AN EXPERIMENT IN TAKT TIME PLANNING APPLIED TO NON-REPETITIVE WORK

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ABSTRACT

Takt time planning has been used in construction, but was limited to highly repetitive projects such as highways, pipelines, high-rise buildings, and single family homes. This paper reports on an experiment in takt time planning applied to non-repetitive work, at the Sutter Health Women's and Children's Hospital in Sacramento, CA.

Takt time planning is based on location breakdown structures with the objective to make work flow continuously. Expected benefits include reduction in project duration and associated costs, increased transparency and predictability of work flow, increased ability to define and deliver work packages of information and materials when needed, and improved design of operations. All of these benefits were confirmed in the experiment.

This paper describes experiments in takt time planning, evaluates the findings, and recommends further improvements in the takt time planning process for future experiments.

KEYWORDS

Collaboration, reliability, takt time planning, time compression, work flow.

INTRODUCTION

This paper reports on experiments in takt time planning at Sutter Health Anderson Lucchetti Women's and Children's Center (WCC), a new 395,241 SF acute care hospital in midtown Sacramento. The nine-story, 242-bed building is designed to be one of the leading pediatric and women's health centers in northern California. The Boldt Company is the project's construction manager/general contractor and EwingCole is the project's architect. Sutter Health requires that its capital projects be delivered using Lean Project Delivery, in accordance with their Integrated Form of Agreement (IFOA) contract (Lichtig, 2005). Boldt and EwingCole replaced a previous team mid-way through the project, and were challenged to complete the project to time and cost targets by numerous design problems and changes.

Takt time is the rate of production matched to the demand rate for what is being produced. Takt time planning refers to the use of appropriate location breakdown structures in each phase of construction and allowing successive trades the same amount of time (the takt), to complete their work in each location. Takt time planning

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was introduced at WCC first in the exterior framing phase[4], then in the interior framing phase of hospital construction. Processes for defining locations and the time allowed for each successive trade to complete work in those locations were developed, tested and refined. Despite major challenges posed by design changes and the imperfections inevitable in a first attempt, the feasibility and effectiveness of takt time planning was demonstrated in these experiments.

Following this introduction, this paper includes sections on the roots of takt time planning, expected benefits and costs, description of takt time planning in the interior framing phase, findings, and conclusions.

ROOTS OF TAKT TIME PLANNING

Takt time is easiest to understand in a machine-paced flow line, where it is obvious that each workstation along the line must complete its work during the time the product is in its work zone. Otherwise, the product moves down the line not ready for the next workstation to add its parts or perform its operations. To minimize movement of workers, work zones are kept as small as possible, given the speed of the line and the capability of each workstation (Baudin, 2002; Hopp & Spearman, 2008).

Takt time is also used in labor-paced flow lines. The use of takt time in fabrication shops was published by Ballard, et al. in 2003, showing that productivity was more than doubled in a precast concrete fabrication plant when work was organized in production cells, around product families, and takt time scheduling and control was used. Productivity doubled without any changes in labor, skills, technology, or design constructability. Another more recent example of takt time use in labor paced flow lines is published by Yu, et al. (2013).

Fabrication shops are similar to construction projects, because the pace and sequence of work is driven by labor rather than by machines. However, in construction projects, the product is fixed in the earth and the parts being assembled become too large to move through workstations. This makes construction a type of fixed position manufacturing, in which the workstations move through the product, rather than vice-versa. Breakthrough on this front came with Kenley & Seppänen's 2010 *Location-Based Management for Construction*, in which the traditional activity-based work breakdown structures were replaced by location breakdown structures. As Kenley and Seppänen note, location breakdown structures have been used in construction for many years, but were restricted to highly repetitive construction such as highways, pipelines, single family homes, and high-rise buildings, the most famous of which is the Empire State Building (Wagner, 2002). Kenley and Seppänen's work promises to extend location breakdown structures to non-repetitive work and thus make it a more broadly available alternative to activity-based planning.

Once given location breakdown structures, there is still another step to get to takt time scheduling. The stated purpose of location-based management, according to Kenley and Seppänen, is to eliminate 'workers waiting on work' and 'work waiting on workers.' When both cannot be achieved, the priority appears, in their case, to be

[4] The exterior framing phase experimentation with takt time planning is described in a companion paper "Takt Time Planning for Construction of Exterior Cladding", by Frandson, Berghede & Tommelein, IGLC 21.

maintaining labor utilization - perhaps a result of the tradition of shifting cost risk to subcontractors. However, the takt time concept from manufacturing suggests that the priority needs to be work flowing continuously, without stopping; i.e., the priority is avoiding ‘work waiting on workers’.

Two arguments can be made to support this priority, both drawn from Toyota. Taiichi Ohno claimed that overproduction is the cause of most of the other forms of waste he identified (Ohno, 1998). For example, inventory in excess of production needs accumulates when work is done before downstream workstations are ready. Continuous flow of work means the work product is always being advanced, and hence, when perfectly realized, there is no inventory in queue and no overproduction.

Liker (2004) included “Create continuous process flow to bring problems to the surface” ☐in the 14 principles of the Toyota Way. Continuous flow of work is needed in order to reduce waste and to promote continuous learning and improvement.

To summarize, literature review reveals that moving from activity-based to location-based breakdown structures is essential for applying the takt time concept in fixed position manufacturing, which includes construction, and that a further variable is where priority is placed when a choice must be made: on the flow of work or the flow of workers. Takt time planning places priority on the continuous flow of work.

EXPECTED BENEFITS AND COSTS OF TAKT TIME PLANNING

The expected benefits of takt time planning are reduced project durations and costs. There is, however, a risk of capacity loss. It is to be expected that one or several trades following one another through locations such as rooms or pre-defined floor areas will require different amounts of time to complete their work. The trade that requires the greatest amount of time is naturally called the bottleneck trade. Whatever is done to increase the production rate of the various trades, whether increasing productivity or adjusting capacity, some trades will go faster and some will go slower through the pre-defined floor areas. Those who are faster than the bottleneck trade risk losing capacity if, after trying to adjust capacity or change work methods, they cannot find alternative uses, like backlog work, for any surplus. The bottleneck trade risks losing capacity as a result of varying labor content from one area to another, again unless capacity can be adjusted to variations in workload, or other productive uses can be found for any excess capacity. The case study will include description of the methods used to minimize capacity loss, such as reducing variation in production rates, and the methods used to find productive uses for capacity in excess of what is needed for takt, such as identifying workable backlog[5] in each weekly work plan.

The assumed benefits and costs of takt time planning are summarized in Figure 1.

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[5] The usage of workable backlog to absorb otherwise excess capacity was not measured and tracked in this experiment. However it is apparent from our experience that the amount of workable backlog in this case study was not sufficient to reduce the pressure to improve the operations in order to meet takt and did not have a negative effect to team’s motivation to seek gradual improvements. Further research on the use of workable backlog in takt time planning is needed.

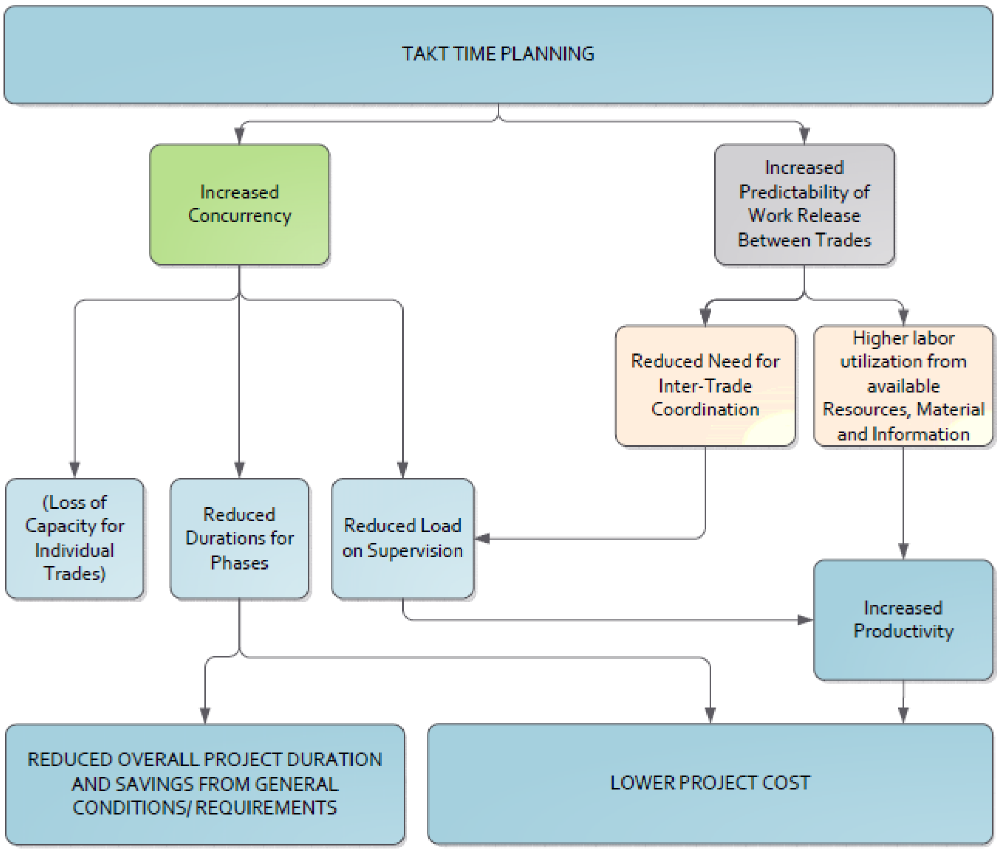

Figure 1: Expected Benefits & Costs from Takt Time Planning

Takt time planning typically increases concurrency as illustrated in Figure 2 below.

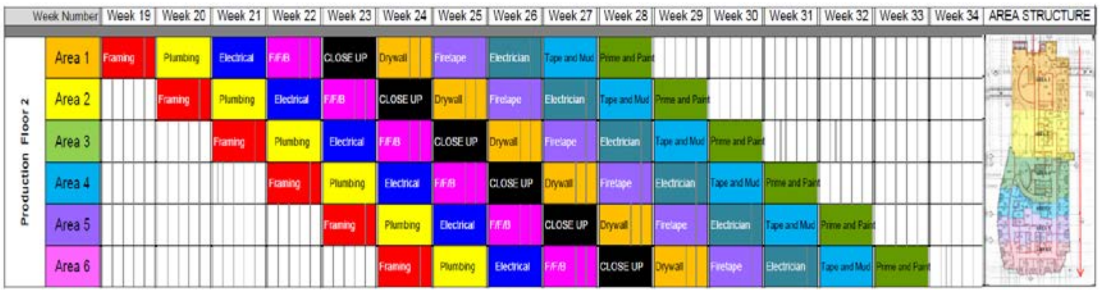

Figure 2: Increased concurrency of trades to eliminate WIP and reduce duration

Note: example from WCC Level 2 Framing and Drywall Phase (Red-Framing, Yellow-Plumbing Rough-in, Dark Blue-Electrical Rough-in, Deep Pink -Fire stopping, Backing and Fire Alarm, Black-Drywall close up inspection, Orange-Drywall and Insulation, Purple-Fire tape and Head of Wall Fire stopping, Teal- Electrical Low Overhead and Low Voltage Pathways, Blue-Tape and Mud, Green-Prime and Paint.

In Figure 2, each color represents different trade (in some cases trades) working in one area at a time for 5 days and moving on to next area for next five days. Takt area structure in this case for Level 2 can be seen on the left side of the figure.

Labor productivity is the product of the capacity utilization rate (the percentage of paid labor time spent productively) and the output rate per unit of productive time.

Capacity utilization is at risk from variation in labor content from area-to-area and from variation in durations between trades, but takt time planning also drives both utilization and output rates higher. If takt time can be met, then the predictability of work release between trades increases substantially, which facilitates matching capacity to load, reduces the coordination load on supervision (because daily coordination is now needed within trades, but not so much between trades), and encourages planning and preparation-all of which drive productivity higher.

Further, if takt time can be met, the resulting reduction in duration can reduce general condition costs sufficiently to offset increases in direct labor costs. For example, in the case study project, the 7-month planned reduction to the exterior framing phase was calculated to yield $14 million in savings. Even if the bottleneck trade doubled its labor costs, the net savings was estimated at $12 million.[6]

These expectations pose two primary questions:

- Are project phases planned using takt time completed in less time than when planned traditionally; i.e., based on activity breakdown structures?
- Is there an increase in labor productivity during project phases planned using takt time? And, is that increase greater than the capacity loss resulting from variation?

We will return to these questions after describing an application of takt time planning.

TAKT TIME PLANNING: INTERIOR FRAMING PHASE

The steps in the process of takt time planning were:

- Identify the trades that will work in the phase and how their tasks will be grouped together. Tentatively specify area structure, also called takt areas that will become location breakdown structure for work.

  The interior framing phase, which included six full floors, was divided into four sub-phases:
  a. Overhead phase with MEP racks, pneumatic tube and ductwork;
  b. Framing phase with framing, MEP in-wall rough-in, fire stopping and backing;
  c. Drywall phase with drywall, tape and mud, some low overhead MEP and paint;
  d. Finishes phase with ceilings, casework, MEP trim, flooring and other scopes all the way to air balancing and fire alarm testing.

  The remaining interior work on all the other floors in the building was planned using a more traditional approach and some areas that were not on the critical path were designated "workable backlog". Area structures for later testing and possible revision were tentatively identified for each sub-phase.

- Gather information from trade partners.

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6 Unfortunately the team was unable to capitalize on the early completion of the exterior and capture those savings. The start of interior production, the successor work, was delayed while overcoming major design challenges.

Each foreman for each trade with work to be done in a sub-phase described his scope of work and preferred start-finish points in the work flow sequence. He then colored up plot plans showing what work his crew would do each day.

- Sequence trade groups and the trades within groups, identify bottleneck trades in each group, and roughly estimate their achievable production rates within the takt areas.

  Trade sequence was determined through collaborative pull planning sessions according to the Last Planner System®. Pull planning was done for one takt area. The output of the pull plan becomes the trade sequence for successful completion of the takt area with manpower and duration. Pull plans specify handoffs between the trades. All durations include 100 percent ready work with needed inspections, drying times etc., so tasks are said to be completed only when the work or work area is ready to be handed off to the next trade. This enabled identification of the bottleneck trades and a rough estimate of their production rates.

- Balance work flow determining takt time in each sub phase. Adjust area structure if needed.

  Different trades' work duration through takt area were analyzed and balanced to the same constant, a takt. In all phases except Overhead, takt time was set at five days to maintain the weekly cycle and maintain the area release on a same weekday thru longer periods of time. To adjust everyone's duration to takt time, crew sizes were modified or the trades capacity and design of operations improved. Design of operations was at this time focused mostly on the bottleneck trade. Starting from Drywall phase takt areas were revised to accommodate more equal areas to the bottleneck trade. Refer to Findings for reflections and learnings on this takt time planning experiment.

- Use takt time strategy to plan for resources, material and information.

  The takt time plan was used to determine resource requirements and develop the material fabrication sequence, kitting plan and just-in-time deliveries. Design information needs were then prioritized and synchronized with the takt plan.

FINDINGS

Drawing conclusions from the case study was made complicated by interruptions in the construction process to respond to design problems. These complications included reducing the original plan for the interior framing from doing three floors at a time to one floor at a time, and periods during both exterior and interior framing when the work was completely or partially stopped. Nonetheless, some conclusions can be drawn:

- Takt time planning does not require segregation of repetitive and non-repetitive work areas. The takt areas were not segregated, and as of March 7, 2013, the percentage of takt areas completed on schedule during the interior scope was 100 percent for framing phase and 94 percent for drywall phase, with only one missed close-up inspection. Further, as shown in Figure 3, daily commitment reliability increased over time with all daily commitments met on 49 out of 69 days. The simplicity of the takt plan and the breakdown of the work into daily, and in some cases hourly, increments, was an important factor in meeting daily commitments and finishing areas in takt.

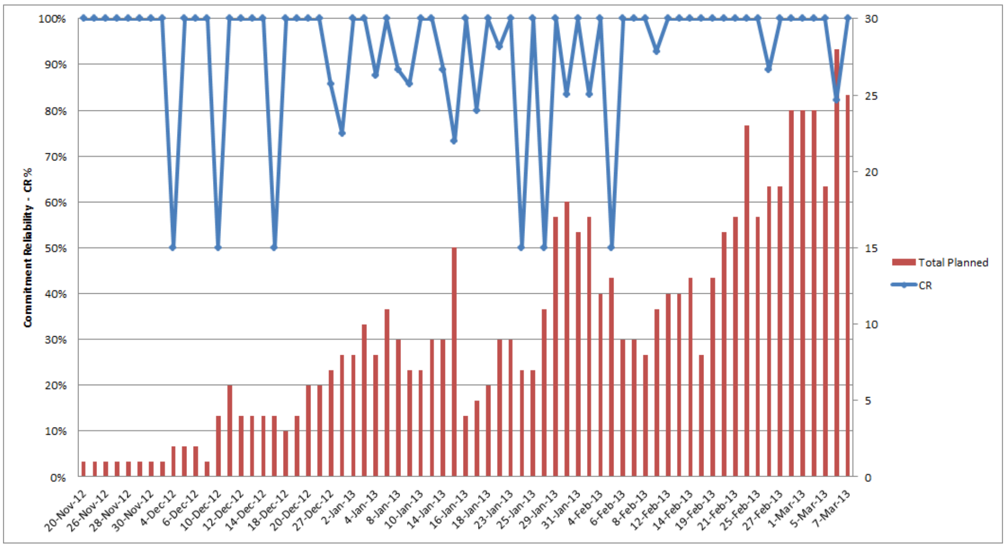

Figure 3: Framing and drywall phase daily commitment reliability (avg. 91%) with number of total planned tasks.

- The need to meet takt drove both bottleneck trades and non-bottleneck trades to improve the design of construction operations. For example, KHS&S, the framer, switched from stick-building to on-site prefabrication of exterior panels. ISEC, the door and hardware contractor, developed a rotary door preparation station that both accelerated production and improved ergonomics. Almost all trades started kitting material to have just-in-time deliveries.
- Overall alignment of trades to a common and transparent pace increased project Lookahead Reliability[7] from zero to almost 70 percent on a five-day lookahead and more than 45 percent on a 10-day lookahead (see Figure 4) during interior framing. The pre-takt time planning measurements were approximately 10% and 5%, respectively. Higher Lookahead PPC provides more lead time for planning and preparation, and facilitates pulling materials to site with less risk of increasing on-site inventories.

[7] Lookahead PPC measures the extent to which a daily work plan, made 5 or 10 days ahead of a target date, matches the commitments actually made on that date. Lookahead Reliability is also referred to as Tasks Made Ready, see Ballard, 2009)

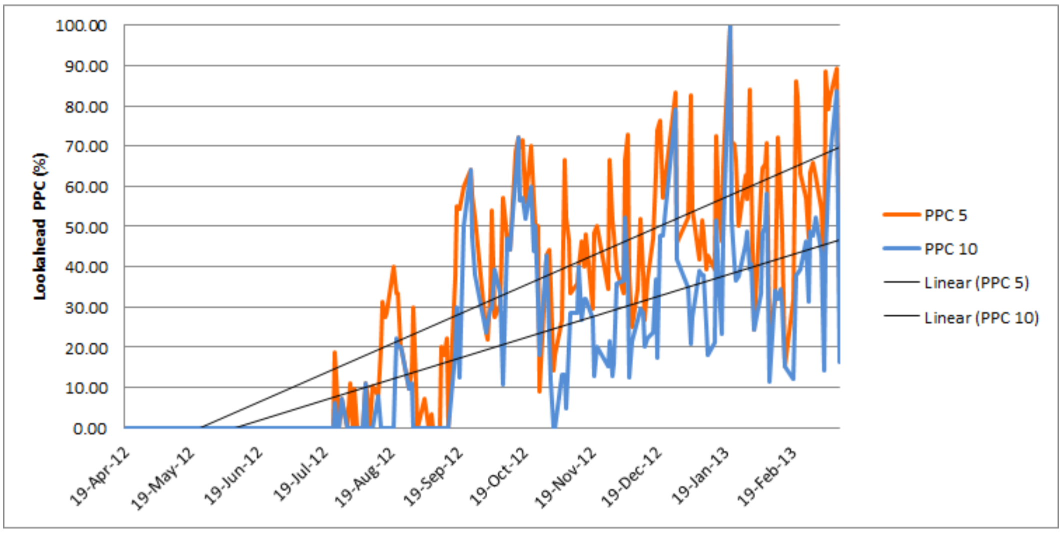

Figure 4: WCC interior overall Lookahead PPC

- When trades are mixed closely together in locations, coordination between them is required. That coordination becomes more difficult and more prone to failure when the release of work from one trade to the next is unreliable. The high reliability of release of takt areas from one trade to the next, as well as the restriction of takt areas to single or selected trades reduces the coordination burden on supervision and other resources both within and outside the trades. Supervisors and construction engineers have time to support the trades in determining quality requirements and in performing first run studies to test and refine the design of construction operations. They can spend more time on material and quality planning, and also on root cause analysis of accidents, defects, and plan failures in order to avoid similar problems in the future.

- Projects should be set up for takt time planning from the start. Full BIM models would enable faster quantity take offs and more exact determination of takt time and location breakdown structures. In this experiment, the initial location breakdown structures had relatively wide variations in labor content. Because the model was not sufficiently detailed, the trades had the burden of doing manual quantity take-offs in an effort to determine the manpower needed from one work area to the next.

- The process of takt time planning would benefit from better understanding the interdependence of variables such as takt time and location size and definition, identification of the bottleneck trade, and initial estimates of the bottleneck trade's production rate.

Answers to the questions posed earlier regarding benefits and costs of takt time planning can also be gleaned from the interior framing case study:

- A) Are project phases planned using takt completed in less time than when planned traditionally, based on activity breakdown structures?

The interior framing phase is not yet complete. However, according to the original activity-based plan, the work starting with MEP overhead through MEP trim was to be completed in 82 weeks. In the original three-floor takt time schedule the same scope was planned to be done in 38 weeks – a 54% compression. When that plan was changed to single-floor, it had a planned duration of 57 weeks - a 30.4% reduction compared to the original 82 week target. At this point in time, the team slipped nine weeks due to design problems, but the last 12 weeks have been very stable with design solutions being released on time and all the trades meeting their takt. The team expects to finish this work scope in 68 weeks - a 17% reduction.

- B) Is the net impact of takt time planning on labor productivity positive or negative?

  From this case study it is difficult to come to a clear conclusion if the net impact of takt on labor productivity is positive or negative. Hard data is lacking and opinions differ. Several non-bottleneck trades did not see much difference in labor productivity whether using activity based scheduling or location based takt time planning. Bottleneck trades in framing and drywall phases assumed that smaller locations and pressure to get a certain area built out in five days reduced productivity. Whatever the loss or gain in productivity may have been in fact, it is unclear if negative factors came mostly from design challenges that resulted in some confusion and rework, difficulties to eliminate some types of trade damage and not fully stabilize make ready processes, or actually from takt time planning.

  The takt time planning was perceived as an opportunity to expose problems that helped the team to realize breakdowns in takt supporting processes such as constraint identification and removal, built-in-quality and robust problem solving. Even though the takt cycle was met almost 100% of the time, on future projects the team is planning to improve the system to be more stable and to provide better outcomes as it comes to labor productivity.

CONCLUSIONS

The experiments at Sutter Health’s WCC Project support the conclusion that takt time planning on a construction project is both feasible and beneficial. However, more rigorous evaluation of experiments is needed in future research, specifically regarding the impact on project costs, durations, and labor productivity. In addition, those future experiments should further refine the takt time planning process.

Takt time planning poses a risk of capacity loss as a consequence of the inability to define locations that have identical labor content for the bottleneck trade and as a consequence of the differences in production rates between successive trades. However, takt time planning also drives labor productivity in the positive direction through simplification and transparency of work flow and the drive for improved design of operations. Research is needed to determine the conditions in which the net impact on labor productivity is positive.

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