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TAKT TIME PLANNING OF INTERIORS ON A PRE-CAST HOSPITAL PROJECT

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ABSTRACT

This research presents a case study of Takt time planning developed for interior construction in a healthcare facility in Sacramento, California. This research uses design science to test the method of Takt time planning and answer the research question: how does a team develop a Takt time plan and what challenges exist during plan execution? Data was collected from a project, where one of the researchers worked the entire time during the planning and execution of the work. Evidence for the claims come directly from the scheduling data.

The purpose of this research is to improve upon current practices of planning and project delivery during the interior phase of hospital construction. Findings from the research reveal how the Takt time planning process can help improve construction schedules with (1) smaller batches of work and/or (2) an improved understanding of the work contents. However, executing to a Takt time plan requires rapid feedback and problem solving in order to maintain the plan, depending on the pace of the job. As such, all aspects of the production system need to be aligned in order for a Takt time plan to be executed successfully. A limitation to the research is that it comes from a single case study. The implications from the research are that there may be types of projects or phases of projects where buffering with capacity alone may not make sense during interior construction, and early schedule data collected within the Last Planner system may provide that indication. The research contributes new research questions regarding the relationship between non-field and field production. The research also contributes insight into how to apply Takt time planning on a project.

KEYWORDS

Takt time planning, Production Planning and Control,

INTRODUCTION

This paper presents a case study of Takt time planning developed for interior construction in a healthcare facility in Sacramento, California. The scope of work that was planned to a Takt time began with layout of mechanical/electrical/plumbing (MEP) components on the concrete floor, just after the floors were poured, and ended with hanging of gypsum wall

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board. The project must meet various building codes including California's earthquake design codes and the code requirements from the Office of Statewide Health Planning and Development (OSHPD). The project is a $16,000,000, 2-story, 26-bed, 1,800 m^2 (19,000 ft^2) psychiatric care facility and expands an existing 120-bed hospital. It was delivered with an Integrated Form of Agreement contract.

Development of a Takt time plan for the interior trade activities was selected on this project due to the nature of the work and the speed of the construction schedule. Construction of foundation work began in March 2015 and the entire job was planned to be finished and ready for the owner to move in October 2015. The interior work was released by the pre-cast erection work in two phases (consisting of separate halves of the building). The interior pre-cast walls contained rough installed (known as "rough-in") MEP components, which in theory enables faster inwall rough-in activity durations because installation work is already completed upon pre-cast erection. This paper covers the development and execution of a Takt time plan for the first phase of interior construction.

LITERATURE REVIEW

Takt is German for the word beat. Takt time is "the unit of time within which a product must be produced (supply rate) in order to match the rate at which that product is needed (demand) rate" (Frandson et al. 2013). The purpose of Takt time planning is to create flow on a construction site around a beat or multiple beats for different construction phases.

Several case studies have tested methods for Takt time planning on construction projects (Linnik et al. 2013, Frandson et al. 2013, Frandson and Tommelein, 2014). This research also follows previous efforts to pace multiple activities to the same rate in construction (e.g., Willis and Friedman 1998; Horman et al. 2003; Court, 2009, to name a few.).

METHOD

This research uses design science to test Takt time planning. Design science involves four activities: (1) building an artefact (the method of Takt time planning), (2) evaluating an artifact, (3) theorizing why the artifact works or doesn't, and (4) using evidence to draw the conclusion (March and Smith 1995). The goal of the research is to solve a practical problem (in this case the problem of producing flow on site) and to generate new theory.

Design science research is also iterative. This case study iterates on the method of Takt time planning developed during case studies described in Frandson et al. (2013) and Frandson and Tommelein (2014).

Below is an outline of the research steps for this case study.

- Review the relevant literature and lessons learned from previous case studies of Takt time planning.
- Begin Takt time planning with the project team following the procedure outlined in Frandson et al. (2013).
- Detail how the Takt time plan developed.
- Evaluate how the project team executed their work according to the Takt time plan.

Rationalize the differences between execution and the plan.

Theorize how the method of Takt time planning (i.e., the artifact) works or can be improved.

DEVELOPMENT OF THE TAKT TIME PLAN

This research, and the related planning work, began in February 2015 and started with identifying Milestones. The team identified Takt time planning as a means to deliver a fast schedule and agreed to go through the Takt time planning process. The team involved in the Takt time planning process was comprised of the foremen for the plumbing, HVAC, and electrical scopes; project managers for plumbing, HVAC, electrical, and drywall scope; the general contractor represented by a superintendent and project manager; the architect, and the structural engineer. The team had experience using the Last Planner system for production control. From here on forward, the term “production team” refers to these foremen, project managers, superintendent, and the researchers. One of the researchers also acted as the scheduler and production engineer on the project.

Figure 31 presents the installation durations provided by the trades in an initial pull planning session held before the research began. The resulting schedule is not shown here, but what is evident from the figure is that these durations would create a schedule significantly longer than the proposed end date if each trade were to have the space to themselves and the work has finish-to-start relationships (or everyone would be working simultaneously and not to the desired sequence). It is unclear to the researchers what effort the project team invested to turn the pull plan into a schedule that met the Milestones before this research started.

Figure 32 shows a colored map of the initial zones (zones A, B, and C on Level 1 and the same on Level 2) created before the start of the research. The stated rationale for initially identifying these three zones was that zone A contained the patient rooms (e.g., similar work), and zones B and C had roughly equivalent work densities (time needed to complete certain amounts of installation work on site) for each MEP trade. Zones B and C contained the spaces necessary for staff and operations (exam, break area, nurse station, storage, etc.). Per the initial pull plan, the activity durations for each individual trade were not balanced through the initial zones.

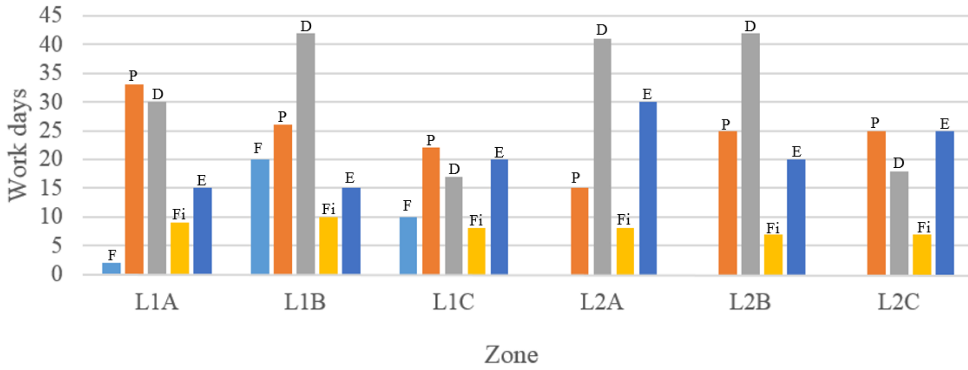

Figure 31: Initial installation durations provided from Pull Plan meeting
per zone (L1A = Level 1, Zone A; L2B = Level 2, Zone B, etc.) and
per trade (F = framer, P = Plumber, D = Duct, Fi = Fire Sprinkler, E = Electrical)

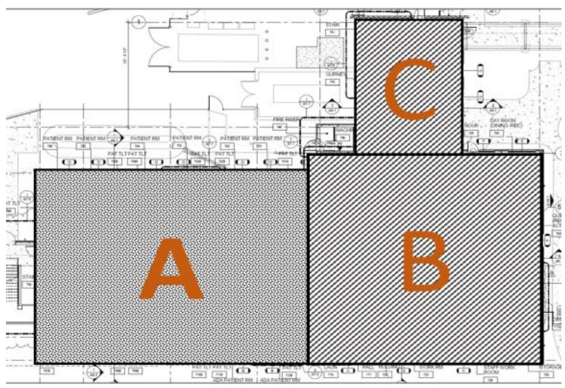

Figure 32: Production areas for MEP installation phase

Based on the Milestones and concrete floors releases to the interior trades, the researcher calculated the required minimum Takt time in order to complete the schedule in the allotted time. The minimum Takt time was calculated by dividing the total number of days for a phase through one zone by the number of activities that needed to move in succession through the zone (e.g., 55 days for a zone with 11 activities results in a 5-day minimum Takt time if all activities move at the same pace). In these early meetings the team agreed to release the pre-cast concrete work in two batches in order to split the project into two phases. These phases would also become the zones the trade activities would work through (e.g., Phase 1 = zones B & C, Phase 2 = zone A). The team then aligned their Takt time plan to four zones: Phase 1 and Phase 2 through levels 1 and 2.

Figure 33 presents the different schedule scenarios on a line of balance diagram, each one represented as a single activity. The time left for the finishes phase of interior construction is delineated by a set of vertical lines. The rationale for the different scenarios was to communicate how much time different Takt times provided for the remainder of the work. The researcher assumed each scenario contained 10 activities (5 passes of MEP overhead, wall framing, and 4 inwall MEP passes) through 2 zones in Phase 1, 11 activities through 2 zones in Phase 2, and a week for layout/fire sprinkler work. The vertical lines each reflect the start date for the finish phase and how much time would remain to complete that scope (which also includes testing and starting up the equipment). With this information, the team decided upon a Takt time, balanced the work, and created a schedule.

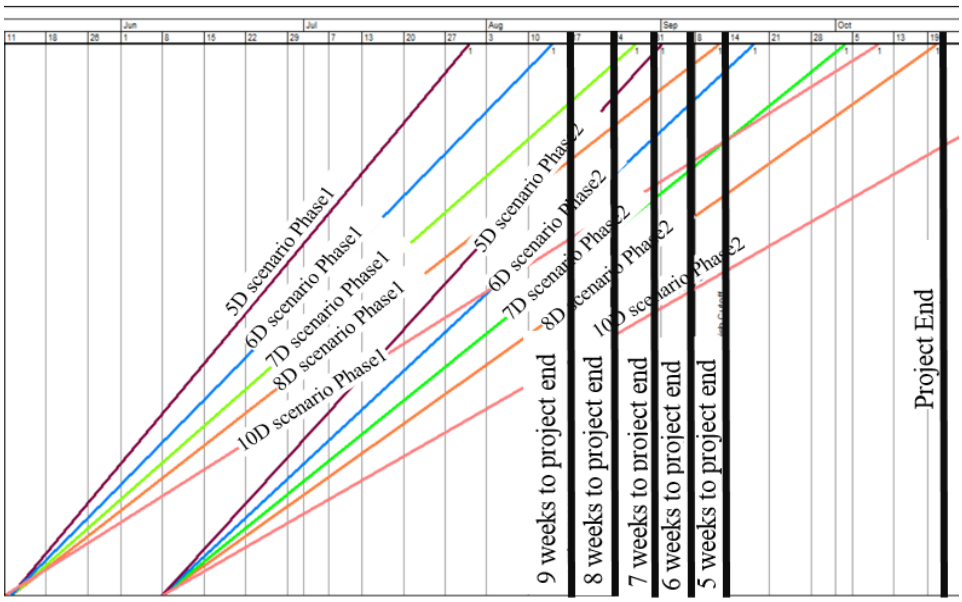

Figure 33: Takt time scenario calculations

Based on the starting production data collected from the initial pull planning session, a 10-day Takt time was the proposed target that the team could meet. However, the researcher's schedule analysis showed that this Takt time would not meet the project requirements (e.g., the demand rate) based on the assumptions of how many passes (i.e., how many times would a trade need to 'pass' through the area and complete all their work for the given phase) would be required through four zones. The option that came closest to meeting the constraint of leaving 8 weeks for the finishes phase was working to a 5-day Takt time, with one crew per trade, through four zones, broken into two phases of work. This was proposed as the design target for the production team to identify how to structure the trade activities so that they would be able to meet this hand off.

After the production team agreed upon the target, the team began to validate the sequence identified in the pull plan and the durations. The durations were validated by marking up the plans for the mechanical piping, duct, and plumbing work. As an example, from this process the duct foreman identified that he had 8 days of duct work per phase per floor. The electrician did not mark up floor plans, but the foreman committed to completing his work in whatever time the other trades were allowed. The electrical foreman was confident his crew could complete the work as fast as the other trades because he had work only in the electrical room, minimal overhead work (just one rack that would take 1 man 3 days to complete), and minimal inwall rough-in because the work was already in the pre-cast walls. Through the course of two meetings, the team committed to a 14 activity sequence at a 5-day Takt time for the overhead and inwall work shown in Figure 34.

PRECAST ERECTION (TAN)	CAST IN PLACE CONCRETE (Light Grey)	DRILL AND LAYOUT ANCHORS, TOPTRACK (Grey)	CAST IRON/ FIRESPRINKLER / VERTICAL SHAFT WORK (Orange)	PRIORITY FRAMING / TOP DOWN (Light Purple)	OH DUCT / PRE RACK PLUMBING (Blue)	OH DUCT / PRE RACK PLUMBING (Blue)
OH PLUMBING / ELECTRICAL HOMERUNS (Green)	TEST AND INSULATE (Yellow)	2ND PASS FRAMING (SOFFITS/WALLS/ HARD LIDS) (Red)	ELECTRICAL INWALL ROUGH and Branch (Lt. Blue)	PULL WIRE / PLUMBING ROUGH IN (Lt. Blue)	HANGING (Lt. Green)	TAPING (Purple)

Figure 34: 14-activity sequence for the interior MEP work (from 1-14)

By working to the production target, the team structured the different activities each trade needed to perform into the 14 activity sequence parade with a 5-day Takt time. Only one of the 14 activities, OH DUCT/PRE RACK PLUMBING, required two 5-day Takt times. The reasons for this were (1) the duct work was dense through zones B&C and could not fit into 5 days and (2) the plumber needed to install some mechanical piping before the duct was installed in some areas in that zone. Furthermore, the amount of work the plumber needed to install before the duct sequence did not require the entire space for a Takt time, so the production team decided to combine the activity with a duct installation sequence. The remaining activities in the sequence were all amenable to a 5-day Takt time. By amenable, we mean that the team was willing to work in the sequence at the Takt time, even if it was not their preferred way, in order for the benefit of the project as a whole. The electrical room work was set as a leave-out area from this Takt time plan. The electricians committed to performing this work around their work in the 14 activity sequence. Each of the 14 activity sequences was formed from a batch of smaller tasks. The 14 activities were also known as "train cars" on site, in order to extend that analogy that everyone needed to move through the space in the same order at the same rate.

Following the agreement on the 14 activity sequence, succeeding production planning meetings aimed to (1) identify the specific hand offs of work for every activity, (2) identify the priority walls (i.e., walls that need to be framed before overhead MEP equipment is installed) and (3) restructure the work as needed to keep a feasible production schedule.

It took one meeting to populate a list of hand offs for all of the activities in this phase. The list was populated by placing one poster size sheet of paper on the wall for every sequence for every week (i.e., "OH DUCT/PRE-RACK PLUMBING had two sheets, one for each week). The trade partners simultaneously filled out the sheets and reviewed the work as a team at the end. The meeting revealed to the researcher how smaller activities could be sequenced within the larger activities and when work really needed to be done. For example, there were multiple alternatives for insulating mechanical piping and duct. The electrical work also had flexibility in when it could be performed, so the decision was to balance the work across the available activity sequences amenable to electrical activities.

RESULTS

The first production activity sequence was vertical work / fire sprinkler rough install. It did not complete as planned because of a pre-cast shaft opening for the vertical duct work. The space was so large that the shaft wall could not be framed, for there was no concrete. Without concrete, there is nothing to attach top and bottom track to. The result was that some specific tasks within the activities could not started as planned and were left out while the remaining activities progressed. A better Lookahead process may have caught the opening conflict with the framing, but the project circumstances resulted in not much time between pre-cast panel erection, pouring the concrete floors, and the start of MEP layout.

The average activity started 3.9 days later than planned, and the standard deviation for the activity starts was 16.2 days. The longest delays came from the work left out due to the shaft challenges. The actual shaft work installation was delayed by 50 days, and the overhead plumbing installed after it was delayed by 28 days. The soffits and ceilings left out due to the shaft was delayed by 28 days as well.

Production tracking for the patient room work was performed weekly. Production tracking is the process of recording the performed work in order to identify what was done, deviations for the plan, and understand causes to plan deviations. The daily production plan, Weekly Work Plan, and colored floor plan were all posted in the field on the first floor (Figure 35). Instead of reviewing production at every daily huddle, the team went straight to identifying problems in the field, where the problems were tracked in an issue log and labelled on a floor plan with stickers.

Figure 35: Field production boards

Figure 36 presents the PPC for the field activities and 'Make Ready' plan for the project. The 'Make Ready' PPC is essentially the PPC for the non-field activities of the project, because the 'Make Ready' plan contained specific activities for the designers, project engineers, owner, and project managers. The activities on the Make Ready plan were generated when people screened construction activities weekly and identified specific activities that needed to be done to make the work ready (e.g., create and send drywall trade the elevation for the west wall of the north stair). The intent of splitting the 'Make Ready' Plan activities from the field was for organizational purposes. This allowed for improved tracking for each plan and did not clutter the field board with non-field related activities. Last, the name 'Make Ready' plan had a PPC metric associated with it, 'Make Ready' PPC, but this should not be confused with the Tasks Made Ready (TMR) metric. TMR measures what percentage of activities in a target week that are included in a later plan for that target week. The 'Make Ready' PPC is a filter of the project's PPC for the non-field activities, and contained activities that were tied to field activities that would be (or soon would be) delayed if the non-field activities were not completed.

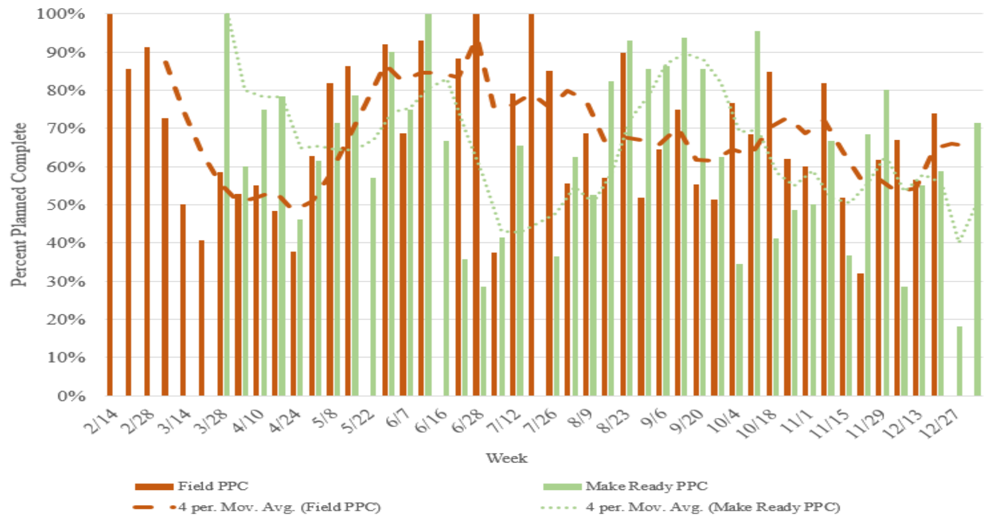

Figure 36: PPC for Field and 'Make Ready' plan over the course of the job

DISCUSSION

The Takt time planning process started with pull plan data that did not result in a feasible schedule. It was not clear to the researchers why the team had iteratively worked on their pull plan to meet the Milestones. The project team did see Takt time planning as a means to produce a schedule that would be feasible however, so it could be that the pull plan was not updated because the Takt time planning process would build off of the data anyway. Indeed, through Takt time planning the team collaboratively found ways to structure work into a 14-activity sequence that adjusted total schedule durations required by each trade (Figure 37). Note that framing did not have any work initially in Level 2 Phase 1, but this changed during the planning process. We rationalize these reductions in activity durations by an improved understanding of the work involved, the work environment, the sequence, and the project requirements. Changes in crew sizes would also affect the data, but the initial schedule data was not resource loaded so performing this analysis is impossible.

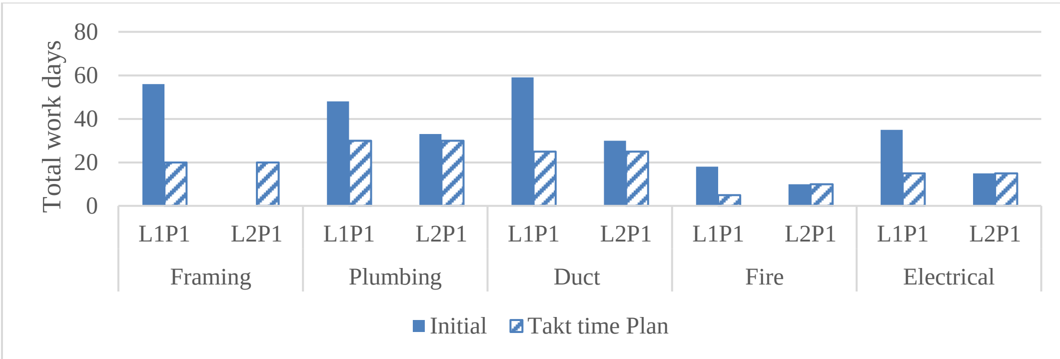

Figure 37: Changes in durations from initial to Takt time plan (L1P1 = Level 1 Phase 1)

While the Takt time planning process resulted in a feasible schedule with seemingly improved durations, the plan could not be followed perfectly. One cause for this was a misalignment between the rate at which the field could complete work and the rate at which the work could be made ready by the non-field personnel. As such, using a capacity buffer (e.g., Frandson et al. 2015) to maintain fast, reliable flow is not effective in these circumstances when the bottleneck is not production related. There may also be potential opportunities on a project during execution to strategically use a time buffer to allow for the non-field related work to catch up. An example time buffer may be added between the layout of walls and MEP work, and the start of the first sequence of actual installation. Overall, the lesson learned is that in order for a Takt time plan to execute accurately, all aspects of the production system need to be aligned.

The relationship between the field and the Make Ready work was a surprise. It seems intuitive that if field work is not being made ready (i.e., there is a low Make Ready PPC), then the field PPC would decrease because the Make Ready work contained activities that needed to be completed that week or else field activities would be delayed (or soon would be). However, the researchers found no correlation between the two values, nor a correlation between the PPC of Make Ready plan and the following weeks' PPCs in the field.

One explanation for why there is no correlation is that people simply do not plan to do work that they know is not ready that given week, instead they "make do" and work on something else that is captured in the commitment meeting. As such, there may not be a correlation between the PPCs values for the Field and Make Ready plan. This sort of "make do" behaviour may be caught if Tasks Anticipated (TA) were tracked, for the committed work would differ from the previous week's plan one week out. These are new questions for future research. Would the TA metric realize this behaviour? Should there be a correlation between PPC's if the field and non-field activities are tracked separately? How would a Task Made Ready (TMR) metric capture these effects? A production relationship certainly exists between the Make Ready work and the field, for the field activities will not complete if the work isn't being made ready. As such, the actual schedule figures reflect that relationship, where some activities started much later than planned.

CONCLUSION

This paper described and evaluated the use of Takt time planning on a construction project. Through collaboration, a project team used Takt time planning to take an infeasible construction schedule and develop a schedule that would fit the project requirements.

The project was not able to perfectly follow the Takt time plan. The second activity in the 14-activity sequence could not be completed as planned, which resulted in some work being left out and completed later. Nevertheless, balancing the work to a 5-day Takt time provided new insights into the production system and provide contributions to knowledge. First, a balanced production system in the field requires that the entire system, including the capability of the project team to make work ready, must be balanced as well. Second, during execution, there are likely strategic moments on projects to place time buffers that allow project teams to resolve problems before field activities are impacted, so it would be good to identify and use these opportunities in order to improve project performance. Third, if work is not ready, PPC data for the field and non-field may not correlate, but more data from multiple projects is required to improve understanding of this relationship as well as understand how the TA and TMR metrics relate or identify the problem.

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