to its relative complexity, it is quite common to have ten if not more specialty contractors involved, all requiring access to and sharing site space, material hoists, as well as other resources. In addition to space and the aforementioned resource dependencies, the work of one trade often forms the substrate for the work of the next trade (e.g., framing must precede hanging drywall, priming, and painting).

For certain scopes of work, there is a natural flow to doing building construction work (Riley et al. 1995) and work will proceed in a Parade of Trades. However, that flow can be flexible: some work can be done out of order without becoming cost prohibitive. Dependencies exist but can be modified, e.g., while it is preferrable to paint walls before putting flooring in a room, if flooring needs to come first then protection can be added to avoid paint spilling on it.

## COST

For each trade, the cost of an activity is a function of worker pay based on their skills, and the cost of materials, tools, and equipment (plus overhead and profit). Worker costs (as opposed to equipment costs in wind farm projects) are relatively high compared to the other costs. At the risk of overgeneralization, the resources required for healthcare project delivery are not as capital intensive as those required to deliver wind farm infrastructure.

Furthermore, the cost of work in a process, step-by-step, is relatively speaking commensurate across trades. To achieve schedule milestones, crews may be doubled up and work in different locations concurrently with no cost penalty (as explained earlier). Shared resources (e.g., material hoists and manlifts) may be expensive and scarce, but of note is that many trades take turns using them so that potentially many process steps are impacted by them (unless their use can be scheduled off-takt).

## DEFINING THE TAKT

The customer process of rough-in and finishes, the commissioning phase, involves numerous systems (heating ventilation and air conditioning, potable and perhaps also grey water, medical gasses, building controls, etc.). Upon project turnover, the move-in phase involves getting people to occupy and use the building. The costs arising from missed handoffs between those processes and opportunity costs are high. A goal of takt planning therefore is to hit the project commissioning and turn-over milestone dates and to do so reliably.

# DISCUSSION

## UNDERSTANDING THE THROTTLES

Lowering of process-step cycle times can be done by applying throttles, as previously mentioned (also see Lerche et al. 2020, 2022, and Tommelein and Emdanat 2022):

1. Apply PDCA to reduce the cycle time of a process step (but do not confuse fundamental improvements with learning curve effects) as well as reduce its cycle-time variability.
2. Use technical solutions to reduce assembly durations, e.g., replace slower mechanical or hydraulic tools with faster electrical tools to shorten the duration of bolt tightening in module joints. Find alternative tool solutions to improve installation process steps (Zhao et al. 2018). Redesign work processes.
3. Crew up (or down) when worker availability is not a constraint (as may be when highly specialized workers are required, such as unique equipment operators) and sufficient work space is available.
4. Add equipment capacity to expedite work.
5. Divide process steps into smaller ones, esp. those with few technical dependencies and not requiring heavy equipment. E.g., if the crane is the drum, then try to remove steps that require crane use in order to alleviate its workload. Use a small crane for assemblies up to a defined height, before using the main crane for higher lifts.
6. Take some scope out of a process step and perform that scope at another time.
7. Pre-fabricate assemblies. As when working with larger modules being fabricated elsewhere, move assembly upstream from the construction site to a manufacturing site.
8. Design fewer process steps into the product, e.g., the cable case in Lerche et al. (2022).
9. Change the product design but be mindful that this can affect individual process steps positively or negatively (e.g., Figure 3 illustrates step durations of two contractors who completed similar processes but chose different designs).
10. Eliminate interface assemblies by “thinking in” the assembly process, e.g., apply mistakeproofing by using electrical plugs on both sides instead of hard wiring (e.g., Figure 4 in Tommelein 2008).
11. Add buffers to protect the bottleneck step in a process (i.e., ensure its efficiency and effectiveness), e.g., build up an inventory buffer of modules at quay side, ready for vessels to carry them offshore in order to protect the installation process step.

    Of note is that in the offshore literature there is a tendency to focus on the transport of personnel (Lerche et al. 2022), optimizing the use of vessels that are not directly involved in process steps (Petersen et al. 2016) and are not a process bottleneck. This practice merely reduces flow-variability but does not improve process performance.

Decisions in this regard must be made early enough to be most effective, however, even when made at the last minute they can still be beneficial to process performance.

## IMPLICATIONS FOR TAKT PLANNING

Based on a project’s type (Table 1) some throttles for takt planning are used more easily and cost-effectively than others. Steps for constructing wind farm infrastructure have numerous technical- and key resource dependencies; they involve expensive and unique equipment. As the dimensions of prefabricated units get larger, opportunities to devise alternative plans and flexibility in planning tend to diminish (you cannot beat physics). One runs into limitations on available equipment sizes and highly skilled operators, on allowable loads on bridges, overhead obstructions, ground pressures, allowable truck loads and volumes (weight per tire, weight distribution), etc. Equipment (the drum) determines the operable takt. It may be that one piece of equipment is available, but no additional one is readily available or affordable. In situations like this, planners must first resort to using SMED to improve drum throughput.

Table 1: Takt planning comparison

| Case 1 | Case 2 |
|---|---|
| **STEP IN TAKT PLANNING**<br>1. Step and process definition: Dependencies define process step sequencing, Space, Steps in the process | |
| a. Dependencies express technical execution strategies.<br>b. The dimensions of the modules determines the need for space (location), and what can be done in adjacent spaces.<br>c. Requires fewer different trades (e.g., electrical and mechanical) with fewer and 'bigger' steps. It is clear who you need when and in what sequence. | a. Dependencies are based on choices related to logical sequencing of work, and there is some flexibility in that (e.g., paint walls before putting in flooring or vice versa, though the former may be preferred)<br>b.. Work can be broken into "chunks" of various sizes which creates flexibility in deciding what to do where.<br>c. Numerous specialist trades are needed and must coordinate their shared use of space (especially on 'fast' projects where concurrency can be achieved). |
| **2.** Customer takt | |
| Customer demand for speed is based on the business case but constrained by what is feasible given available equipment capacity (e.g., large vessels). | Customer demand for speed is based on the business case and drives the determination of production rates (quantity installed per crew hour) and resource loading. |
| **3.** Individual step cycle time | |
| Step cycle time may be on the order of hours, driven by equipment costs. | Step cycle time may be on the order of a fraction of one day to a few days, typically less than the time window covered in a weekly work plan. |
| **4.** Process operable takt | |
| Specialized equipment defines operable takt (and cost), i.e., drum (in CC). Lerche et al. (2020) revealed how the industry's tendency to focus on the drum beat defined by costly equipment. | Work density and resource availability defines operable takt (e.g., how many electricians can productively work in an electrical room?). |
| **5.** Process operable takt | |
| Protection of the drum by buffering with inventory (e.g., stage 2 or 3 times more modules than will be transported on any one vessel). | Use capacity buffering and workable backlog. |

Planners can view processes from both a design- and commercial perspective. When engaged early in design they can balance these perspectives, whereas later that becomes increasingly difficult. When balancing is accomplished to the extent possible, they can design the takt plan based on the drum's beat and synchronize other process steps based on the drum.

In contrast to equipment-intensive work (e.g., foundation piles, segmented bridges, or wind turbine towers) that is dominated by the pace at which that equipment can "go," processes for healthcare project delivery have more substrate- and fewer technical dependencies. Worker-intensive work presumably has flexibility in crewing up or down. It is relatively easy to get more people and not too costly to provide the crew with needed tools and equipment.

Before construction starts, Case 1 has shown that actively thinking of repetition in design can be beneficial. Such repetition is also beneficial as the modules are prefabricated. Prefabrication means taking work out of a (site) process or moving work to another process in order to reduce a given step duration(s) and therefore the corresponding process duration. Case 2 can also benefit from prefabrication. In addition, Case 2 can benefit from designs that use multiple smaller components distributed in space, rather than a few larger ones focused in one area, when this leads to a decrease in work density by zone.

During construction, both cases benefit from conducting first run studies and designing operations, defining standard work, and mistakeproofing to help achieve reliability in step execution. While case 1 further can take advantage of repetition, it can further strengthen the effect from the other throttles, as the modules introduce limited variation. This also means that Case 1 can seek improvement through tool selection due to high repetitions, e.g., moving from slowly rotating hydraulic tool heads to electrical. Process step improvement for Case 2 relies on trades judiciously choosing the "best" trade tools.

Both cases reveal that increasing resource capacity can lead to process improvement, this is presumed easy for both cases, while Case 1 has a limitation of geographical space or work location constraints. Secondary around the resources, Case 2 also shows that scope of a step can be combined vs. divided and/or reallocated to other steps within limits of constraints imposed by numerous trade jurisdictions. As Case 1 dominantly require mechanic or electrical resources, the use of multi-skilled trades is possible, this is supported by the offshore settings being less restrictive in terms of labor union jurisdictions.

# CONCLUSIONS

By means of two samples of projects of different types, we illustrated that takt planning methods vary due to consideration given to relative cycle times and associated resource costs of individual steps in their production processes, while accounting for the dependencies between those steps and between processes. The costs associated with the use of various throttles to change workload peaks play a role in the planning process. To our knowledge, little has been written to date about the relative costs of process steps in takt plans, and how these costs affect the opportunities planners have and choices they make when leveling workloads to determine the so-called "operable" takt time. We found that the CC method stemming from the ToC offers useful perspective on methods for takt planning especially in cases where a single, expensive resource or step clearly defines the process bottleneck, and the bottleneck's cycle time well exceeds the cycle time of other process steps. More in-depth study is in order of how cost considerations affect the choice of a takt planning method.

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