TAKT TIME PLANNING FOR CONSTRUCTION OF EXTERIOR CLADDING

Adam Frandson[1], Klas Berghede[2] and Iris D. Tommelein[3]

ABSTRACT

This paper presents the concept and steps taken, as well as a case study on production scheduling, to implement the use of Takt time. It starts with an overview of traditional construction scheduling and contrasts that with the use of production scheduling using Takt time. It then presents a process for Takt time scheduling and illustrates its application by means of a case study. Takt time was used to drive installation of the exterior cladding system on a healthcare facility in Sacramento, California. Thanks to the use of a production schedule with a four-day Takt, the traditional construction schedule of 11 months for partial completion of the exteriors was reduced to 5.5 months. This case study illustrates the successful development and application of Takt time, challenges, benefits, and lessons learned.

KEYWORDS

Takt time, production planning, scheduling, exterior cladding.

INTRODUCTION

WHAT IS TAKT TIME?

The German word 'Takt' refers to 'rhythm' or 'cadence,' that is, to the regularity with which something gets done. It is a design parameter used in a production settings (be it manufacturing, construction, or other) (Hopp and Spearman 2008), defined as: *Takt time is the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand rate).*

Setting a rate for production is not a new concept in construction. For many years, practitioners have used the line of balance on projects, including lean projects (e.g., Seppanen and Aalto 2005, Kemmer et al. 2008). Practitioners in the US housing industry have been using demand management and 'even-flow production' to balance resources and reduce cycle times (Ballard 2001, Wardell 2003, Bashford et al. 2004, Yu et al. 2009). Bulhoes et al. (2006) demonstrated that controlling the production of a concrete structure using small, repetitive cycles resulted in improvements in productivity, reductions in cycle times, and reductions in waste. Takt time has been used successfully in home building (Wardell 2003), modular home manufacturing (Valarde et al. 2009), and highway construction (Fiallo and Howell 2012). However,

1 Graduate Student, Civil and Environmental Engineering Department, Univ. of California, Berkeley, CA 94720-1712, USA, Phone +1 (661) 644-2978, afrandson@berkeley.edu

2 Production Manager, The Boldt Company, Western Operations, 2150 River Plaza Drive, Suite 255, Sacramento, CA 95833

3 Professor, Civil and Environmental Engineering, Department, and Director of the Project Production Systems Laboratory (p2sl.berkeley.edu), 212 McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, USA, Phone +1 (510) 643-8678, tommelein@ce.berkeley.edu

little has been documented to date as to what methodology can be followed specifically in architecture-engineering-construction to design a production system with Takt time. This paper, a follow-on to the paper by Linnik et al. (2013) on "An experiment in takt time planning applied to non-repetitive work," aims to fill this gap. We here present the method for and findings resulting from the implementation of Takt time to drive the installation of exterior cladding on a healthcare project.

SCHEDULING FOR PRODUCTION

A challenge in delivering construction projects is developing not only the overall construction schedule but also the schedule for production. The first schedule tends to be developed in a more top-down fashion, the second in a more bottom-up fashion. The two are interrelated, of course, and must therefore be designed to be in accordance with one another. Regardless of where one starts, developing these two schedules will require some going back-and-forth.

Here we refer to the ***overall construction schedule*** as the schedule from start to finish of a project represented, e.g., with activities-on-nodes when using the Critical Path Method (CPM). In the language of the Last Planner System™, this schedule corresponds to the so-called master schedule. Effort going into planning based on 'typical' or assumed ways of doing construction (e.g., based on estimating guides and experience gained on past projects) leads to the identification of activities-on-nodes that delimit scopes of work. These activities can be used to subcontract out work. This schedule can be used to assess overall project feasibility and to identify long-lead items. Furthermore, it can serve as the basis for identifying major milestones which in turn 'feed' into the phase scheduling process.

The ***schedule for production*** is the output of production system design. Instead of being based on assumed ways of working (including estimates and experience), it is based on information obtained from those who will actually do the work, describing alternative ways in which they can do it, how they may prefer to do it, and why (e.g., answering questions such as: What are the resource implications of doing the work in one way or another?).

The way in which the production schedule gets developed differs significantly from the way in which the overall construction schedule 'traditionally' gets developed: specifically, it requires production system design, not simply breaking the work down in pieces and then estimating each piece (as is done when creating work packages). However, we say 'traditionally' here because we think that the master schedule too should be an output of production system design. Merely breaking the whole into pieces and then addressing each piece in the best way possible (in and of its own), in the expectation that their optimal completion will optimally fit the whole, is naive especially when many interdependencies exist between those pieces.

To develop a schedule for production, it is essential to listen attentively to those doing the work. When all have been heard and their individual schedule alternatives have been tuned so as to mesh together, everyone must commit to doing the work as agreed. One needs to know who specifically will be involved (e.g., subcontractors must be on board and their foremen involved in the process), so production schedule development is done phase by phase, each phase delimited by major milestones as identified on the master schedule.

TAKT TIME

TAKT TIME IN MANUFACTURING

Takt time is a design parameter for machine-paced manufacturing lines, implemented to ascertain that the rate of customer demand rate will be met, yet not exceeded (Hopp and Spearman 2008). It is widely used in the Toyota Production System.

Developing a Takt that matches the capability of all workstations in a line (or system) and, vice-versa, adjusting the capabilities of workstations to match Takt, is a balancing act critical to production-system success. When Takt time and workstation capabilities are greatly unmatched, either product will accumulate in-between workstations when the next workstation is not yet ready to perform its operation on the product, or a workstation will starve (wait for work) when it performs its operations much faster than its predecessor. Variation in production rates makes this balancing act more challenging (e.g., Tommelein et al. 1999).

Designing with Takt time as a parameter helps create a pull system of production. Pull systems are demand-rate driven: designing for downstream demand rates allows for production systems to maintain a steady flow because output rates and demand rates are matched. In contrast, push systems are plan- or forecast driven: output rates and demand rates are not necessarily matched. Pull systems tend to be smoother in flow than push systems are. Enabling a production system to continuously flow helps production problems to come to the surface, so they can be addressed (Liker 2006).

TAKT TIME IN CONSTRUCTION

Applied in construction, Takt time is a design parameter for the flow of work, a flow that is labor paced. (In some types of construction, e.g., equipment-intensive work, the flow can also be machine paced). Production system designs question are ‘How fast can some specific work flow?’ and conversely ‘How fast should such work flow in order to meet some specified project deadline? The goal is to have the Parade of Trades (Tommelein et al. 1999) progress at the demand rate.

One alternative for defining the demand rate is to use the time frame within which to complete work, assuming it is set, known, and ‘validated’ in the sense that it can be matched by the available resources and means-and-methods. Another alternative is to consider available resources and means-and-methods, identify the maximum production capacity of the slowest trade and study if it can be improved, use that improved maximum to infer an achievable demand rate, and then align the other trades to match it. One may have to go back and forth between both alternatives; however, the latter one was used in the case study that illustrates this paper.

Introducing Takt time into construction means going from uneven task durations for each trade in a sequence to a consistent task duration for every trade, while maintaining a production rate that meets the requirements of the master schedule. To accomplish this, for each phase of construction, the project is broken down in physical areas (zones) where trades may spend up to a certain amount of time (the Takt time) in order to complete their elements of work. Delimiting these zones vs. setting the rate at which trades can move through them, is a design problem.

Figure 1 illustrates the balancing act that is required when solving this design problem. Assume the project work space has been divided into a set of zones. The x-axis shows Zone 1 through Zone 4, as an example, but there could be many more zones in a (phase of) a project. In each zone, each trade identifies the scope of their work, their means of working, and their crew loading. Accordingly, the y-axis shows how much time each trade will need to complete their work in each zone.

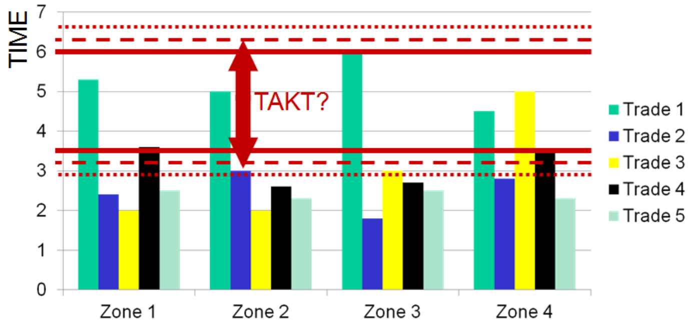


Figure 1: Selection of Takt time vs. Trade-specific Duration of Work in each Zone

Takt time sets an upper-bound on the time any one trade is afforded to take in any one zone. Some trade may be the slowest one in one zone and another trade in another zone. If the Takt time is set high, then many trades will have idle time. When one trade goes faster than all others, the system suffers from the waste of overproduction. Trades with idle time would work under capacity so they may want to decrease their crew size, perform workable backlog elsewhere, etc. If the Takt is lowered, then increasingly more trades will be increasingly likely to exceed it (In this paper, for brevity, we omit discussion of the impact of variation on the time each trade needs in each zone, but this is an important consideration in the Takt-time system's design). Trades that exceed Takt time can address their production imbalance by considering the use of different means-and-methods, doing some work outside of the Takt time (e.g., setup or prefabrication), increasing crew sizes, etc. This IS production system design, the down-to-the-details effort required in work structuring.

Why Develop a Production Schedule Using Takt Time?

Advantages of planning production using Takt time vs. using 'traditional' construction scheduling, are that trade crews (production units):

- Have the opportunity to discuss with other trades how each one can (alternatives) and would like (preference) to do their work, so that together they can determine the system bottlenecks (pace setters) and what approach suits which trade in order to best produce the project as a whole;
- Know exactly where they will be working and when, so that, if any coordination in that regard remains, it can be worked out without much ado, and no surprises should arise during schedule execution;
- Know their place in the trade sequence, so that they can focus on intra-trade resource coordination (e.g., staging areas for materials and assemblies, access paths for delivering materials, shared hoisting means, etc.);
- Can count on plan predictability (regarding the time and space where they will work) and therefore can plan in detail exactly how they will work (including

planning for safety, quality, logistics), without having to simultaneously spend time planning for alternatives (contingency needed in case the plan should fail);

- Get immediate feedback on the progress they are making (Do they or do they not meet their Takt? Are quality requirements met, as assessed either within-trade or in the intra-trade hand-off? Etc.), because the unit of control is relatively small (units of Takt time are on the order of a day or a few days, so there are many such units in a phase that lasts a few months);
- Can have their progress assessed in small batches for payment purposes; and thus,
- Can be more productive than they otherwise may be.

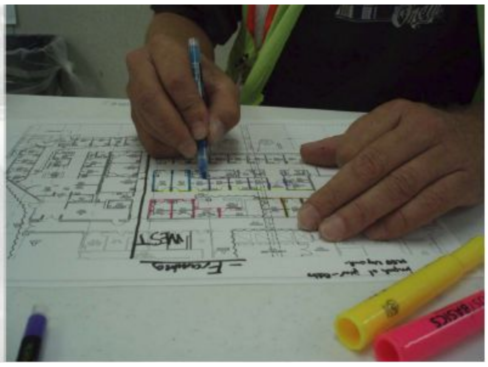
PROCESS FOR PRODUCTION PLANNING USING TAKT-TIME

Through experimentation, the production team identified six phases for the process that results in the identification of a Takt time, which is then used in production planning. Although we list these phases in sequential order here, their implementation requires iteration:

- Gather information.
- Define areas of work (zones).
- Understand the trade sequence.
- Understand the individual trade durations.
- Balance the workflow.
- Establish the production plan.

The Takt-time process begins with the need for planners together with the trades to understand the desired workflow of the trades; how the trades want to perform the work (means-and-methods) and how much time they expect to require based on the crew capacity they can provide. The next step in production planning is defining the trade-specific logical groupings (i.e., batches) of work and understanding the sequence of work through these batches. When these batches of work (and their corresponding zones) are defined, the duration each trade requires in each of these zones is calculated. Those involved then find a balance. From this balanced workflow, a production plan based on a Takt time is created.

Phase 1 - Gather Information: Trade by trade, identify what work exactly is to be done where exactly. One method for gathering such information is to have those who understand the details of the work (e.g., foremen) use a colored marker to highlight a floor plan in order to show the work they can do, e.g., in a day. This results in 'color-ups' (Figures 2 and 3). Color-ups differ from quantity take-offs (which describe a more general nature of the work to be performed and in what amount, in order to support estimating and procurement) in that they require thought on how exactly the work will be performed, by whom, where, and in what sequence. Planners can work with trades by asking questions such as, 'If you could start anywhere on day one, where would you begin?' Each trade uses a different color to mark up their scope of work on the floor plans. This process helps to identify the preferred durations and individual trades' production plans. These color-ups also identify the natural breaks in the work (e.g., at fire-rated walls) and areas that require a break (e.g., joints). In addition, the color-ups identify the preferred sequence of work (i.e., work from the shaft out, left to right, etc.).



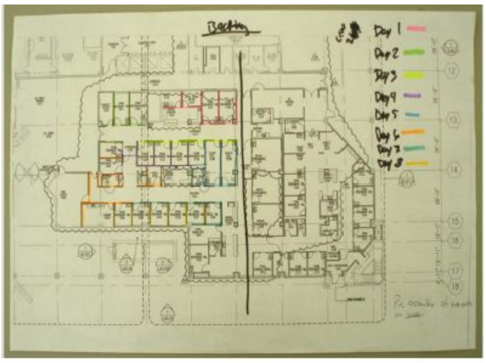


Figure 2: Person Developing a Color-up Figure 3: Example of a Color-up

Color-ups provide essential input in the Takt-time planning process. However, it is not necessarily the case—and in fact it will be quite unlikely—that individual trades will get to do their work exactly as they showed it using color-ups.

Phase 2 - Define Zones: Takt time will be defined as the time a trade is afforded to complete their work in a zone. Accordingly, zones are the areas that trades will be controlled to. The building's ideal zones are batches of work that all take the same amount of time for each trade to complete. Initial zones are created from the information obtained in the previous phase (Figure 4). At this point, the Takt time is still undefined, for there is still not enough information to establish one. Ideally the BIM and the zones can be aligned, but this is currently a challenge due to the level at which the model has been developed vs. the level of detailed knowledge required of production rates for individual trades.

Phase 3 - Understand the Trade Sequence: Understanding the trade sequence requires trade coordination meetings. Who needs to work through a zone, before vs. after whom, and how many passes each trade will require are all vital to understand. While the general sequence of trades is obtained from pull planning, more detailed sequence information is necessary for developing a reliable Takt time.

Phase 4 - Balance the Workflow: The combination of established zones and known sequence information allows for the balancing of workflow. The identified production planning concerns at this phase are: What trade activities need to slow down? What activities need to go faster? How can zones be further adjusted to balance out the workflow?

Phase 5 - Understand the Individual Trade Durations: Balancing the workflow requires first-run studies to establish more accurate durations in order to gauge the trades' work in each zone. First-run studies are critical in identifying the soundness of the design and the details provided. Obtaining workflow balance is not something that occurs immediately. Rather, it gets established through a gradual, continuously-improving process that establishes the Takt time.

Phase 6: Production Planning: The rate at which the activities proceed through the zones with a balanced workflow is the Takt time for the set of activities. Using this production rate, the zones can be broken down into smaller time increments. The purpose of managing to a time interval smaller than the Takt time is to track progress as work proceeds so as to be able to forecast of when the Takt time will likely not be met. Corrective action can then be taken right away, as soon as possible, well before the Takt is exceeded.

CASE STUDY

This paper presents a case study of Takt time developed in planning the production of the construction of the exterior cladding system at the Anderson Lucchetti Women's and Children's Center (WCC) in Sacramento, California. Given its location, the WCC must meet, among various building codes, California's earthquake design codes including the requirements of the Office of Statewide Health Planning and Development (OSHPD). The WCC is an 8-story, 242-bed, 36,700 m^2 (395,000 ft^2) facility that focuses on women and pediatric care. This center is a part of a multi-project $735 million health care program (Boldt 2012).

The owner of the project is Sutter Health, a not-for-profit health care provider in Northern California. The architect on the project is Ewing Cole Architects. The construction manager and general contractor on the project is The Boldt Company.

Development of a Takt time for the exterior trade activities was selected as the first Takt-time experiment on this project. The exterior was broken down into zones and information was gathered from trades. The sequence of work was framing, windows, scaffolding, sheeting, applying water proofing (Exo-Air), applying a second kind of water proofing (ETA), and patching. The team conducted first-run studies and observed that framing took significantly longer than the other trades and therefore required the most adjustment (Figure 5).

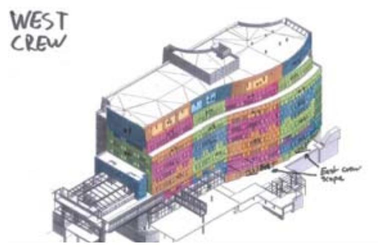


Figure 4: Example of zones defined by information from the previous phase

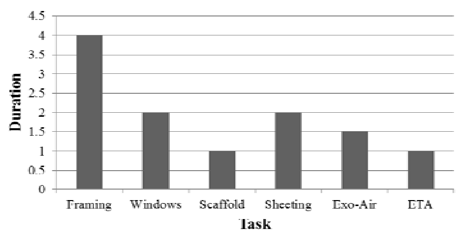


Figure 5: Initial Durations through one Zone of Work

An option for balancing the framing activity relative to other activities was to use an additional crew. One window crew, being twice as fast as one framing crew, could support two framing crews. The same was true for scaffold, sheeting, Exo-Air, and ETA. A buffer balanced the window crew. As framing went up to the next floor while the windows completed, the framing crew would move up and the window crew would have to go away. This was due to the fact that as the framing crews went up, the window crew needed to stagger back because there was one window crew for the two framing crews. One limitation to using one window crew to two framing crews was that you can only have as many windows crews on a side as you have sides. Thus if you have four zones, you can only have four crews. The buffer was used for the windows crews and they moved off the floor to work on something else that was workable backlog. In this circumstance, the workable backlog was work in the stairways. This allowed for framing crews to move up and get off of the elevation. So as the trades went up, it allowed the framing crews to get off the elevation. Figure 6 reflects the flow of work and the four-day Takt time established for the exterior work.

Once the production plan was established, the GC managed it with daily meetings in addition to the normal weekly work-planning meetings. A general superintendent and a project engineer were dedicated to the exterior work. The teams were formed as an Integrated Project Delivery team. The superintendent acted as a leader and facilitator for all of the different trade superintendents. The general superintendent made the final decisions, and the project engineer was responsible for updating and checking the plans. The team members acknowledged that this framework took much more coordination than the traditional method of building an exterior. The general superintendent was also involved with organizing the daily production plans that were filled out online and ensured that they were updated and reliable. Overall, the superintendents were identified as the cornerstone to the entire production planning process.

RESULTS

After establishing a four-day Takt time, the first three production plans were missed. However, every remaining production plan was realized. The team agreed that the initial start of Takt-time production planning required more work than traditional production planning, for there was learning and each member was urged to think of alternative sequences and methods to build. One reason given for why the Takt-time production planning process took more work was that “in order to improve production slightly, crews just have to work a little bit harder; however, to improve production dramatically, the entire team must work together and really think about every task.” Overall, the production schedule required 11-months to achieve partial completion and exceeded the demand of the master schedule. Through the development of a Takt time and the resulting even flow of work, the same scope of exterior work was actually completed in 5 months (Figure 7). Indeed, trades were able to move through small areas quickly and their work was controlled accordingly. The increased production rate was also met despite the fact that temporary roofing and a change in the framing method from stick-build to panelization were added to the scope of work, which were not initially planned for.

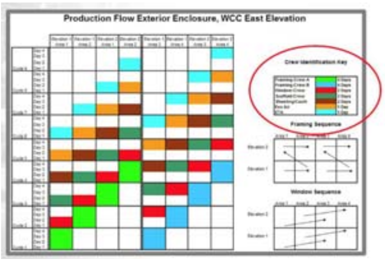


Figure 6: Sequence of work for exteriors

Figure 7: Exteriors after +/- 5 months

LESSONS LEARNED

Several lessons were learned from implementing Takt time for the exterior work on this project. First, the number one challenge identified was communicating the production plan. Clear communication using the correct medium is important because it helps make daily commitments possible. Making sure everyone on the production team is on the same page with a clear and consistent goal is critical.

Second, the production team identified that Takt time required a new degree of discipline in order to hold to the plan, for it would have been easy in the beginning of the production planning process to revert to the traditional planning process. The change required a change in people's mindset. This level of detail in production planning created stress for the trade foremen because each crew was held accountable to a daily quantity of work, and the whole job depended on it. This is a type of stress that individuals were not used to. The production team realized that a good plan from the beginning sets a Takt time; this establishes a sense of urgency. However, if the building process is not well-understood, then all the Takt time adds is stress. The production team solved this challenge by initially understanding the team's concerns and adding time onto the Takt time. Eventually the production problems were solved, everyone was fully committed to the production plan, and everyone was able to realize it.

Third, the team learned that production planning at a daily level requires a higher level of support for the people on the planning team. If daily-level production is to be controlled, then a general contractor needs to be aware that they have to be ready to support people on all different levels. Simply publishing the plan is not sufficient. Personal growth and well-being needs to be managed and supported as well. This goes for the trade superintendents, foremen, laborers, and project engineers.

CONCLUSIONS

Takt time in construction serves as a design parameter for production planning. The six phases gone through in order to obtain a Takt are: (1) understanding the individual trade activity requirements, (2) defining the zones of work, (3) understanding the trade activity sequence, (4) applying durations, (5) balancing the workflow, and (6) managing the production plan. The Takt time sets the rate at which each zone is completed and thereby balances the workflow.

On this project, the WCC production team used a four-day Takt time to balance the trade activities for the east and west faces of the building. The original schedule provided 11 months to complete the work. Using the Takt time and managing production at a daily level, the team completed the work in 5 months.

The benefit to using a Takt time to manage production is that it provides a clear daily goal for each activity, productivity increases, problems must be solved promptly, and construction aligns with fabrication production. The results also suggest that frequent (e.g., daily) project cost control is possible due to detailed level production is managed to. The challenge related to using a Takt time for production purposes is that clear communication and a higher degree of planning for each task is required. Overall, this example of Takt time used in construction demonstrates that balancing and managing the production of all trade activities through an area of work (zone) on a short interval, though challenging, provides overall benefit to a project.

ACKNOWLEDGMENTS

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