

TAKT PLANNING WORKSHOP

Patrick Theis,
Iris D. Tommelein, and
Samir Emdanat

Project Production Systems Laboratory
University of California, Berkeley
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Selected Bibliography on Takt Planning in Suggested Reading Order

Linnik, M., Berghede, K., and Ballard, G. (2013). “An Experiment in Takt Time Planning Applied to Non-Repetitive Work.” In Formoso, C.T. and Tzortzopoulos, P., *Proceedings 21st Annual Conference of the International Group for Lean Construction*, Fortaleza, Brazil, 31-2 August, pp. 609-618. pp. 1-10

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.

Frandsen, A.G., Seppänen, O., and Tommelein, I. (2015). “Comparison Between Location Based Management and Takt Time Planning.” *Proceedings 23rd Annual Conference of the International Group for Lean Construction (IGLC 23)*, 28-31 July, Perth, Australia, pp. 3-12. pp. 11-20

ABSTRACT: Construction planning methods may or may not explicitly model space as a resource. This paper compares two methods that do. The first method is used in the Location Based Management System (LBMS). The second method is Takt Time Planning (TTP). Both are iterative design methods for planning and controlling construction work, both focus on creating a balanced production schedule with a predictable timing of work while also preventing spatial interference between trades, but they differ in how they achieve these goals. The contribution of this paper is to (1) highlight the similarities and differences between these two methods and (2) describe a proposal for future exploratory research to evaluate the systems using common metrics.

Tommelein, I.D. (2017). “Collaborative Takt Time Planning of Non-Repetitive Work.” In: LC3 2017 Vol. II – *Proceedings 25th Annual Conference of the International Group for Lean Construction (IGLC 25)*, Walsh, K., Sacks, R., and Brilakis, I. (eds). Heraklion, Greece, pp. 745-752. DOI: doi.org/10.24928/2017/0271 pp. 21-28

ABSTRACT: This paper describes an approach for takt time planning (TTP) that was developed and tested on a pilot project in California. A companion paper by other authors describes their approach for TTP that they applied in a different project type-, commercial-, and geographical context. The aim of these papers is to articulate TTP methods used so as to allow for comparison, refinement, and improvement.

The here-described approach was piloted on the gut-and-remodel of a small healthcare project. The owner chose to deliver this project using an Integrated Form of Agreement (IFOA) contract. Accordingly, the project team members working together as trade partners were driven to explore opportunities to use lean practices.

The researchers offered the IFOA team an action research opportunity to study together, not so much if-, but rather how takt time might be used to plan and execute their work because, at first glance, units of repetitive work were not obvious. The researchers embedded with the team developed a TTP approach on the basis of “work density” and then successfully used it on two project phases.

The contribution of this paper is that it presents a characterization and proposes a formalization of a method for collaborative TTP of non-repetitive work. This may inform the use of TTP on other projects, as well as serve as a basis for comparing and contrasting takt time- and other planning methods.

Emdanat, S., Meeli, L., and Christian D. (2016). “A Framework for Integrating Takt Planning, Last Planner System and Labor Tracking.” *Proceedings 24th Annual Conference of the International Group for Lean Construction (IGLC 24)*, Boston, MA, USA, sect. 2, pp. 53-62. pp. 29-38

ABSTRACT: This paper proposes a framework for incorporating direct field labor hours and costs into an overall production strategy centered on Takt Time Planning (TTP) and the Last Planner® System (LPS). An integrated tracking tool, vPlanner Production Tracker, has been developed to associate labor information with production activities utilizing the same database. The association of field labor hours including budgeted, estimated, and actual with production activities provides an early indicator of risk on projects. The proposed framework improves the consistency and efficiency by which the information is created and maintained so that the system can be scaled to support large projects that span multiple years. This is done to shorten the cycle time between monthly financial forecasting and field labor utilization. The goal is to improve the effectiveness of identifying and mitigating risks of field labor overruns and also the realization of savings opportunities due to improved field labor utilization. The paper outlines the improved workflow processes and presents an analysis of the data collected over several months from a pilot project.

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

Meeli Linnik¹, Klas Berghede² and Glenn Ballard³

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

¹ Production Engineer, The Boldt Company, Sutter Medical Center Sacramento Project, 2710 Capitol Avenue, CA 95816-6005, USA, Phone +1 415/710-2824

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

³ Research Director, Project Production Systems Laboratory (p2sl.berkeley.edu), 214 McLaughlin Hall, Univ. of California, Berkeley, CA 94720-1712, USA, Phone +1 415/710-5531, ballard@ce.berkeley.edu

was introduced at WCC first in the exterior framing phase⁴, 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 backlog⁵ in each weekly work plan.

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

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.

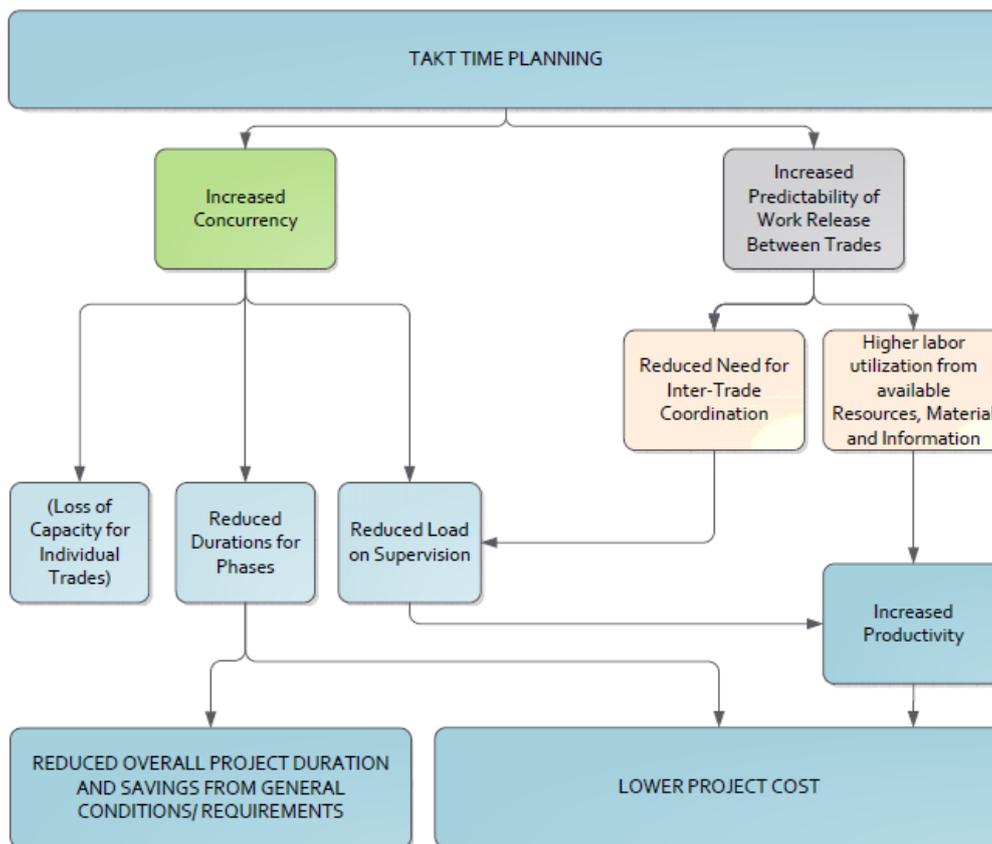


Figure 1: Expected Benefits & Costs from Takt Time Planning

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.

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.

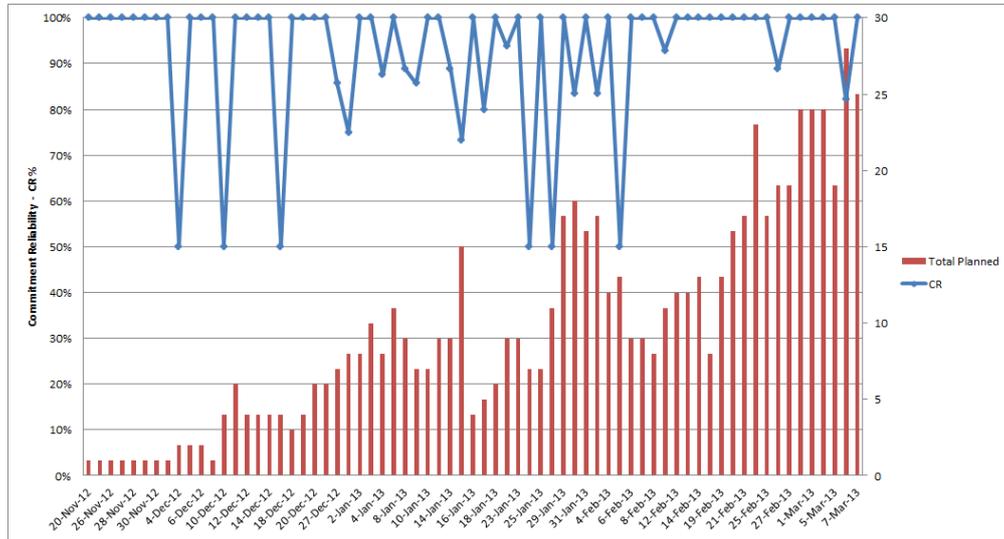


Figure 3: Framing and drywall phase daily commitment reliability (avg. 91%) with number of total planned tasks.

- 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 Reliability⁷ 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)

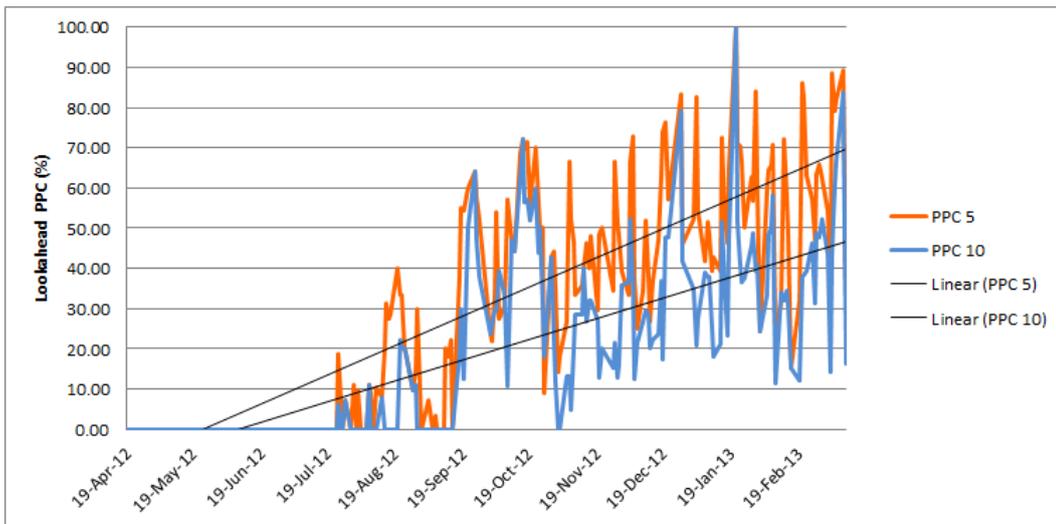


Figure 4: WCC interior overall Lookahead PPC

- 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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COMPARISON BETWEEN LOCATION BASED MANAGEMENT AND TAKT TIME PLANNING

Adam G. Frandson¹, Olli Seppänen², and Iris D. Tommelein³

ABSTRACT

Construction planning methods may or may not explicitly model space as a resource. This paper compares two methods that do. The first method is used in the Location Based Management System (LBMS). The second method is Takt Time Planning (TTP). Both are iterative design methods for planning and controlling construction work, both focus on creating a balanced production schedule with a predictable timing of work while also preventing spatial interference between trades, but they differ in how they achieve these goals. The contribution of this paper is to (1) highlight the similarities and differences between these two methods and (2) describe a proposal for future exploratory research to evaluate the systems using common metrics.

KEYWORDS

Location Based Management System (LBMS), Line of Balance (LOB), Takt Time Planning (TTP), buffers, resource continuity.

INTRODUCTION

Space is a resource to consider when planning construction projects (for brevity, we use the term “planning” to include scheduling); despite being omni-present it is often overlooked. Space is important especially in construction because, unlike manufacturing where the work moves to the people, on a construction site the people move to the work (Ballard and Howell, 1998).

Two planning methods that take space into account are compared in this paper: (1) the Location Based Management System (LBMS) and (2) Takt Time Planning (TTP). This paper follows the comparison of planning methods presented by Seppänen (2014) that was based on his deep understanding of LBMS but his narrow interpretation of TTP.

First, this paper presents background on location based planning in construction. Second, it will describe the two methods of planning. Third, it discusses the

¹ PhD Student, Civil and Envir. Engrg. Dept., Univ. of California, Berkeley, CA, USA, Afrandson@berkeley.edu

² Professor of Practice, Civil and Structural. Engrg. Dept., Aalto University School of Engineering, Espoo, Finland, olli.seppanen@aalto.fi

³ Professor, Civil and Envir. Engrg. Dept., and Director, Project Production Systems Lab., Univ. of California, Berkeley, CA 94720-1712, USA, tommelein@ce.berkeley.edu

similarities and differences between these two methods. Finally, the paper describes a proposal for future research to evaluate the systems using common metrics.

HISTORY OF LOCATION BASED METHODS

Location based methods for planning and control have a long history. In the late 1920s, builders of the Empire State Building used location based quantities and a kind of flowline diagram to plan and control the work. Their goal was to establish a production line of standard parts (Willis and Friedman, 1998). In the 1940s, the Goodyear Company developed a systematic method for location based planning called Line of Balance (LOB). LOB was deployed for industrial programming by the US Navy in WWII (Lumsden, 1968) but also applied to repetitive construction. LOB was a graphical technique that relied on repetition, so it was implemented in highly repetitive building projects, such as housing development programs (ibid.), road construction, etc. Suhail and Neale (1993), Arditi, Tokdemir and Suh (2002), and others continued modelling location based planning using LOB lines consisting of Critical Path Method (CPM) networks with tasks that are repeated between locations.

The flowline method (a term coined by Mohr in 1979) was based on work by Selinger (1973, 1980) and his supervisor Peer (1974). A difference is that LOB diagrams do not explicitly show the movements of crews because tasks are presented as dual lines, whereas flowlines represent each task as a single line. Flowline thus requires more detailed planning because it is necessary to be explicit about resources use. Mohr (1979) discussed the detrimental impact of work breaks on production, and the risk of return delay when crews leave the site.

The next developments attempted to integrate CPM and location based models in such a way that they could be computerized and allow for non-repetitive construction. Russell and Wong (1993) developed a method termed *representing construction* that allowed for multiple types of CPM logic within a location based model, free location sequencing and non-repetitive tasks in addition to other features. They allowed for work to be continuous or discontinuous, part of workable backlog or cyclic. Logic could be typical or non-typical. Harris and Ioannou (1998) reconciled the work on location based planning done by others and highlighted that one cannot minimize the duration of a schedule while maintaining continuity of resource use at all times.

Much work related to methods of location based planning has been done by Kiiras (1989) and Kankainen (e.g., Kankainen and Sandvik, 1993). That work was based on planning to manage schedule risk through continuous flow of work and control aimed at reducing interference. Over 30 action research case studies were documented in masters' theses.

LOCATION BASED MANAGEMENT SYSTEM (LBMS)

LBMS PLANNING METHOD

Kenley and Seppänen (2010) developed their Location Based Management System (LBMS) by building on this previous work. Their innovations on the planning side include (1) layered logic and (2) calculations adapted from CPM that make it possible to optimize the schedule while allowing the enforcement of continuous work. Flowline remains the means to visualize schedules.

As starting data, LBMS requires the Location Breakdown Structure (LBS), tasks, quantities for each location and task, labor consumption rate for each quantity item, workhours and workdays (calendar) for each task, optimum crew composition for each task and logic between tasks. Tasks can include several locations of similar, repetitive work in sequence of production. By default the schedule calculation is based on achieving continuous flow by delaying the start date of early locations (Kenley and Seppänen, 2010, pp.123-162).

Kenley and Seppänen (2010, pp.204-213) present guidelines for defining the LBSs of a project. LBS is a critical planning decision because it impacts the quantity take-off, the number of logic relationships required to schedule a project, as well as variation of quantities between locations. LBMS calls for physical, clearly defined locations so that there is no ambiguity about location boundaries. Kenley and Seppänen (2010) propose that the same LBS should apply to all or most trades, and certainly to all trades in the same phase. For interior work, they recommend dividing locations by type of space (e.g., office vs. corridor), because different trades' working different functional spaces with different logic and different quantities. These spaces can be grouped by location and then type (e.g., North patient rooms vs. North operation rooms). Finally, they propose eliminating implicit buffers by planning small locations and using finish-to-start relationships. Implicit buffers arise when locations are large enough for multiple trades and finish-to-start relationships are used because it would be possible to start the successor earlier without causing interference. Seppänen, Ballard and Pesonen (2010) proposed that LBS be defined in a collaborative process involving trades in Last Planner® phase planning meetings.

Tasks are defined based on work (1) that can be completed by one trade in a location before moving on to the next location, and (2) that has the same external dependencies to other tasks (Kenley and Seppänen, 2010, p.216). Tasks and dependencies can be planned collaboratively in phase planning meetings. Typically, logic will be defined separately for each space type (e.g., corridors, office rooms, operation rooms, etc.) because the required logic may vary (ibid, p.219). In practice, this requires a different phase plan for each space type (but not for different locations including several spaces with the same type).

Seppänen, Ballard and Pesonen (2010) recommend that between two phase planning meetings trades collect quantity data and labor consumption rates. Trades estimate quantities for each identified task in each location and labor consumption (manhours/unit) for each quantity line item. A task can contain multiple quantity line items if there are different types of work performed by the same crew in the same location (e.g., large vs. small diameter ductwork). The selected labor consumption should be the optimal rate for production of the work for optimal crew (the natural rhythm as defined by Arditi, Tokdemir and Suh, 2002). This rate assumes that all the prerequisites of working will be available and workers will be able to work continuously without interference from others (Kenley and Seppänen, 2010, p.218). The goal of LBMS control mechanisms is to ensure that these optimal conditions are achieved for as many trades as possible, prioritizing tasks with high manhour content.

Optimization is done collaboratively with trades in the second phase planning meeting. The starting point of the meeting is a location based plan with one optimal crew for each task. This will result in a plan with tasks, some progressing at a gentle slope and others with a steep slope in a flowline diagram. In the meeting, workflow is

optimized by starting with trades that have the gentlest slopes, so-called bottleneck trades (Seppänen, Ballard and Pesonen, 2010). The available optimization tools in order of desirability are (1) changing slopes by changing the number of crews or scope, (2) changing location sequence, (3) changing soft logic links, (4) splitting tasks (planned breaks) or making tasks discontinuous. The goal is to find a common slope for each phase (Kenley and Seppänen, 2010, pp. 221-230).

Finally, meeting participants analyse schedule risks (the likelihood of a delay occurring) and add time buffers so control actions can be taken if needed. The goal is to find a schedule with minimum cost that achieves the duration target and has an acceptable risk level. They may analyse the risk level through Monte Carlo simulation or qualitatively based on decisions taken to achieve the required slope. Risk is minimized first by trying to minimize variability. To account for any remaining variability, time buffers are added between the tasks to protect hand-offs. Their size depends on variability of the preceding task, the dependability of the trade, and the total float of the task (Kenley and Seppänen, 2010, pp. 233-239). Simulation can be used to inform buffer sizes. In terms of social process, Seppänen, Ballard and Pesonen (2010) propose that buffer sizes are discussed in the optimization meeting.

LBMS CONTROL METHOD

The control method of the LBMS includes monitoring progress, calculating performance metrics, and forecasting future production based on actual production rates. Alarms are calculated when there is a risk of interference between trades (Seppänen, 2009). The forecast is adjusted to prevent production problems by planning control actions (Kenley and Seppänen, 2010, p.254). The analysis of alarms can be done by a dedicated production engineer who identifies any deviations, prepares material for team review, and facilitates a control action planning session with trades to get commitments to implement control actions (Seppänen, Evinger and Mouflard, 2014). The development of the forecasting method and empirical research on its effectiveness in addressing production problems has been researched by Seppänen (2009) and Seppänen, Evinger and Mouflard (2014). It should be noted that this system is based on having time to react with control actions before interference happens. This requires buffers in the location based plan.

LBMS control includes tracking of actual production rates and labor consumption at least weekly, but preferably daily for any tasks affected by committed control actions. Progress data is self-reported by trades and validated through site walks by the production engineer and superintendents (Seppänen, Evinger and Mouflard, 2014). The root causes for any deviations are analysed. Main deviation types are start-up delays, production rate deviation, splitting of work to multiple locations, out-of-sequence work and interrupted work (Kenley and Seppänen, 2010, pp.346-348). The impact of deviations is analysed by the production engineer using the schedule forecasts and alarms and validated with the superintendent(s). Finally, the production engineer initiates a collaborative control action process involving all affected trades to get back on track (Seppänen, Evinger and Mouflard, 2014). Possible actions include changing the production rate, changing the work content of the task, breaking the flow of work, changing the location sequence and overlapping production in multiple locations (Seppänen and Kankainen, 2004). Additionally resources can be assigned to work on workable backlog tasks if they would otherwise need to leave the site (Seppänen, 2014).

If there is insufficient time to react with control actions or control actions are not taken, an alarm can turn into an actual production problem. Production problems can be (1) start-up delays (a trade is unable to mobilize when committed), (2) discontinuities (a trade demobilizes), or (3) slowdowns (a trade's production rate decreases due to interference) (Seppänen, 2009). If (1), the forecasts are used to pull the trade on site when locations are available. If (2), the forecasts are used to find out a suitable return date. If (3), one of the trades will get to own the location and the other(s) must work on workable backlog or demobilize. All these decisions are made collaboratively with the trades based on the production engineer's input.

TAKT TIME PLANNING (TTP)

TAKT TIME PLANNING METHOD

The use of Takt time to plan construction work is rooted in the use of Takt time in (lean) manufacturing to set production rates that match the demand rate (e.g., Hopp and Spearman, 2008). Takt time is defined as: “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)” (Frandsen, Berghede and Tommelein, 2013).

Frandsen and Tommelein (2014)—knowledgeable in CPM, LOB, and numerous space scheduling methods—developed the TTP method described in this paper and tested it on a pilot project; they have follow-on research underway. They see TTP as a method for work structuring (Ballard, 1999; Tsao et al., 2004) in order to design the production system for continuous flow. The objective is to produce a production plan (a plan used to steer and control construction work on- and off-site) that provides a balanced work flow for a certain scope of work in the time allotted. That scope typically spans a construction phase (e.g., overhead MEP installation, in-wall rough installation, interior finishes), that is, a period of time during which a number of trades have to perform interrelated work. “Balanced” refers to the desire to create a stable pace of work (matching the demand rate) for each trade, with each trade proceeding through a sequence of zones (not necessarily the same sequence or the same zones for all trades). This is similar to the “week beat” scheduling described by Court (2009). As is the case for locations in LBMS zones are “physical, clearly defined locations so that there is no ambiguity about location boundaries” and they may vary from one another. Zones, pace, and sequence are all system parameters that get determined through the iterative process called production system design.

A key characteristic of TTP is that each trade must complete their work in each assigned zone within a set amount of time, namely the Takt time. This design parameter, once set, is constant throughout the phase. In order to accomplish reliable work completion (the hand-off to the next trade), after driving out all variation that can be driven out yet recognizing that numerous uncertainties can hamper the execution of work, TTP uses capacity buffers. Trades must underload their production units, that is, assign them to work at, e.g., 70 or 80% of capacity.

One source of variation that is driven out through the design of zones is the variation in work density. “Work density” refers to the situation in an area on site based on (1) the amount of work required by one trade in a particular area, (2) the trade's crew sizing and capabilities, and (3) the trade's means and methods (when prefabricating off site, the work density decreases). As such, some areas have a higher

work density than others (e.g., compare electrical work in a lobby compared to an operating room). Different trades will have different work densities as well. Thus, through data collection and design of the zones this work density variation from zone-to-zone and trade-to-trade can be reduced.

PROCESS OF TAKT TIME PLANNING

Frandsen, Berghede and Tommelein (2013) described TTP as a six step process consisting of (1) data gathering, (2) zone and Takt time definition, (3) trade sequence identification, (4) determination of individual trade duration(s), (5) workflow balancing, and (6) production schedule finalization. The first five steps occur iteratively, similar to the 'rough to fine' production system design described in Ballard and Tommelein's (1999) paper on continuous flow.

Data Gathering: Developing a TTP requires collecting production data from each trade individually and the team as a whole well in advance of construction. A master schedule may have been established, but before any production planning is done, data gathering begins with a production team meeting, consisting of trades involved in the work and the general contractor (GC), to discuss the product of TTP. The team must set their overall production target (e.g., "a chosen Takt time, with a consistent trade sequence through out every zone and balanced work zones"). The target may be specific and based on previous experience with similar work, or more general if the work and production team are new to using Takt time. It must also reflect the time the team will have to complete the work and milestones in-between (e.g., specified in the contract including the master schedule).

The data to gather in conversation with the trades is specific to them, their work, and the project context. How do they want to move through this project's space? What alternatives are available? What are the material and manpower constraints, or work method alternatives? What work needs to be performed before they start work? What is the sequence of work internally (e.g., electricians want to set trapezes, run conduit, and then pull wire)? Can the sequence be split, or can the work be performed in a later phase (e.g., does the electrician have to pull wire immediately after the conduit is run)? Trades may color up plans in order to show their desired work flow, what can be completed and when and under which assumptions. In order to understand the set of options deemed feasible for a trade, though perhaps not optimal from their perspective, alternatives must be discussed with each trade so as to allow for a set-based approach in developing the phase schedule. Each trade's set of options can then be tested against the sets of options available to other trades, so as to develop a combined plan that is better for the project as a whole than could have been obtained had each trade individually offered only their most-preferred option, or had the GC pushed a schedule on the trades to comply with. A GC schedule embodies too many assumptions and constrains the trades' abilities to do what they do best. Better plans can be developed when the team is incentivized to address the "Who pays and who gains?" question with overall project optimization in mind.

The trade representative in the conversation must be able to provide this level of detail, e.g., the foreman able to commit to doing the work. The benefit to planning early with these details is that people develop deep understanding of both their production capabilities and the resulting plan from the collected information.

Zone and Takt Time Definition: Zone and Takt time definition relate to one another because the duration required to complete a task is dependent upon where and

what needs to be built. Zones are defined by means of an improvement process, starting from zones, e.g., (1) already established in previous work phase. (2) created using the data gathered in a holistic manner (i.e., all the trades are considered when creating the zones). (3) designed to best satisfy (and then improve upon) the work of one trade because it is evident from data that their work will be the “bottleneck.” This initial set of zones is the starting point for iteration.

Trade Sequence Identification: Given a set of zones, the trade sequences are obtained from each trade individually and then combined through phase planning in order to honor sequential dependencies while working through the construction documents or building information model with the team. When identifying the trade sequence—which doesn’t need to be a line sequence (as in the Parade of Trades (Tommelein, Riley and Howell, 1999)), it’s important to document the requirements each trade has in order to correctly hand off zones from one trade to the next.

Balancing the Plan: Balancing the plan occurs in a rough-to-fine fashion. From the proposed zones it is now possible to refine the task durations for each trade. Typically trade task durations will vary through the zones. Once the variation is known, the production team can begin to balance the production system.

The production team has several methods to balance the work flow and design the production system. We list these methods next but do not mean to imply any order in which to apply them. The team can iterate upon the zones. If the zones are consistently uneven across the trades, the team can redesign them. Ideally, if it is early enough the actual design of the project could be changed to improve production. Zones may be unbalanced due to the nature of what is being built (e.g., an operating room contains more work of certain kinds than a standard patient room). As such, some trades may have to leave out certain work and perform it “off Takt.” The team can also revisit the work methods, trade scope (providing the contract structure enables money to flow across boundaries), and restructure the trade sequence in order to balance the work. Perhaps a trade can individually, or jointly with other trades, prefabricate more work, thus reducing their field installation times so they can meet a lower Takt time. The trade sequence could also change by splitting the trade work into multiple tasks (e.g., split electrical conduit installation from pulling wire) and thereby enable a faster Takt time. The overall schedule then shortens because a reduction in Takt time scales across the number of zones the trades move through.

Production schedule finalization: Finalizing the production schedule requires validation, i.e., every trade needs to ascertain that their sequences are feasible and that they can perform the work in each zone to which they are assigned in the given Takt time. A sequence deemed infeasible can possibly be made feasible by “flipping” the sequence between two or more trades through zones in order to maintain the overall production schedule.

Finalizing the production schedule also provides an estimate for the planned buffer in capacity every trade in the sequence must have. This planned buffer in capacity may be used to absorb variation in the field or to help perform the work left off Takt. While the latter may enable the off Takt, “leave out” work to be scheduled more closely, the trade-off is the buffer in capacity is reduced.

TTP CONTROL METHOD

Successful execution of a TTP demands that every trade makes their hand offs, thus it is critical to control the schedule at levels shorter than the Takt time in order to gauge

if the hand off will likely or not occur as planned. This creates a sense of urgency on the project (Frandsen, Berghede and Tommelein, 2013). Visually communicating both performance and the plan to everyone is an important part to distributing control, identifying deviations, and maintaining the schedule.

Should one Takt time be missed by a trade, then the work for that Takt may be completed immediately with overtime, completed during the following Takt time provided it doesn't interfere with the succeeding trade, or left out. The work may be left out if the problem is unique to that particular zone (e.g., missing design details) or it can be picked up in a future task providing no work depends on it (i.e., the work cannot be structured in any other way). The reason for the miss should be researched and a countermeasure developed so as to avoid repeatedly impacting future tasks. The benefit of using Takt times to the project is that problems are identified and corrected quickly, instead of passing that production variation to the succeeding tasks.

SUMMARY

TTP requires collaboration among production team members to develop a plan deemed best for the project overall, and time to iterate from a production strategy to a detailed, feasible production schedule that is balanced. The planning first begins with gathering support from the team to proceed with TTP. Each team member then communicates their individual production system requirements and explores alternatives. Then the team works in an iterative fashion to identify the most suitable sequence, set of zones, and duration to work through the space.

DISCUSSION

Comparing LBMS with TTP shows more similarities than differences. Both methods aim for continuous flow of work through production areas at a set beat for each phase of work. Both methods also use the ability to trade scope (esp. when commercial terms encourage it) in order to improve the production system. Differences to highlight are how each method uses buffers, control, and how resources are allocated.

Construction planners can use four types of buffers: (1) time, (2) capacity, (3) space, and (4) plan buffers (workable backlog). LBMS buffers with (1), (3), and (4). Time is the preferred buffer, but space is also used when work is scheduled in areas larger than what a crew requires to complete their task productively. In contrast, TTP buffers with (2), (3), and (4). Capacity is the preferred buffer, accomplished through underloading. Space (zones) unoccupied by any trade during a given Takt can also serve as a buffer.

The two methods differ in controlling the schedule. LBMS starts with a top down approach of engineers tracking progress, running forecasts, and identifying problems that are then solved collaboratively. In contrast, TTP starts with visual workplace to make clear to all, who is doing work, and where, in order to distribute control. While the trades may provide frequent updates to the GC, they're OK to work as long as they are completing what needs to be done in the space and time allotted.

The resource allocation difference discussed here focuses on people. LBMS chooses to fully load resources on production tasks and use the same crew size continuously. The durations on the fully loaded production tasks assume optimal production rates ("optimal" here is defined as free from any causes for interference). The tasks are then buffered with time in order to maintain the productive use of

people. In contrast, TTP chooses to underload crews on production tasks in order to maintain a timely, predictable hand off. Thus, people are expected to finish ahead of the Takt time, and can then work on “off Takt” work (e.g., workable backlog or leave out work), prepare for the next Takt sequence, conduct first run studies, train, or innovate to improve their work. If crews are working much too quickly, then less manpower is required to complete the production task reliably within the Takt time.

CONCLUSION

The dearth of empirical data on the use of TTP hinders a more fact-based comparison between the two methods. In order to allow for a deeper comparison, future research should gather data including:

- For each location and trade: planned and start/finish dates, resource graphs, production rates, resource consumption (manhours/location)
- days locations were suspended (no work in location)
- days tasks were suspended (no workers working on a task in any location)
- workable backlog locations / tasks, hours and dates spent on workable backlog

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COLLABORATIVE TAKT TIME PLANNING OF NON-REPETITIVE WORK

Iris D. Tommelein¹

Abstract: This paper describes an approach for takt time planning (TTP) that was developed and tested on a pilot project in California. A companion paper by other authors describes their approach for TTP that they applied in a different project type-, commercial-, and geographical context. The aim of these papers is to articulate TTP methods used so as to allow for comparison, refinement, and improvement.

The here-described approach was piloted on the gut-and-remodel of a small healthcare project. The owner chose to deliver this project using an Integrated Form of Agreement (IFOA) contract. Accordingly, the project team members working together as trade partners were driven to explore opportunities to use lean practices.

The researchers offered the IFOA team an action research opportunity to study together, not so much *if*-, but rather *how* takt time might be used to plan and execute their work because, at first glance, units of repetitive work were not obvious. The researchers embedded with the team developed a TTP approach on the basis of "work density" and then successfully used it on two project phases.

The contribution of this paper is that it presents a characterization and proposes a formalization of a method for collaborative TTP of non-repetitive work. This may inform the use of TTP on other projects, as well as serve as a basis for comparing and contrasting takt time- and other planning methods.

Keywords: Lean construction, collaborative planning, takt time planning (TTP), work structuring, work density, Last Planner System (LPS)

1 INTRODUCTION

Takt is increasingly being used to structure construction work and thus "shape" schedules of work anticipated and control of work being executed (e.g., Linnik et al. 2013). Use of takt imposes a rationale and methodological structure that aims to achieve continuous flow in the schedule. This is done by using capacity buffers and defining clearly delineated handoffs between trades, thus marking schedule control points that can help increase predictability in system performance.

This paper details a takt time planning (TTP) method for work structuring that was piloted on a project in the San Francisco Bay Area. A companion paper (Binninger et al. 2017) describes a takt planning method in use in Germany. In subsequent work, the authors of these papers will present a framework for characterization of takt planning methods, and illustrate its use in comparing their methods as described. Frandson et al. (2015) already compared TTP with Location Based Management (LBMS). Further comparison of these and other planning methods is warranted.

The word "Takt" or "Taktzeit" in German means "beat," the regularity with which something gets done. Since "Takt" in German, like "beat" in English, by definition pertains to time, saying "takt time" is redundant; this notwithstanding, the latter is commonly said.

¹ Professor, Engrg. and Project Mgmt. Program, Civil and Envir. Engrg. Dept., Director, Project Production Systems Lab., University of California, Berkeley, CA, USA, tommelein@berkeley.edu

When takt is used in a lean context, it is interlinked with many other lean concepts, such as continuous flow, standardization, load leveling, predictability, etc. Takt refers to the heartbeat of assembly lines in the Toyota Production System. Once a beat is suited to each line and set (different lines each having their own beat), lines can move in sync with one another in a continuous flow process. Whether at Toyota, in new product development and manufacturing at large, or in construction, takt may be defined as: *the unit of time within which a unit of production must be produced (supply rate) in order to match the rate at which that product is needed by the customer (demand rate)* (after Hopp and Spearman 2011 p. 467-468). So-defined, takt is a design parameter that may be used in production in manufacturing, construction, or any other setting.

The approaches used in industry today and conceptualizations of the use of takt appear to vary. With this paper and ongoing study the author aims to create conceptual clarity and highlight distinctions between takt planning methods and the contexts in which they apply. This paper lays out methodological steps, based on the fundamental concept called “work density,” used to define takt in a production system’s design. These steps detail the method for collaborative TTP of non-repetitive work that the researchers developed and piloted while embedded with a team delivering a small project in California.

2 TTP ROOTED IN SPACE SCHEDULING

The author’s study of TTP is rooted in her research on “space scheduling” (Tommelein and Zouein 1993 p. 266) that stemmed from the observation that the resource “space” is omnipresent yet—paradoxically—often overlooked in construction management. Many of today’s construction management books still consider only 5 resources (i.e., time, money, manpower, machines, and materials) and overlook space. Yet, space is the 6th resource to be managed, not only in the process of layout planning (e.g., while locating temporary facilities such as material laydown yards and equipment) but also of scheduling. Line-of-Balance methods (LOB) (e.g., Lumsden 1968) to plan production of repetitive units, tend to treat space as a scalar (1D) variable and thereby abstract away significant complexity encountered when managing 2D or 3D space (e.g., Riley and Sanvido (1995) studied patterns of flow). With the advent of computer tools such as BIM, space has become more “visible” and easier to draw management attention to. Many software tools exist today to show in 3D and simulate in 4D how site space use in and around the facility being built evolves during construction (e.g., Navisworks, Synchro). TTP is a kind of space scheduling.

After describing the context of the pilot project, we present the rationale and methodological structure of the approach we used to shape this project’s construction space schedule on the basis of takt.

3 GEOGRAPHICAL AND PROJECT CONTEXT

We developed the here-described approach for collaborative TTP on a 700 m² (7,500 ft²) gut-and-remodel healthcare project. This project, located in the San Francisco Bay Area, was constructed over the course of about 12 months in 2012-2013 at a cost of about USD 3 million (Dunnebie et al. 2014). The owner, Sutter Health, chose to deliver this project using an Integrated Form of Agreement (IFOA) contract. Jointly with the owner, designer, and general contractor (GC), the IFOA project team comprised specialty contractors, several of which had previously worked together on other projects. Team members were thus driven to collaboratively explore opportunities for using lean practices.

The researchers, Iris Tommelein and graduate students—in early planning of the project Josh Mohayai and soon thereafter Adam Frandson—offered the IFOA team an action research opportunity to study together, not so much *if*-, but rather *how* takt time might be used to plan and execute their work because, at first glance, units of repetitive work were not obvious. The researchers embedded with the team ended up developing an approach and successfully using it on two out of four project phases, namely above-ceiling work and in-wall work (Frandson and Tommelein 2014).

The project scope included demolishing the existing interior of about half a floor in the facility and then constructing a new interior. The work was planned in phases: (1) demolition, (2) framing and above-ceiling work, (3) in-wall work, and (4) finishes. All work had to be done while maintaining the structure as well as the live fire sprinkler system, and maintaining full operation of the remainder of the facility. This constrained site access, forced some work to be done at night, and restricted some day-time work (e.g., drilling to mount anchors in concrete floor slabs was permitted only at certain times so as to not disturb healthcare providers and patients during their business hours).

4 THEORETICAL FORMULATION

4.1 Takt Time in Manufacturing vs Takt Time in Construction

While in manufacturing, the assembly line for the product being built keeps moving and workers are more-or-less stationary (nevertheless moving with the line while performing their task), in construction, the product (facility) being constructed is stationary and workers move from one location to another to perform their task *in situ*.

The speed of the line and the corresponding rate of work at stations must be designed so that each worker at each station can complete what is assigned to them and still have some time left within the takt time given. Under ideal circumstances, each station's task will be reliably 100% done within the allotted takt. Of course, in a world subject to variation, one can never be 100% sure so when a deviation from the standard task occurs, the "time left" serves as a capacity buffer. This buffer ensures that each worker has some time remaining within their takt, in case they notice a condition that warrants pulling the andon for others to come to their assistance, and address the condition without having to stop the line. Determining the appropriate task to be done at each station and thus the capacity buffer is key to the production system's design, because when the "time left" is insufficient, workers must stop the line to manage the situation.

Translated from manufacturing to construction, TTP seeks to define spaces (we call these spaces that are tied to a takt time "zones") in a facility as it is being constructed so that each trade can get their work reliably done in each zone, according to their planned sequence of work, in an amount of time (takt) that is the same for all trades who need to work in that zone. Just like a line's takt will likely vary from other lines' in a single manufacturing plant according to the tasks performed at the various stations in each line, takt and the corresponding zones will likely vary from one phase of construction to another on the same project.

4.2 Takt Time Planning is a Work Structuring Method

Generally speaking, TTP is a work structuring method. Work structuring means breaking an entire project into smaller pieces (so-called "chunks") so that these pieces will be manageable. Ballard (1999), Ballard et al. (2001), and Tsao et al. (2004) defined work structuring as addressing the following questions:

1. In what units (chunks) will work be assigned to production units?
2. How will work chunks be sequenced?
3. How will work be released from one production unit to the next?
4. Will consecutive production units execute work in a continuous flow process or will their work be decoupled?
5. Where will decoupling buffers be needed and how should they be sized?
6. When will the different chunks of work be done?

Manageability of the pieces may be assessed based on the degree to which certain production system objectives are met. Structuring of work using TPP has as objectives:

1. Have trades work in a way they prefer.
2. Aim for constant crew sizes and continuous work flow (i.e., no work interruptions).
3. Avoid trade stacking (i.e., only 1 trade works in any 1 zone at any time).
4. Use timely on-takt handoffs.
5. Balance the whole while pushing for speed.

4.3 Finding Repetition in Non-Repetitive Work based on Work Density

Answers to the work structuring questions will affect the various production system parameters that act as throttles in the system. These parameters pertain to the product to be constructed and to the process (means and methods) used for construction, namely:

1. Components and characteristics of the product to be constructed, describing the work to be done as typically shown in plans and specifications, perhaps in a BIM.
2. Worker trade skills, informing what work can be done by an individual worker (e.g., a specific journeyman or apprentice) or crew that will be designated in the weekly work plan to complete an assignment.
3. Alternative breakdowns of the scope of work, e.g., by trade (boundaries of work between trades, based on union jurisdictions or other drivers) and sequence.
4. Alternative means and methods available to each trade to do their work.
5. The number of trade resources that can be assigned when using specific means and methods, and corresponding space and time needed to complete work.

The setting of these parameters defines chunks of work and how they will flow or not (e.g., when decoupling buffers are added). A chunk is work of a certain scope that will be performed by a crew of a certain configuration (number of crew members and their individual and combined skills), using certain means and methods. Aiming to meet the stated objectives, the goal pursued in TTP is to define chunks to be done in certain locations (zones), so that all chunks can be performed in the same amount of time (takt) and in a sequence that emulates continuous flow.

An ideal flow may present itself as a Parade of Trades (Tommelein et al. 1999) moving through space with one trade following the other in sequence, all marching to a drum beat, and—ideally—with no variability. However, it is unlikely that all construction work can be cast in such a mold. If it can be, then creating a TTP is relatively straightforward, but how to develop a TTP when work is not repetitive in that way? Linnik et al. (2013) broached this topic. The manufacturing analogy is to decide what work can be done on any one of several specific lines vs. done off-line (e.g., workable backlog in the Last Planner System). A related system design question is: At what speed should the line (Parade) progress? The speed needed to match the project requirements may not be achievable when one or

several bottleneck trades limit the pace for everyone. Adjustments to dependencies and sequencing of trades in the Parade and potential investments (e.g., alternative means and methods) then need to be considered to alleviate the bottleneck.

The approach we used is based on a mathematical concept, what Tommelein (in Dunnebier et al. 2014) called “work density” expressed in unit of time per unit of area. It is a trade-specific characteristic defined as follows: *Given a certain work area, work density describes how much time a given trade will require to do their work in that area, based on the product design and the scope of work done by that trade for a given task in the schedule (thus depending on work already in place and work that will follow), the means and methods the trade will use to do their work while accounting for their crew’s capabilities and crew size.* Work density thus captures what will be done, by whom, when, where, and how. (Note that “work density” differs from “schedule density” defined in the context of change and delay analysis for productivity loss claims, e.g., Finke 2000. It also differs from workhours/location as used in LOB and LBMS because units of area are not necessarily the units of space that will be used in the TTP.).

4.4 Collaborative TTP Method

The 5 steps of the TTP method we formulated and tested on a pilot project (Dunnebier et al. 2014) and later used on projects similar in size and context, is based on the cycle of work structuring (Figure 1).

Step 1 - Collect Data: The researchers collected data from the team by construction phase several weeks before each phase’s start. Tommelein and Ballard (2017) define “In the hierarchy of task breakdown, a phase is part of a project, the hinge point in regard to specifying what needs to be done vs. how to do it. It is a time period of a project, starting at a defined

milestone, during which a specific group of activities is scheduled to be accomplished (e.g., building design, completion of foundations, erection of exterior walls, building dry-in), leading to the accomplishment of a defined end milestone. A phase comprises processes.”

1.1 A description of the overall scope of work shown graphically, e.g., using drawings or BIM (Figure 2), and written in specifications to represent the product to be constructed. This product data is produced by designers prior to the start of construction, possibly reflecting input provided by contractors or suppliers.

1.2 A delimitation of the scope of work that will be done by each trade and, for each one, a description of the means and methods, sequence in which they want to work, and resources they plan to use.

On the pilot project, we collected this data from each trade foreman directly responsible for managing work (or supervisor, when the foreman was not yet identified or available). We asked them to bring a hard copy of the plan showing their scope (trade-specific plans look different from architectural plans, e.g., showing fabrication and installation detail), had them verbally describe the way(s) in which they wanted to approach their work while coloring-up the plan, using a different color for each chunk of work they expected to be

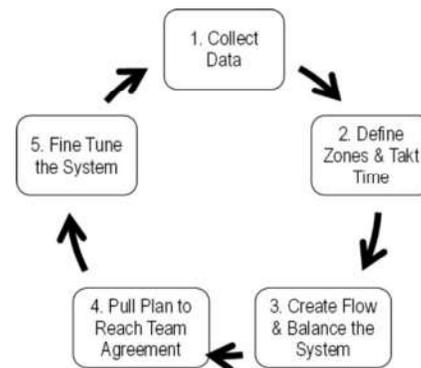


Figure 1: Process Steps for TTP (after Ballard and Tommelein 1999)

able to complete in each successive 2-day time interval (shown in sequence on Figure 3). This time interval and coloring describe work density.

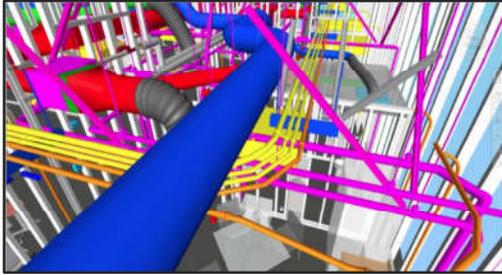


Figure 2: Building Information Model of Interior Overhead Space on Pilot Project

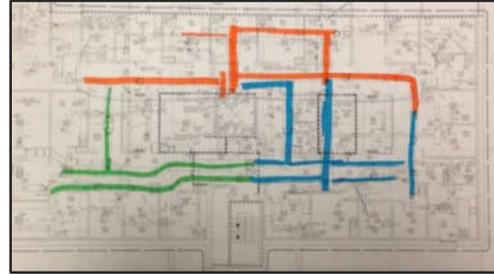


Figure 3: Input from Mechanical Trade using Work Chunks of 2-Day Takt, Sequenced Orange, Blue, then Green

A key part of the discussion is to have the foreman consider and articulate alternative approaches, and—if time permits—capture those in alternative color-ups. Clarity on a set of alternatives offers flexibility later in the TTP process, when the inputs from all trades get combined into the phase plan, and trade-offs may have to be made across trades.

Step 2 - Zones and Takt Time: The design of zones and takt is an iterative process.

2.1 After obtaining color-ups from each trade, the researchers overlaid these with a grid pattern to compute work density. Figure 4 schematically illustrates greater work density in increasingly darker colors for each trade (4.a mechanical, 4.b framing, and 4.c electrical). The number inside each grid cell is the time the trade needs to complete their work in the corresponding area (cell), given their assumed means and methods as well as crew sizing.

2.2 Subsequently, the researchers defined a zoning (a zone is a grouping of grid cells) to superimpose on the grid cells so that all space is covered and no zones overlap. Figure 4.d exemplifies one such zoning, with cells grouped into zones numbered [1] through [7].

The time each trade needs to complete their work in each zone is computed by adding up the numbers in the cells included in each zone. For example, in zone [5], mechanical needs $2+1=3$ time units, framing needs $1+2=3$, and electrical needs $6.8+0.9=7.7$. Figure 5 charts this data by zone, using a column for each trade. It shows peaks and valleys in work density. A perfectly balanced system would have columns of equal height.

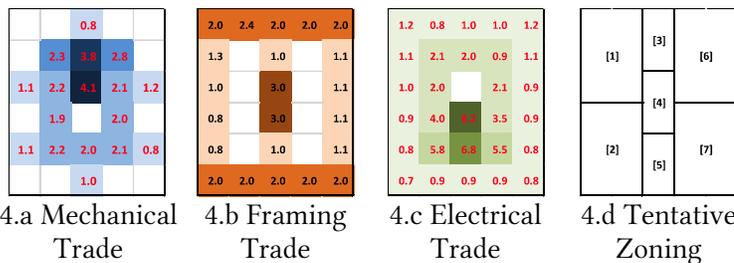


Figure 4: Work Density for Different Trades and Zoning

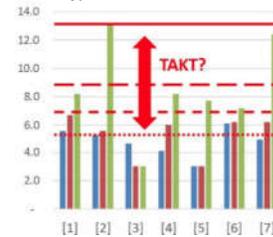


Figure 5: Time needed per Zone per Trade

2.3 Finally, the researchers chose a takt through trial-and-error (ongoing research is looking into how to systematize this step) by setting an upper limit on the time for trades to complete their work in each zone, allowing for some- but not too much underloading (capacity buffering).

The researchers repeated steps 2.1, 2.2, and 2.3 while considering alternative crew sizes, means and methods, task allocation, and the like, so as to alter the work density and thereby make columns more even in height. This repetition ended when a takt-zoning combination was found to be satisfactory.

Step 3 - Create Flow and Balance the System: The researchers used the work flows shown in color-ups, to the extent possible, to illustrate how each trade’s work would progress over time with work structured using a 2-day takt and Figure 4.d’s zoning. They shared the resulting “schedule mock-ups” (Figure 6) with the trades to get feedback and buy-in.

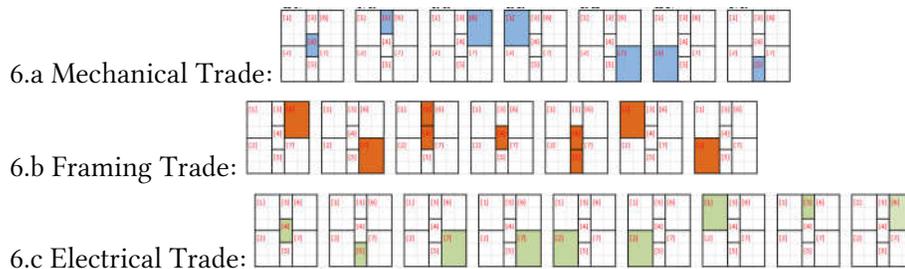


Figure 6: Patterns of Work Flow per Trade in 2-day Takt with Zoning

Steps 1, 2, and 3 prepared each trade to come to the phase planning meeting with their preferred plan and alternatives, as well as understanding of their plan flexibility based on advantages of doing work one way vs. another.

Step 4 - Pull Plan to Reach Team Agreement: At the team’s phase planning session, the researchers explained to all what they had learned from the color-up sessions and shared their analysis of takt-zoning alternatives. The team’s discussion that followed, on the timing of work within the milestones delimiting the phase, revealed concerns but also possibilities. E.g., considering the in-wall phase, the framer proposed to prefabricate wall sections to above-ceiling and convinced trade partners of the value of having all space to themselves to work fast, and then clear the way for everyone else. Shared understanding informed the subsequent pull planning effort, during which the trades meshed their patterns of work flow (Figure 7). The result was a takt plan, albeit not necessarily an optimal one since many zones are not worked in (zones left white are waiting on workers).



Figure 7: Meshed Patterns of Work Flow by 2-day Takt with Zoning

Step 5 - Fine Tune the System: Finally, trades added to this takt phase plan work to be done in areas other than those zoned (e.g., underfloor, on roof) as backlog to fill “time left.”

Dunnebie et al. (2014) and Frandson and Tommelein (2014) expand on the practical implementation of this takt plan. In summary, the work structuring done based on takt-zoning resulted in phase plans that were successfully used with the Last Planner System.

5 CONCLUSIONS

This paper outlined the rationale and methodological steps for TTP piloted on a small healthcare project. Due to the non-repetitive nature of the work, the interdependence of scopes of work by different trades, and the small space available to work in, this TTP effort

had to be collaborative. The means and methods that each trade could use on the project and their possible production speeds, could not have been known a priori. For this kind of TTP, detail is needed that is not readily available as book knowledge.

6 ACKNOWLEDGMENTS

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A FRAMEWORK FOR INTEGRATING TAKT PLANNING, LAST PLANNER SYSTEM AND LABOR TRACKING

Samir Emdanat¹, Meeli Linnik² and Digby Christian³

ABSTRACT

This paper proposes a framework for incorporating direct field labor hours and costs into an overall production strategy centered on Takt Time Planning (TTP) and the Last Planner® System (LPS). An integrated tracking tool, vPlanner Production Tracker, has been developed to associate labor information with production activities utilizing the same database. The association of field labor hours including budgeted, estimated, and actual with production activities provides an early indicator of risk on projects. The proposed framework improves the consistency and efficiency by which the information is created and maintained so that the system can be scaled to support large projects that span multiple years. This is done to shorten the cycle time between monthly financial forecasting and field labor utilization. The goal is to improve the effectiveness of identifying and mitigating risks of field labor overruns and also the realization of savings opportunities due to improved field labor utilization. The paper outlines the improved workflow processes and presents an analysis of the data collected over several months from a pilot project.

KEYWORDS

Takt Time Planning, Last Planner System, Production Planning, Labor Tracking, PDCA

INTRODUCTION

LPS is a production management system designed to improve workflow reliability by shielding near-term work from the variability and the uncertainty surrounding downstream processes (Ballard and Howell, 1994). Detailed handoff work plans for near-term work are created through collaborative planning among those team members responsible for directing the performance of the work. One of the fundamental elements of LPS is the systematic application of the Make Ready Process (MRP). This process ensures that all known constraints that may affect planned activities are identified, planned, and resolved before the start dates of the impacted activities (Ballard and Howell, 1997). The systematic application of the system in its entirety creates a steady stream of unconstrained work that can be performed with more certainty in alignment with overall project target milestones.

¹ Director of Management Services, Ghafari Associates, Dearborn, Michigan, semdanat@ghafari.com

² Production Engineer, The Boldt Company, San Francisco, California, meeli.linnik@boldt.com.

³ Director of Integrated Lean Project Delivery, Sutter Health, Facility & Property Services, Sacramento, California. chrisdig@sutterhealth.org.

TTP aims to reduce the variability in the downstream processes themselves by pacing the production rate of standard activities across right-sized geographic areas within distinct work phases (Linnik et al. 2013). This is achieved by fixing the durations and varying the crew sizing of standard activities performed by the various trades in succession. The end objective is a steady stream of predictable work, performed in the proper sequence, across the defined geographic areas, and, with appropriately planned crew sizes. This disciplined planning approach aligns not only the workflow at the site, but also the overall flow of materials and information through the supply chain starting in design and moving into detailing, fabrication and delivery processes required to support the Takt sequence. Recent experimental studies (Frandsen et al. 2014) suggest that TTP has the potential of improving LPS implementations because of its focus on the design of predictable flow of materials and resources across clear geographic locations.

The effects of implementing TTP and LPS on improving field labor forecasting have not been explored. Currently, a long feedback loop exists between monthly financial forecasting and production labor utilization. This results in poor reaction time when attempting to adjust the production system to mitigate financial risk or recognize savings opportunities due to labor utilization. The authors have been collaborating on a new approach to reduce the duration of the feedback loop. This paper presents the results of this collaboration and introduces a framework for incorporating direct labor hours and costs into an overall production design strategy centered on TTP and the LPS. It presents this in the context of ongoing work on a large hospital project in San Francisco, California, namely the St. Luke's Campus Hospital (STL) presented later in this paper.

An integrated tracking tool, namely vPlanner® Production Tracker, has been developed to associate labor information with production activities within the same underlying database. It integrates labor information with the existing features of the base vPlanner system database. The software has been used by the STL project team since 2014 to manage TTP information on a rolling basis spanning at least six months of future activities. In addition, the team uses the system for managing LPS processes including the Make Ready Planning, Weekly Work Planning, and Daily Commitment Management.

The use of vPlanner on the project was required by the owner. Sutter Health needed a solution for production management that could accurately represent the highly complex and dynamic networks of commitments that are required to plan the design and construction of its healthcare facilities. Additionally, Sutter needed a solution that allowed rapid revisions of that complex network as challenges were uncovered during Make Ready Planning. For those reasons, among others, Sutter Health selected vPlanner as its tool of choice for planning work on its most complex and challenging projects including the STL project.

The development of the Production Tracker tool is an attempt to resolve some of the workflow challenges that teams face when implementing TTP and LPS using separate processes and tools that are manually coordinated with the associated familiar problems of human error, duplication and lack of visibility of the two-way impacts of each system on the other.

This paper presents the objectives for developing and implementing this framework and the associated tool, the problem it solves, the initial findings, and outlines directions for future research to extend this approach.

OBJECTIVES

The association of field labor hours (including budgeted, estimated, and actual) with production activities improves the alignment between resource assumptions and work execution. This provides an early indicator of risk on projects that is mainly associated with overruns on field labor hours. Additionally, it provides an opportunity to involve those directly responsible for managing the work to validate and inform budgetary and labor assumptions before the work is executed. The resulting collaborative nature of the approach promotes transparency, trust, and cross team learning. Below are the main objectives for developing the framework and associated workflows and software solution:

- Reduce the cycle time for data collection and analysis so that teams can react more quickly and mitigate the risk of unforeseen variation.

- Improve collaborative planning aimed at clarity of handoffs and predictable flow by validating resource assumptions prior to work execution.

- Align TTP with resource planning and budget control.

- Reliably execute against those plans using LPS methodologies.

- Ensure uniformity and increase the consistency of data collection and tracking.

- Improve on the overall efficiency by which the information is created, maintained and tracked so that the approach can be scaled to support large projects that span multiple years.

It is important to note that while this approach has merits under a variety of contractual arrangements, it adds the most value in collaborative open-book contracting arrangements such as Integrated Project Delivery (IPD) where the interests of the team are aligned around the success of the project as a whole.

PROJECT CONTEXT

This approach is being implemented on the STL Project; a new 237,000 sq.ft., seven story hospital in San Francisco, California for Sutter Health. The \$330 million project is being designed and delivered utilizing an IPD contract. It is due to open in 2019. The open book nature of the project, its size, and the team's commitment to continually improve how they manage work provided an ideal setting for implementing this approach.

The STL team has been using LPS and TTP since the project started and has mastered both techniques. Taking those efforts to the next level was a natural next step for this high performing team. The authors are active participants in this project at different capacities. One is the owner's representative, one is responsible for production management and one is the project's Lean/IPD coach and the developer responsible for the tool used to implement this framework.

The approach was introduced into the production environment in February 2015 which marked the start of construction. Multiple work phases are complete including foundations through concrete deck construction. At the time of writing this paper, the project team has completed over 10,000 commitments and tracked labor data for over

5700 production activities. The completed activities represent approximately 24% of the risk-reward scope of work on the project. The ratio of actual hours against budgeted hours is showing a 7.5% in field labor savings.

The team is currently tracking production activities and field labor hours related to interior construction including fireproofing, MEP systems and framing with the intent to follow this process to project completion. While some risk-reward trade partners are providing labor mix rates and actual costs, the main focus of the pilot implementation was the tracking of field labor hours.

WORKFLOW AND DATA ORGANIZATION

Production Tracker was designed to support the workflows for associating labor hours with Takt activities developed in collaboration with the project team to define the overall process and the desired outcomes. Key team members collaborated over the course of several months to identify the objectives and map out the current and future state workflows for documenting and reporting on this information. The outcome of those discussions informed the design of the Production Tracker software module. The team included the owner, the general contractor's production managers and general superintendents, the financial reporting team, the project managers of the various trade partners and their superintendents. The assembly of this cross functional team was essential to cover all aspects of information flow from daily commitments to financial reporting. This section presents the definitions used to document the various activity types, standard work assumptions, and labor categories. The next section outlines the main elements of the standard future state processes required for implementing the proposed approach.

DEFINITIONS

Planned Activities: all the remaining activities on the Phase Plan including all planned Takt activities, milestones, and constraints identified after performing the make ready process.

Production Labor Activities: a subset of all the planned activities of a phase. The production manager, in collaboration with the team identifies which Planned Activities should be marked for labor tracking.

Standard Work: a statement of all the assumptions regarding the activities that a specific trade must perform as part of a Production Labor Activity. A clear standard work definition ensures consistency when trades provide labor estimates as it defines the conditions of satisfaction for completing those activities.

Budgeted Labor: the estimator's view of the project budgeted labor. It represents the hours, mix rate, and dollars associated with a given production activity as defined in the original project budget, or, the Estimated Maximum Price (EMP). Data captured in the EMP is used to assign applicable cost codes to production activities. When the data does not align with Takt geographic locations (most often it will not due to EMP being set before geographic locations development), the responsible trade project managers will distribute the cost codes to the Takt areas based on their best knowledge of the work.

Estimated Labor: the superintendent's view of the field labor hours required to perform the work. It includes the hours, mix rate, and dollars associated with the Production Labor Activities as defined in the standard work description of the

activity. Estimated Labor information is not the same as that of the EMP. It is determined by each responsible trade superintendent after detailed analysis of geographic areas, complexity and method of the work, and Takt plan duration assumptions for pacing the work.

Baseline Labor: a copy of the Estimated Labor after each trade partner completes the Estimated Labor for a phase. It is used for comparative purposes as the trade partners are required to keep the estimated labor for Planned Production Activities up to date in accordance of their best understanding of the remaining work.

Actual Labor: the actual hours spent and the labor mix rate associated with the Production Labor Activities. Actual Labor is provided by each trade partner after the commitment status is updated in the system to reflect that the work has been completed on a weekly work plan.

Remaining Labor: the calculated value of the total of all the estimated labor values for the planned production labor activities of a given phase. It does not include the estimated labor of the completed activities.

Projected Savings or Overage: the calculated difference between the budgeted labor and the total of remaining and actual.

WORKFLOW PROCESSES

Key participants from the project team (project managers, estimators, and superintendents from the various trade partners) collaborated for several weeks to map out the overall process for integrating financial reporting, Takt planning, and labor tracking. The resulting process identifies quality control gates to ensure that the right data is being captured, at the appropriate level of detail, and at the appropriate time.

For any given phase, and at least six weeks prior to the start of labor tracking, the production manager ensures that the Production Tracker captures all the planned production activities for the phase by creating associations with the existing production activities in the plan. This configures the system with all the planned activities that should be assigned labor hours.

The production manager schedules a work session with the team to confirm the standard work assumptions for each production activity. This ensures that the team is still in alignment regarding how to estimate or aggregate Estimated Labor information for each activity based on a clear understanding for the work sequence, geographic location, and the conditions of satisfaction.

At least four weeks prior to the planned start date of a phase each trade partner's project manager reviews their budgeted labor hours and inputs the budgeted labor hours and mix rates in Production Tracker in accordance with the budgeted amounts of the Estimated Maximum Price (EMP). This step allocates the appropriate budgeted labor hours in the system according to the estimator's view of the work.

Two weeks prior to the planned start of a phase, each trade partner enters the estimated labor hours and crew mix rates in the Production Tracker tool based on his or her best understanding of the effort required to perform the work in those specific locations in accordance to the standard work definitions. This step sets the Forecast Labor information based on the Last Planner's view of the work.

One week prior to the start of a phase, the Production Manager reviews the information for completeness and locks the estimated labor to set the baseline estimated hours and labor mix rates based on the trade partner data. This establishes the Forecast Labor Baseline in the system for comparative purposes.

No later than one week after Production Labor Activities are marked completed as a result of the LPS Weekly Work Planning (WWP) process(i.e., 100% of work done in one area), each trade partner inputs the actual hours for their completed activities. It is important to note, that the system automatically reflects the status of the WWP tasks in the production tracker. This ensures that completed labor hours can only be associated with completed activities on the WWP.

On an ongoing basis, trade partners keep their remaining estimated hours up to date in accordance with their best understanding of the field labor hours required to complete the work in each Takt area.

The Production Tracker tool automatically aggregates the data into visual report graphs that are configured to budgeted, actuals, remaining as well as projected savings or overages. **Figure 1** shows a summary view of labor hours by floor. **Figure 2** shows a detailed view of the same information organized by floor and then grouped by Takt area for a more detailed analysis. As the STL team implemented this process, they focused primarily on field labor hours. Reporting on crew mix rates and actuals was not always required.

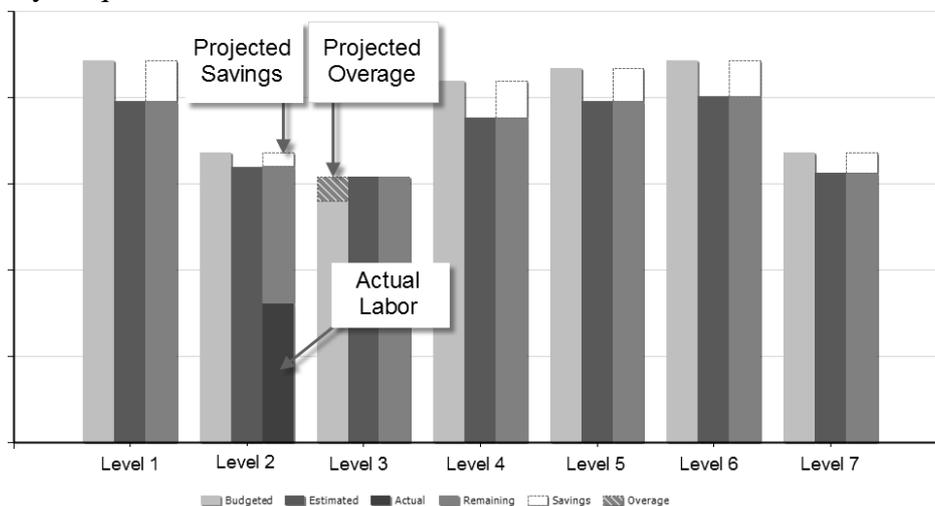


Figure 1 Labor Tracking for a Phase Summarized by Floor

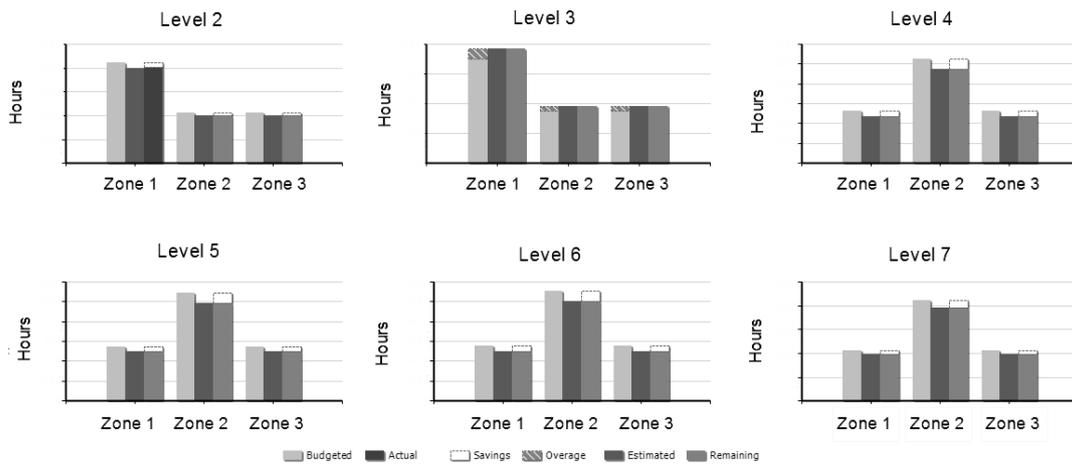


Figure 2 Detailed View by Floor and Takt Area of the Data Shown Figure 1

REVIEW CYCLE

The close alignment of data collected from following the TTP and LPS processes and the proposed systematic tracking of labor hours associated with those same activities provides rapid feedback on how resource utilization aligns with planned and completed activities and how weekly work execution planning aligns with the overall project budget.

An integrated team comprised of representatives of the at-risk partners reviews the Production Tracker charts on a bi-weekly basis during the production tracking meetings. Each trade reports on their production tracking graphs. They overview production progress, bring forth challenges, and discuss improvement ideas. These discussions spur many useful suggestions from one trade to another and allows early adjustments of the production plan to improve the overall production flow efficiency.

For example, in many instances, the trades would propose solutions where one trade will make a sacrifice (i.e. spend more labor hours) to increase the production efficiency for several other trades to yield an overall saving for the phase. The financial forecasting team reviews the same rolled up information on a monthly basis and correlates labor assumptions with overall budget forecasting.

MANAGING LABOR RISK

The alignment of field labor estimated hours with Takt geographic locations makes it possible for the various teams responsible for planning and delivering the Takt phases to better manage their risk and maintain alignment with the overall budget targets. Overages by certain risk-reward participants are often offset by savings by other Risk-Reward participants with a net savings to the at-risk work in the phase. For example, when the approach was first applied to the early slab pours, the team immediately identified areas of potential improvement and implemented counter measures to mitigate the risk including, among other things, improved management of crane time.

This approach frees the overall project management team to focus on issues that impact the overall project while making it possible for each phase team to manage the risks within their production phases in alignment with the overall budget against clearly stated targets.

CHALLENGES AND LESSONS LEARNED

CHALLENGING ESTABLISHED NORMS

When the concept of field labor tracking was first introduced to the project team, many were reluctant to participate out of concern that the effort would be redundant since each trade already tracks their field labor in great detail. However, the close examination of the current state revealed that while each trade tracks their own field labor, the tracking was not consistent across the trade partners, performed at different times, and it was not in alignment with the Takt geographic locations. This meant that the at-risk partners would not know the overall shared risk until many months after the work has been completed. Thus limiting their ability to manage that risk in any meaningful way. The review of the future state revealed that this new approach presented a significant benefit to everyone. In addition, it was noted that this approach would improve the transparency, consistency, and alignment of the data across each project phase and thus improve ownership and trust.

PROACTIVE MANAGEMENT VS PASSIVE MANAGEMENT

Field labor estimates are not typically aligned with TTP and LPS processes. The team made the commitment to estimate in accordance with production areas, and, to have the superintendents directly responsible for managing the performance of the work produce those estimates. In other words, Estimated Labor would not be simply a percent of the budgeted hours distributed over geographic areas. This is important to build a sense of ownership of the proposed estimates and also to ensure that the reporting captures the most up to date understanding of the work in accordance with the definitions of standard work within a Takt geographic location.

Generally, current labor tracking practices do not involve setting targets or tracking by production area. The estimator's quantity take-offs used to set the budget targets are performed much earlier in the project and prior to the completion of the Takt planning. The production team executes the work based on the needs of the site and in accordance with the Takt plan. Without the proactive updating of the estimated values, it would be very difficult to have an accurate forecast on what will take place in the field vs. what actually took place. Traditionally, this contributes to the long lag between budgeting and work execution and results in surprises during monthly financial meetings held months after the work has been completed. Thus limiting the team's ability to re-plan and manage this risk and left with the only option of recording such items, each time, as lessons learned to avoid on the next project purposes.

GO-BACK WORK

Go-back work is a general term that describes new activities associated with previously completed production activities where a trade partner has to go back and perform unplanned work in the form of rework or to complete certain tasks within the standard work of a completed Takt area that could not be completed due emerging constraints and that are not significant enough to interrupt production flow. Assumptions about go-back work are often included in the estimated activity duration and labor estimates. Go-back work contributes, to a large extent, to the common budget reporting issue when the cost codes show that 95% of the work is complete but the last 5% is the most costly. Without clear documentation of go-back work, the team

would be at risk of making inaccurate forecast assumptions and this poses a risk to a project.

Once go-back work was identified as a risk factor, the team collaborated and identified a plan to mitigate that risk. This resulted not only in improvements to the field labor tracking process, but also in improvements to the standard processes of TTP and LPS. A new activity status, namely Completed with Go-back Work, was introduced and implemented into the commitment cycle. During weekly work planning, the team was asked to apply the new status code to any activity that requires go-back work and record all the known go-back work against the completed activity. Both the original activity and the go-back work itself are tagged with special codes so that they can be identified later for labor tracking and process improvement efforts as increasing trends of go-back work could be a symptom of larger quality issues.

This new process helps the team to keep go-back work very transparent and allows the superintendent/foreman to assign estimated hours for go-back activities, not as percentage of budgeted but actually estimating labor hours considering the go-back strategy. This results in an accurate forecast for go-back work and improved risk management.

CONCLUSIONS

This paper presented a framework for aligning field labor hours tracking with the processes of TTP and LPS. This approach improves current practices. It presents an integrated process that increases the consistency and accuracy of the data and the efficiency by which the data is managed. The approach resolves many of the issues that teams face in practice due the complexities of incompatible reporting tools, methods, and processes which make it impractical to perform any type of integration or analysis on the data.

The implementation of the proposed approach on the STL pilot proved effective and allowed the team to maintain the information across the various phases of production planning in alignment with the overall project budget. It promoted transparency and provided an improved process for managing field labor risk especially in IPD projects where there are shared risk and reward arrangements. Moreover, the simplicity of the approach makes it more likely to be implemented on future projects and improved.

Future improvements on the approach would entail more attention to the tracking of quantities within the Takt areas. The systematic tracking of field labor hours, across Takt geographic locations, and the statement of clear standard work definitions, when augmented with reasonably accurate quantities would serve the basis for building a robust knowledge base for measuring the effect of Takt and LPS on labor productivity. While the current implementation allowed for rudimentary tracking of area quantities, additional work remains to be done to improve material quantity tracking and analysis.

While the focus of this paper has been on the tracking of field labor hours for Takt activities, the approach could be extended along similar lines to other types of production work including that of fabrication, materials, design and pre-construction activities and to improve resource planning at the supply chain level.

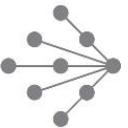
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p2sl@berkeley.edu
Project Production Systems Laboratory
University of California, Berkeley
CEE Department - 760 Davis Hall
Berkeley, CA 94720-1710

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