Increasing Reliability of Design Workflow Using Takt Time Planning

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Poor management of the design process can be detrimental to the success of any construction project. While the construction industry has attempted to increase the reliability of its planning processes, less focus has been on the design phase. This paper presents the case of a healthcare project where the project team made concerted efforts to improve the reliability of the design workflow. The project explored the use of takt time to plan and control the tasks during the design phase. The paper provides details of the design process management and measures reliability of the design workflow by three metrics: (i) Commitment Level (CL), (ii) Percent Planned Complete (PPC), and (iii) Percent Required Complete or Ongoing (PRCO). Analyses showed alignment of consistent long-term planning with short-term planning during the design phase of the project by utilizing takt time.

Key words: Design workflow, planning reliability, takt time planning, Lean project delivery system

Introduction

Design and construction professionals are constantly striving to reduce the uncertainties in their workflows. The processes related to design and construction of any project are complex by nature and require inputs from several project stakeholders with numerous interdependencies and uncertainties (Freire & Alarcón, 2002). Poor planning of construction activities results in delays that can cost almost $100,000 per month even in small projects (Beaty et al. 2016). Similarly, poor management of the design processes has proven to be the cause of document deficiency and rework (El. Reifi and Emmitt, 2013) that can be equally detrimental. The uniqueness and technical complexity of projects can make design tasks less predictable and highly variable (Newell, 2004). The variable workflows create uncertainties in the design processes and negatively affect the project performances. In order to improve project performances, it is critical to mitigate the unreliability in the workflow of the design processes. Scholars have proposed several methods to mitigate this issue that can be categorized into three groups.

One of the methods suggested by Eppinger et al. (1992) to improve the workflow of the design processes is by enhancing inter-task relationships. In this approach, a design dependency matrix is created to represent the flow of information through the various design tasks. The tasks are planned in a way to minimize the need to send information to preceding tasks, unnecessary iterations are then identified, and omitted. The other strategy suggested by more than one study is to modify the inter-agent relationships and increase collaboration (Carter and Baker, 1992; Emmitt and Ruikar, 2013). For example, Emmitt and Ruikar (2013) suggested to improve the communication between designers and other stakeholders so that all the parties can perform and track design reviews in a timely manner. Carter and Baker (1992) on the other hand, suggested to use concurrent engineering to improve design products characterized by rigorous analysis arising from the construction site. Simply put, it is a way of increasing collaboration among designers and construction professionals. Further, BIM-based tools have emerged to facilitate an integrated, collaborative environment from the pre-design stage to post-construction to facilitate the process of concurrent engineering.

Thirdly, some researchers articulated the need to enhance the predictability of design workflow. They argue that long-term or even short-term plans are subject to variability, especially in highly uncertain environments such as architectural and engineering designs. Short-term planning, however, can be comparatively more reliable in collaborative environments. Therefore, these methods encourage planning in a collaborative manner, from which short-term commitment plans emerge. A commitment plan is a list of coordinated promises that should be kept by frontline supervisors and their work groups to accomplish tasks within a time period (Hamzeh et al. 2015). Creating sound assignments is a major emphasis of this method. Techniques for planning and project controls within the paradigm of Lean project delivery system has been found to improve the reliability of the planning process at the operational level by aligning the resources available to the need of the participants. This is done by a collaborative process where overall project scope that should be accomplished is broken down into specific tasks that will be executed with identifying and eliminating constraints for a steady workflow thus increasing the reliability of the planning process. Ballard and Howell (1998) proposed measuring the reliability of the planning by comparing the variances between commitments and actual tasks completed. They proposed that, right amount of work should be performed in the correct sequence, and that only work that can be executed is committed. Right amount of work is defined based on the resource available to the participants and the need of the schedule. This approach focuses on increasing the reliability of the planning process by reducing the variation in the workflow through collaborative planning, creating sound assignments, tracking commitments, and continuous learning process. Creating sound assignments involves gathering information on production rates and utilizing them in the planning process. To facilitate the planning process, Lean delivery system recommends the use of takt time planning. From the German word for 'beat' or 'rhythm,' the 'takt' time is the rhythm/beat that sets the pace of the workflows.

The concept of takt time planning has been mostly utilized during the planning and control of the construction phase with varying degrees of success. However, there is a lack of evidence citing the utilization of takt time for managing the design phase. This paper presents a case study to explore the use of takt time during the design phase of a healthcare project to examine any effect it had on the design workflow for the case study project. The paper provides details of the design process management and measures reliability of the design workflow by three metrics: (i) Commitment Level (CL), (ii) Percent Planned Complete (PPC), and (iii) Percent Required Complete or Ongoing (PRCO). The metrics are discussed in detail within the case study. Analyses showed alignment of long-term planning with short-term planning during the design phase by adhering to takt time. Additionally, focus on critical tasks to meet target milestones, collaborating to create sound assignments, and being able to keep commitments facilitated to increase the reliability of the design workflow.

Takt Time Planning and Expected Benefits

Takt time can be simply defined as "a design parameter used in production settings, be it manufacturing or construction, tuning the rate of work output to the customer's rate of demand" (Frandson and Tommelein, 2014). It is the calculated time within which a product (or parts of a product) must be produced to meet the rate at which the product (or the parts) is needed. Takt time became a topic for interest in both manufacturing and construction industry, as a design parameter used in production settings, controlling the rate of work output to the rate of customers' demand. Takt time planning can be combined with Lean techniques for planning and controls to achieve time saving, money saving, and quality improvement (Frandson and Tommelein, 2014). Lean project delivery system has evolved from the Japanese automobile industry and is used with the primary aim of identifying and eliminating waste(s) in the design and construction processes. The need for efficiency in the workflow of any process forces the workers within the workflow to understand the demands of the customers (immediate customer as well as end customer).

Takt time is easiest to understand in a sequential work process where each worker must complete his/her task in time for the product to move through the process and ready for the next worker to perform his/her task. If any worker in the sequential process fails to complete his/her task in a timely fashion, the product moves down the line not ready for the next worker to work on. The pace and sequence of the flow is determined by the customers' demands and the pace of the workflow is driven by the takt time. The priority is given to work flowing smoothly without stopping. Smooth workflow prevents overproduction, which is the cause of most of the other forms of wastes (Taiichi 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), in the 14 principles of the Toyota Way suggested to "create continuous process flow to bring problems to the surface." Continuous flow of work is needed in order to reduce waste and to promote continuous learning and improvement. To summarize, takt time planning places priority on the workflow and provides a formal method to pace the workflow according to the customers' demands.

The expected benefits of takt time planning are reduced project duration and lower project cost. By providing clear goals of assignments, increasing the productivity, and solving problems promptly this strategy helps to balance and manage the production of the workers, which in this case are the designers/engineers. The process will no doubt increase concurrency and predictability of workflow between different disciplines of design/engineering. It is normal that few designers/engineers following one another in the sequence will require different amounts of time to complete their tasks. The one that requires the longest amount of time is commonly referred to as the bottleneck. Whatever is done to increase the production rates, whether pushing for more productivity or adding capacity, some will go faster, and some will go slower depending on the nature of the tasks. Those that go faster are at a risk of not utilizing their capacity. On the other hand, takt time planning can bring in positive changes in the form of higher utilization of resources, reduced need for coordination between different disciplines, reducing the load on supervision, and reducing the durations of different phases. The assumed benefits of takt time planning has been summarized in Figure 1 below.

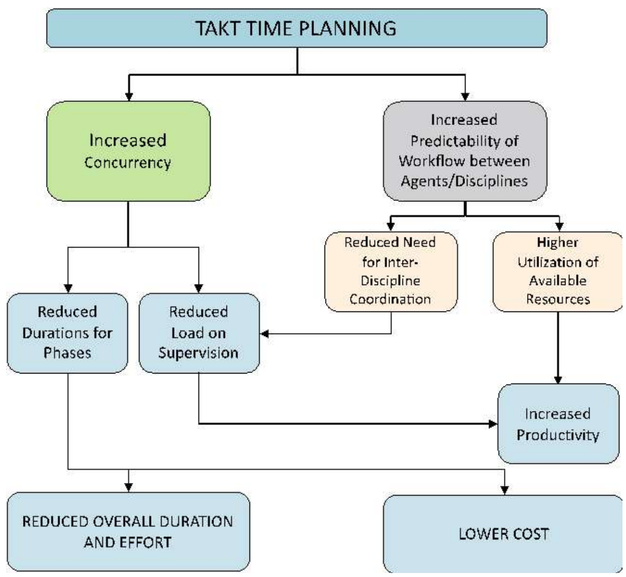

Figure 1 – Expected benefits of takt time planning (adopted from Linnik et al. 2013)

Takt time planning seeks to stabilize the flow of any work process with a predictable rhythm, which meets the schedule demand. Description of the design process management adopted in the case study will explain the use of takt time to facilitate the workflow by clearly communicating the task dependencies, task durations, constraints, and commitments of the designers/engineers.

Case Study

The case study project was an addition to an existing healthcare facility that involved a new four-storied building with 168,000 SF for approximately 71 million USD to be structurally tied to the existing building. Concrete foundation with precast service cores and structural steel structure was selected for the new building. The building skin was comprised of brick, stucco, metal panels, and curtain walls. The new addition had four floors: the first floor being the emergency department with emergency rooms, the second floor housed few operation theaters and shell space, the third floor was the Neonatal Intensive Care Unit (NICU), and the fourth floor was planned for utilities. In addition to the new construction, the project also included the renovation of the NICU in the existing building.

Design Process Management

The design team was comprised of four entities: architects and interior designers, structural engineers, civil engineers, and mechanical, electrical, and industrial process engineers. The owner adopted an integrated project delivery method and brought in the architectural firm, structural engineering firm, prime contractor, and major trade partners during the project feasibility stage. The civil engineering firm, and the mechanical, electrical, and industrial process engineering firm were brought in during the schematic design phase. This formed the core group for the case study project that comprised of owner, designers, engineers, prime contractor, and major trade partners. The core group put together a master schedule for the overall project (Figure 2). Compiling and coordinating the inputs of the core group members helped to strategize the overall sequence.

The master schedule helped set the milestones based on a backward calculation from the contractual finish date, and essentially identified the work that 'should' be done. It provided a basis for structuring each design process. The master schedule at this point was very broad with the timeline marked in months and the durations of the milestones in weeks.

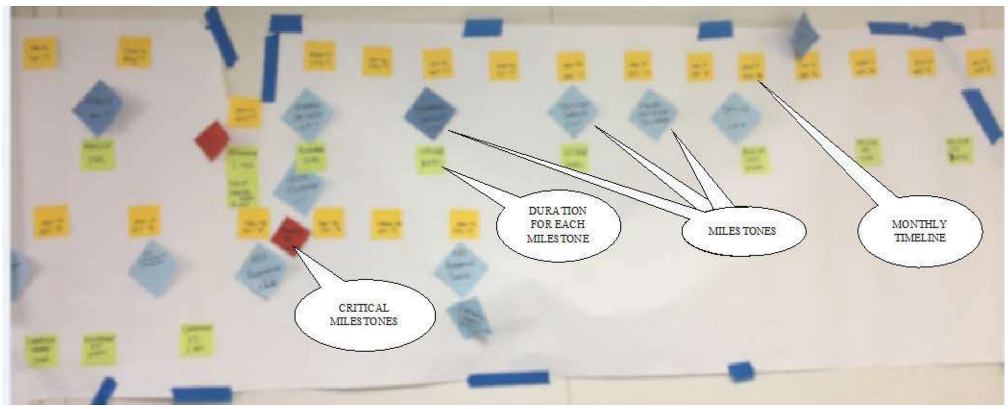

Figure 2 – The master schedule (setting milestones) of the case study project

While the master schedule identified the tasks that should be done at a high level, the subsequent steps were to break down the master schedule into a lookahead plan for a shorter window of time (4 weeks) to present more details. This process again involved the participation of the core group members. The schedule for the case study project was prepared and saved on an online server which was accessible by all the members of the core group. Each member had selective editing capabilities of the schedule that restricted their abilities to alter another member's schedule. An example of a typical lookahead plan from the case project is shown in Figure 3. The lookahead was divided into distinct swim lanes for different disciplines (marked by different colors) for the ease of visualization. With the lookahead meant to scrutinize each task before pulling in based on the milestones in the master schedule, detailed information of the tasks was captured. Figure 3 shows the typical information captured for each task by the core group members such as duration, assigned discipline, person making the commitment, location, and similar. The project team utilized takt time planning in preparing the lookahead plan to facilitate continuous workflow for tasks.

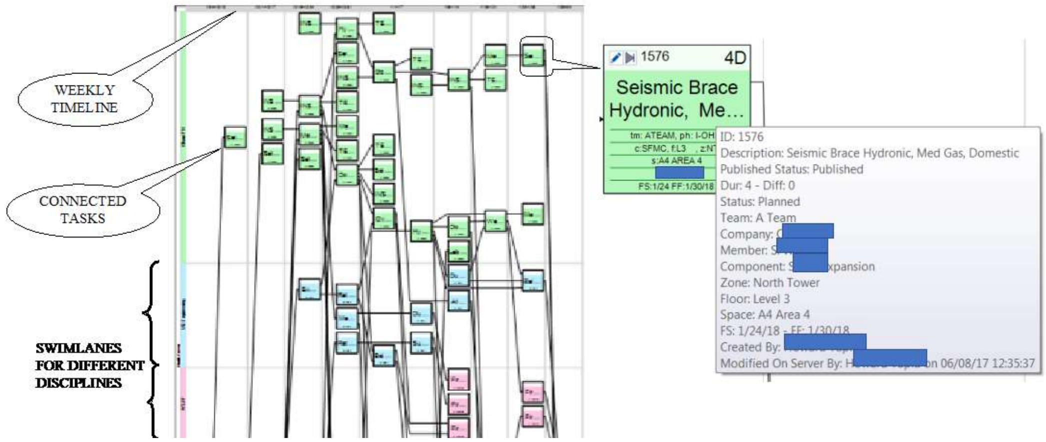

Figure 3 –Extract form lookahead plan template showing different disciplines in different colors

Use of Takt Time Planning

The design process was perhaps the most disruptive component of the case study project. The architects, interior designers, and engineers worked with the owner/end users to facilitate the process of designing, rather than owning the design process. This is very much in contrary to a traditional set up of a healthcare project, where the design team usually works with the client administrator, financial manager, and few clinical managers representing the client. The traditional design process would have started with defining the client needs and identifying the constraints such as the budget, square footage, schedule, downtime or affecting current operations during construction, and similar. From that point on, the design team is expected to lead and own the design process that is vetted by the client from time to time. For the case study project, all the members of the core team were involved actively in making design decisions based on their needs.

The core team used few other techniques that made the design process in the case study project radically different from that of any traditional project. The design team worked side by side with the client representatives listening to what the users needed to do their jobs and challenging them to identify the best possible design decisions that would be most value added. The core team members used precedence studies of peer hospitals and aspirational hospitals to identify and streamline their needs (and wish list items). They also used multiple design options constructing full size mock-ups that allowed the users to physically experience the space by walking through and testing multiple design options. Set based design approach was used to develop a range of options to evaluate range of desired capabilities, the users tested, analyzed, and improved several design configurations until they reached their operational improvement goals and narrowed down the design options.

The overall design process could be divided into four distinct phases: (i) concept design/pre-design, ii) functional design/schematic design, (iii) detail design/design development, and (iv) implementation document/construction documents. For each phase the core team identified the disciplines that would work and how their tasks would be grouped together. While all the client representatives were heavily involved in the first three phases, their involvement reduced in the last phase. With so many entities involved in the design process, it was critical for the design team to be on top of the design process workflow to meet the schedule requirement. The concept of takt time planning was utilized by the team to stay on track. It started with identifying the disciplines that would work in each phase and deciding how their tasks could be grouped together. While grouping, it was critical to gather detailed information about the scope of work involved and preferred/required information to complete the work successfully. The tasks were pulled based on the master schedule and the lookahead plans.

The output of the pull plan determined the sequence for successful completion of the design tasks based on manpower and duration. Pull plans specified the handoffs between the disciplines. Tasks were considered complete when all the core team members accepted and signed off. This enabled identification of the bottleneck tasks and their impact on the overall schedule. The time taken by different disciplines through the tasks were analyzed and balanced to the same constant, the takt time. In all phases except concept design, takt time was set at five days to maintain the weekly cycle and maintain the task release on a same weekday working longer periods of time. To adjust everyone's duration to takt time, capacity was modified. Management of the design schedule was at this time focused mostly on the bottleneck tasks.

Metrics to track the reliability of the design workflow

For the case study project, the reliability of the design schedule was measured by three metrics: (i) Commitment Level (CL), (ii) Percent Planned Complete (PPC), and (iii) Percent Required Complete or Ongoing (PRCO).

CL is the ratio of total committed required tasks to total required tasks for any given week expressed as a percentage. In this regard, a task was considered required when the late start of the same fell within the window of time for the weekly takt planning. The tasks were pulled based on the master schedule, lookahead plan, and controlled by the takt time. The numerator of this ratio refers to the critical tasks of the week and the denominator refers to the tasks pulled from the lookahead plan. Based on how CL was calculated, it demonstrated the reliability of the long-term planning of the project team.

Commitment Level (CL) = Required Will ÷ Should

PPC, which is the ratio of committed tasks completed to the total number of commitments in any given week expressed as a percentage. However, all the committed tasks might not be required based on the pull from the master schedule. No distinction was made between the critical tasks and the backlog tasks while calculating the ratio. PPC is regarded as an indicator of how well the planning process is performing at a weekly level, which was the planning cycle for this project.

Percent Planned Complete (PPC) = Did ÷ Will

PRCO is the percentage of the required tasks that were completed on/before the committed dates including the ongoing tasks. Ongoing tasks are tasks that do not require intermediate handoff, start when promised, and span more than one planning cycle (which is one work week in this case). The ongoing tasks were included in this metric as they came up based on the core group members' updates on the remaining durations of the tasks. The duration of the ongoing task could then be reduced, and it would count towards PPC if its remaining duration still fitted within its promised date. The PRCO helped to capture the level of reliability for short-term planning of the project team. In conjunction with CL, PRCO provided a comparison of short-term planning reliability with that of long-term planning reliability.

PRCO = (Required to be Done + Ongoing on Track) ÷ Required Will

The means and standard deviations of the three metrics are presented below (Table 1) from the case study project. The data presented has been collected on a weekly basis for a total of 31 weeks. The average number of activities in the lookahead plan was 68 with approximately 12 activities consistently added or completed on a weekly basis Among the three metrics, CL showed the lowest mean value with the highest standard deviation.

Table 1: Means and SD of the metrics

Metrics	Mean	SD
CL	0.62	0.22
PPC	0.74	0.16
PRCO	0.78	0.12

A cross tabulation was conducted to measure the correlation among the three metrics. Positive correlations are observed among all the metrics with significant correlation only observed between PPC/CL.

Table 2: Correlation among the metrics

	CL	PPC	PRCO
CL	1		
PPC	0.722*	1	
PRCO	0.687	0.569	1

** indicates significant relationship p<0.05*

Conclusions

Takt time planning was implemented in the case study project to achieve a stable workflow and increase the reliability of the design schedule. The core group members realized the dynamic nature of the tasks and their interrelationships. Using takt time helped the core members to balance the production rate based on the resource availability and target milestones. The CL, an indicator of the long-term planning reliability, if increases consistently implies successful collaboration among the group members. In case of groups that fail to collaborate on a regular basis and constantly focus on the remaining tasks will show a decrease in the CL value. The CL value of the case study project for the period of observation has shown an upward trend (Figure 4). It is clear from the trend that the core group members struggled with the process at the beginning but managed to improve the process as the project progressed. The upward trend is indicative that critical tasks appearing in the weekly cycles were closely following the master schedule and lookahead plan prepared to meet the target milestones.

CL in conjunction with PPC and PRCO provides an indication of both the long-term planning and short-term planning reliabilities. Comparable/similar values of the three metrics indicate the group members were successfully completing their tasks to meet the target milestones. Comparable/similar PPC and PRCO, as in this case, indicate the group members were not overcommitting and meeting their targets with proper pre-planning. They were focused on completing the critical tasks (tasks required to be done) and did not fill out the weekly plan with more backlog tasks than required tasks. If the group was not focused on critical tasks and had wrong priorities, the PPC would have been higher in comparison to PRCO.

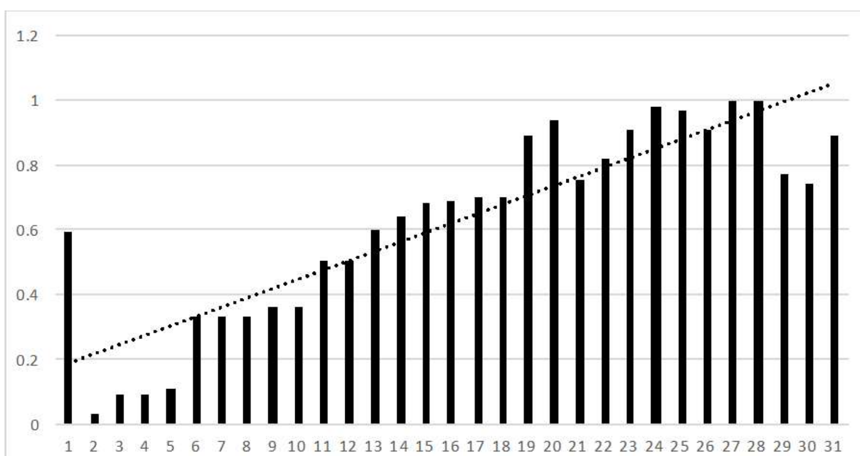

Figure 4 – Trend of the Commitment Level (CL) for the case study project during the observation period

The CL and PPC are complementary metrics that provide a snapshot of how the group's short-term planning was aligned with the overall planning for meeting project targets. A significant positive relationship between CL and PPC indicates that group members kept their commitments, they could create sound assignments, and were able to maintain alignment between the tasks that 'should' be done and 'will' be done. Using takt time had a major role in the group members being able to make sound assignments. They focused on sizing each task based on resource availability and re-planned whenever necessary that maximized the workflow. A steady increase in the PPC value was also observed.

The goal of the case study was to explore the use of takt time planning and examine its effect on the reliability of the design schedule. The project selected for the case study was a 168,000 SF addition to an existing health care facility. The core group of the case study project consisting of the owner, designers, engineers, prime contractor, and major trade partners adopted takt time planning for the planning process. The paper presented an overview of the planning process and attempted to measure the reliability of planning through three metrics: CL, PPC, and PRCO.

The values of CL, and PRCO demonstrated consistent long-term planning aligned with short-term planning. The standard deviations of the metrics serve as indicator of the planning reliability. The standard deviation of the CL was higher than that of PRCO indicating higher planning reliability in short-term planning than that of long-term planning. The case study project showed similar values of PPC and PRCO indicating frequent collaboration with the group members focusing on required tasks to meet the target milestones. This required a systematic approach to the implementation of the techniques and sincere commitment from the core group members for successful implementation. There was the burden of spending long hours and additional effort on the members to maintain the takt of the workflow. The number of tasks committed in each planning cycle also increased as the project progressed, and the group members became more adept at the process.

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