Production Planning Using Location Based Management and ‘Takt’ Time: A Postmortem and Premortem

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The traditional focus on task management for construction project planning does not recognize the dynamics and interdependencies among tasks. Projects would benefit from a focus on production planning in an effort to better distribute resources and manage the allocation of personnel. This paper presents a postmortem analysis of a completed project that relied heavily on the critical path method (CPM) for project planning and a ‘premortem’ analysis of an ongoing project that is using pull planning techniques. The authors used data from these projects for recreating schedules and analyses using takt time analysis (TTA) and location based management techniques. Authors additionally utilized a location based management system to recreate the schedule using flowline to further analyze and identify ways for improving project efficiency. Anecdotal evidence is presented showing that these methods can reduce downtime and facilitate efficient usage of resources.

Key Words: Scheduling, Takt Time, Location Based Management, Production Planning, Flowline

Introduction

Planning in construction has been primarily focused at the project level, utilizing work breakdown structures (WBS) to decompose projects into various tasks that need to be completed. This approach tends to ignore the dynamics and interdependencies of the construction tasks and focus only on transforming of inputs to outputs through optimization of the individual tasks. The task-focused project planning allocates production rates rather haphazardly creating highs and lows in production. An attempt to smooth out the peaks results in resource re-allocation that might inadvertently prolong the schedule or create cost overruns. The concept of production planning (an idea that can be interpreted in various ways) in construction had always been an afterthought and taken for granted until Koskela (1992) pointed out the importance of flow and value generation as inseparable components of the production system. An ideal production system after Koskela (1992) consists of continuous flow through networks of trade workers and creation of customer value.

A production system can be defined as a collection of resources (such as workers, equipment, tools, information, etc.) assigned to design and build a product (either commodity or service) that has value to the customers. When it comes to designing a production system for a construction project, it poses greater challenges due to the temporary nature of the projects where some dynamic groups of workers come together to build a unique product before disbanding to work on other ventures. With new groups of workers almost involved in every project and trades phasing in and out during the overall construction process, gathering information on production rates and utilizing them in production planning is a challenge by itself. In this situation, lean principles recommend use of ‘takt time’ in designing production systems (Rooke et al. 2012). This paper emphasizes how Takt Time Analysis (TTA) facilitates the planning of production system by underlining the lean principle of creating continuous flow. From the German word for ‘beat’ or ‘rhythm,’ the ‘takt’ time is the rhythm/beat that sets the pace of a process. Takt time in the context of a production system is defined as the time in which a product must be produced in order to meet the customer’s demand (Frandson et al. 2013). The customer in this respect can be the end customer (the one paying for the project) or an internal customer (workers down the line).

Takt time is calculated by dividing the available work time by the number of products required in that time. This rhythm/beat sets the pace of the schedule for the project. The objective of TTA is to facilitate continuous workflow for tasks wherever possible and create a stable production system. Within the lean construction paradigm, the Location Based Management System (LBMS) provides the control mechanism to stabilize the system while TTA provides the means to allow continuous flow as much as possible. LBMS is a technical system that transforms the quantities based on locations and productivity information to reliable durations. Consider the task of framing a house before installing the gypsum boards. Assume a scenario wherein the schedule requires the gypsum board installation to start five days after the beginning of framing. If the framing crew has approximately 1000 studs (= demand) to install and they have five days (= available time) to finish the task, the crew needs to install 200 studs per day. So, the takt time for the installation of 200 studs is one day. Further, the takt time to install each stud will be 135 seconds (for completing installation of 200 studs in a standard eight hours work day with one 30-minute break). In other words, to meet the demand of the next trade, the framing crew must complete installation of one stud every 135 seconds, which is the rhythm of their work. While it may not be practical or desirable to break construction tasks down to such detail where the units are single studs and durations are in seconds, this example demonstrates the concept of using TTA as a prescriptive measure for controlling workflow.

Using takt time to set the pace of the construction schedule is not a new concept. Its use was evident during the planning and construction of the Empire State Building (1929-1931) where four tasks such as steel erection, concrete flooring, exterior metal trim, and exterior limestone were used as pacemakers for the entire schedule (Ghosh & Robson 2015). More recently, takt time has shown up in literature related to homebuilding in the U.S. (Wardell 2003; Velarde et al. 2009) and highway construction in Ecuador (Fiallo & Howell 2012). Schedules for recent healthcare projects (Linnik et al. 2013; Frandson et al. 2013) and residential projects (Mariz et al. 2013) have also employed takt time processes. This paper includes a brief review of the use of takt time on construction projects has been presented in this paper and a description of the LBMS and the TTA process. Additionally, the authors have performed a postmortem analysis of a completed project by recreating part of the critical path method (CPM) schedule of a project as location based schedule and applying TTA to identify opportunities lost. To further the discussion on the benefits of TTA, the authors attempted a ‘premortem’ analysis of an ongoing project with TTA.

Use of Takt Time Analysis on Construction Projects

Takt time became a topic for interest in both the manufacturing and construction industries, as a design parameter used in production settings for controlling the rate of work output as it relates to the rate of customers’ demand. TTA can be combined with LBMS to achieve time saving, money saving, and quality improvement (Frandson & Tommelein 2014). Frandson et al. (2013) defined a six steps process for the TTA that comprised of: (1) gathering information of production rate and quantity, (2) defining work areas or zones, (3) understanding the sequence of the tasks (flow), (4) understanding the duration of individual tasks, (5) balancing the workflow, and (6) creating the production plan. The implementation of TTA is not necessarily a simple conversion of the aforementioned steps, but rather an iterative and collaborative process. The planner should consult with the various trades to extract information related to preferred sequence, desired workflow, durations, production rate, etc. The planner should be aware of any assumptions made by the trades in their initial planning and possible alternatives to how each trade can perform their work.

Several case studies have described the implementation process of TTA while highlighting the critical role played by the collaboration between the general contractor and the subcontractors in optimizing the project's Takt time (Linnik et al. 2013; Frandson et al. 2013). Instances of use of TTA in conjunction with the Last Planner System were found in the case study conducted by Frandson and Tommelein (2014). Benefits of TTA identified by the researchers were providing clear daily goals of tasks, increasing the productivity, and solving problems promptly. Overall, the case study concludes that balancing and managing the production of all trades by assigning work zones on a short interval, though challenging, offered overall benefit to the project. A separate study conducted by Frandson et al. (2013) demonstrated how TTA improved the last planner's abilities to improve reliability of planning and reduce variability.

Like the Last Planner System, LBMS also claims to achieve the lean goals of maintaining continuous workflow and reducing variability. While the Last Planner System aims to achieve these goals primarily through a social process where the direct workers plan collaboratively to perform effective constraint analysis and removal, LBMS rely on a technical system that transforms the quantities based on locations and production rates to reliable durations. In addition, LBMS makes the buffers explicit, forecasts future performance, and can identify production risks (Kenly & Seppanen, 2010). Available case studies on LBMS have reported success with schedule compression, less variance, and increased production rate (Kenly & Seppanen, 2010, Ballard & Howell, 2004).

Location Based Management System

The early scheduling techniques of Line of Balance (Lumsden 1968) and Flowline Method (Mohr 1979) evolved into the current location based planning. While line of balance schedules do not explicitly show the movements of crews, flowlines represent each task as a single line. Flowline thus requires more detailed planning because it includes detailed information about the resources. A noteworthy finding by Harris and Ioannou (1998) in this regard highlighted that it is not always possible to minimize the duration of a schedule while maintaining continuity of resource use. Kenley and Seppänen (2010) developed the LBMS based on layered logic and calculations adapted from CPM to optimize the schedule while allowing for continuous resource usage. They recommend the use of flowline to visualize the schedule. To create the LBMS, the planner needs the breakdown of locations, quantities and durations of the tasks based on crew composition and production rate, and logic among the 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 & Seppänen 2010). Preparing LBMS involves a collaborative process of gathering quantity data, estimates of production rates, and list of prerequisite works. The goal of LBMS control mechanisms is to ensure that optimal conditions are achieved for as many trades as possible as shown in the flowline schedule with the slopes of the lines representing the production rates. An ideal LBMS will have a common slope for each location.

Context for the Postmortem Analysis

The project that the authors have chosen for this postmortem analysis is a healthcare project in the southern U.S. The 40,000 square feet building is situated on an approximately 3.5 acre site. The two-story tilt wall structure includes a total of 40 patient rooms, all of which are on the second floor. The construction cost for the building was USD 8.5 million and was delivered using construction management-at-risk. During the negotiation phase of preconstruction, a master schedule was developed using the CPM. An on-site superintendent and on-site project manager oversaw the logistics of construction for the project on behalf of the construction management company. CPM was heavily relied on throughout the planning and controls of the project and the master schedule was updated throughout the project. The adherence of the project to CPM schedule was similar to what is found on many construction sites regarding schedule management. Following the CPM schedule, great effort was made to start tasks as soon as possible, with attention focused on the predecessors.

The focus on the predecessors and installing every item as soon as possible enabled the project team to effectively maneuver the subcontractors during the site and structure phases of construction. It also served the project team well for the first floor of the building where there were a variety of wall configurations, overhead systems, and interior finishes. When the team began work on the patient rooms, the CPM logic of starting every task as soon as possible had some clear weaknesses. Of the 40 patient rooms on the second floor, 38 were single-occupancy and two were double-occupancy. The double-occupancy rooms had the same restrooms as the single-occupancy rooms and had two identical headwall systems in them. Much of the work on the in-wall plumbing was found in the medical gas piping and high and low voltage systems for the headwalls so there were 42 identical patient headwall assemblies and 40 identical patient restrooms. Due to this high amount of repetitive work, the CPM practice of getting crews in a room to complete work as soon as it was possible led to a lot of downtime for crews and an uncertainty regarding the driver of the construction schedule.

To overcome the uncertainty of what was driving the schedule, the project team decided to create a new schedule, departing from the master schedule and only showing the tasks that remained to be completed. This completion schedule focused on four sections of the building, areas A through D, and focused on the tasks that needed to be complete in each of these sections. This division into four sections was based solely on the fact that the architectural and structural plans had the building divided this way. Figure 1 shows the layout of the building footprint with the four areas hatched with different patterns. Preparing the completion schedule based on the architect's delineation of the four areas proved to be problematic. This problem was caused chiefly because the building floor plans were divided into these four sections so that they would fit cleanly into partial floor plans and make for easy viewing of the plans. This breakdown of the floor plan had nothing to do with the goals of the project management team and sequencing of the project. Visually it was very simple and the goal of simplifying the location of work to be done aligned well with the architect's goal of visual simplicity. However, it did not work as a guide for planning the work. Further complicating the matter, the schedule was also broken down by floor, thus there were eight sections in total with four per floor. The problem with this was that a lot of the work for the patient rooms and restrooms was underneath the floor of the room and thus classified as first floor overhead tasks. Again, the rationale behind breaking down the schedule by floor was to simplify the visual element of where crews would be working. Several attempts were made to vary the completion schedule but little success was had when the unit of analysis was section of the building.

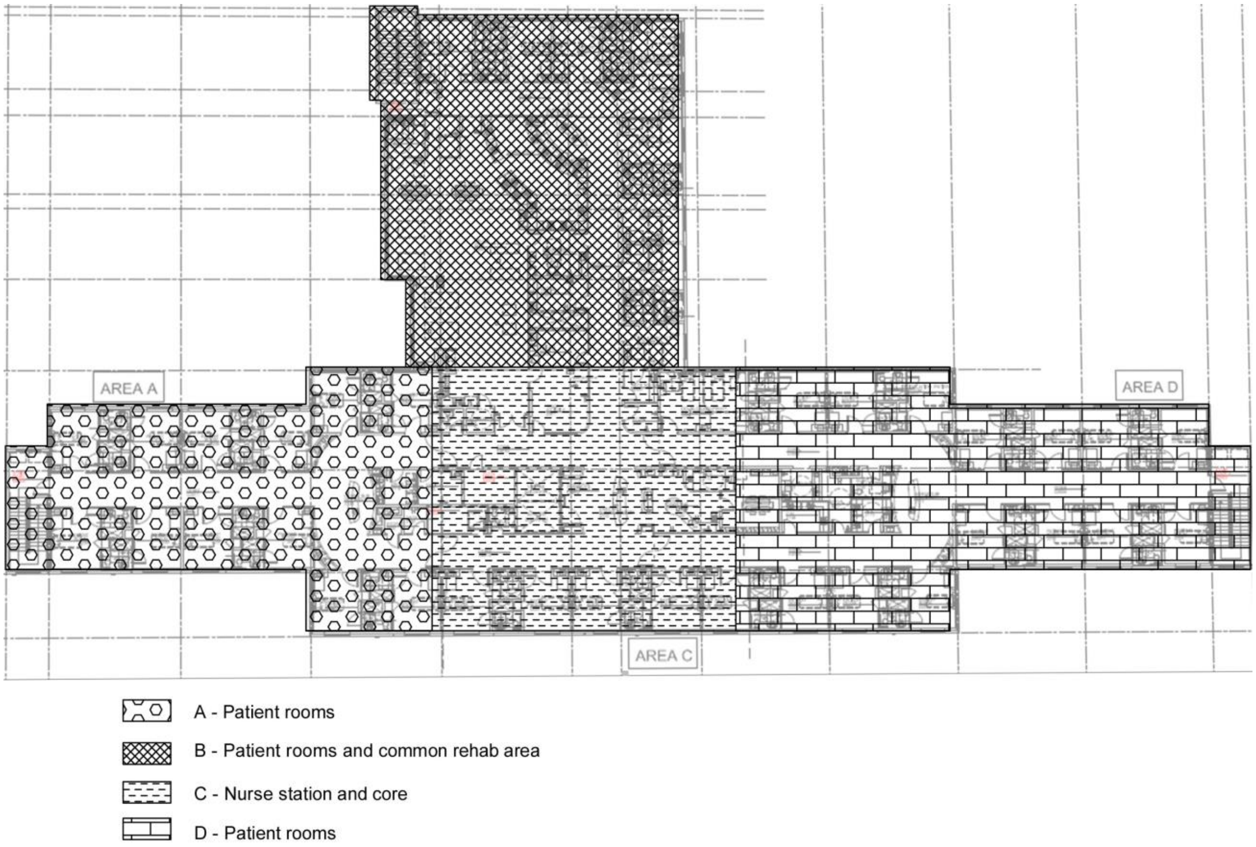
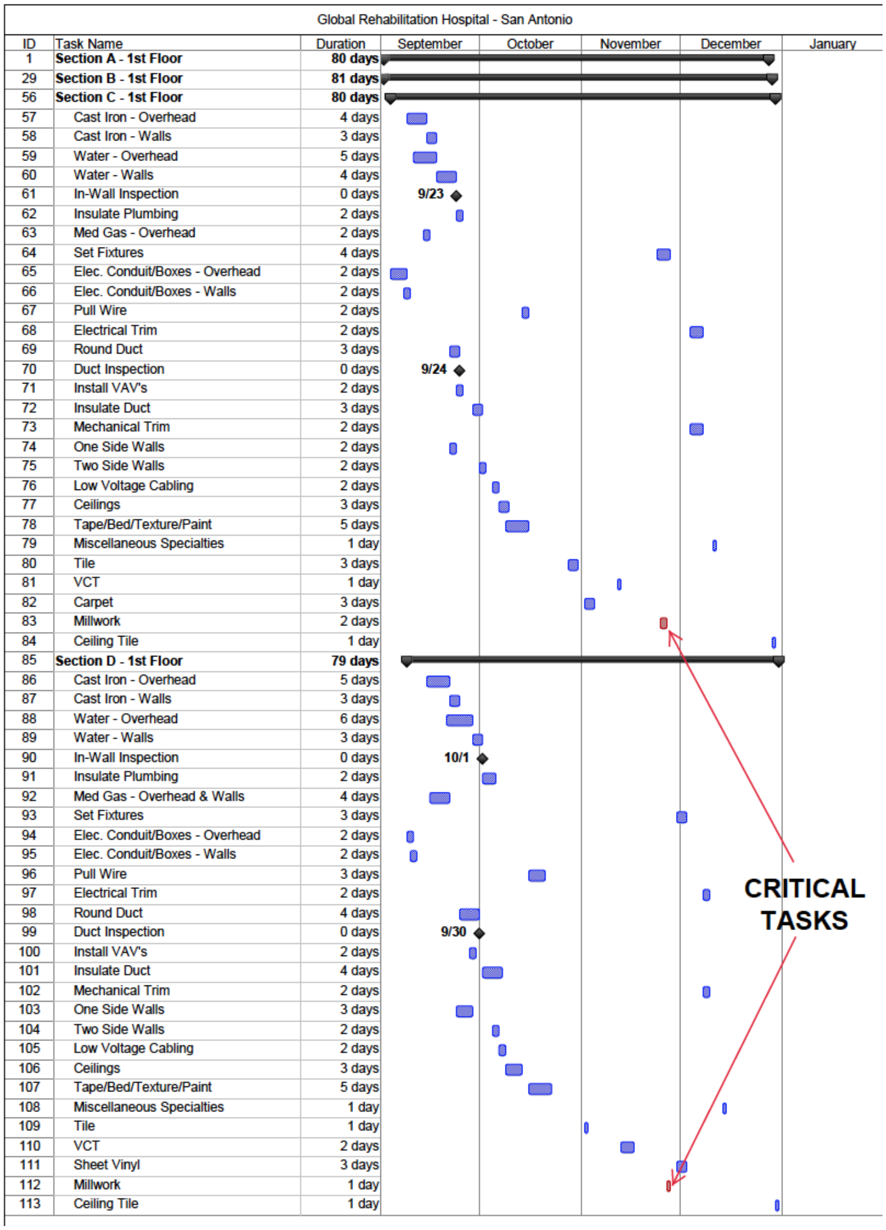


Figure 1: Second Floor Plan of Healthcare Project

With the number of patient rooms and patient restrooms, occurring 42 and 40 times, respectively, there was a lot of repetitive work. Among this sequence of repetitive tasks, there were pacesetter tasks that created a rhythm of the work. Rather than being stuck on the physical space as a unit, the cycle time of the pacesetter task or at least the work specifically related to the repetitive patient rooms and restrooms should have been the focus from the beginning. By the time the project team changed its focus, the items in the common spaces that had never been in the critical path had become critical items. The result was that great effort and overtime work was required in the common spaces to complete the project on time.

Postmortem: Analyzing the Schedule using Alternative Method

The CPM schedule and Gantt chart depicted in Figure 2 indicate the redundancy in the two sections shown and is a snapshot of the completion schedule with approximately five months remaining in the project. The tasks in each section are grouped by responsible subcontractor which is why they are visually scattered. An immediately evident problem with the scattered tasks is that it is difficult to determine the location of all the work that a particular trade will be performing on a particular day. The tasks, however, appear to be sufficiently spaced out with minimal conflicts between trades. While this lack of overlap indicates time buffers and is visually helpful, it is difficult to determine where the down time is for a particular crew when they have work in multiple parts of the building.



Global Rehabilitation Hospital - San Antonio

ID	Task Name	Duration
1	**Section A - 1st Floor**	**80 days**
29	**Section B - 1st Floor**	**81 days**
56	**Section C - 1st Floor**	**80 days**
57	Cast Iron - Overhead	4 days
58	Cast Iron - Walls	3 days
59	Water - Overhead	5 days
60	Water - Walls	4 days
61	In-Wall Inspection	0 days
62	Insulate Plumbing	2 days
63	Med Gas - Overhead	2 days
64	Set Fixtures	4 days
65	Elec. Conduit/Boxes - Overhead	2 days
66	Elec. Conduit/Boxes - Walls	2 days
67	Pull Wire	2 days
68	Electrical Trim	2 days
69	Round Duct	3 days
70	Duct Inspection	0 days
71	Install VAV's	2 days
72	Insulate Duct	3 days
73	Mechanical Trim	2 days
74	One Side Walls	2 days
75	Two Side Walls	2 days
76	Low Voltage Cabling	2 days
77	Ceilings	3 days
78	Tape/Bed/Texture/Paint	5 days
79	Miscellaneous Specialties	1 day
80	Tile	3 days
81	VCT	1 day
82	Carpet	3 days
83	Millwork	2 days
84	Ceiling Tile	1 day
85	**Section D - 1st Floor**	**79 days**
86	Cast Iron - Overhead	5 days
87	Cast Iron - Walls	3 days
88	Water - Overhead	6 days
89	Water - Walls	3 days
90	In-Wall Inspection	0 days
91	Insulate Plumbing	2 days
92	Med Gas - Overhead & Walls	4 days
93	Set Fixtures	3 days
94	Elec. Conduit/Boxes - Overhead	2 days
95	Elec. Conduit/Boxes - Walls	2 days
96	Pull Wire	3 days
97	Electrical Trim	2 days
98	Round Duct	4 days
99	Duct Inspection	0 days
100	Install VAV's	2 days
101	Insulate Duct	4 days
102	Mechanical Trim	2 days
103	One Side Walls	3 days
104	Two Side Walls	2 days
105	Low Voltage Cabling	2 days
106	Ceilings	3 days
107	Tape/Bed/Texture/Paint	5 days
108	Miscellaneous Specialties	1 day
109	Tile	1 day
110	VCT	2 days
111	Sheet Vinyl	3 days
112	Millwork	1 day
113	Ceiling Tile	1 day

Figure 2: Completion Schedule for Sections C and D of the First Floor of the Healthcare Project

The authors rebuilt the schedule using an alternative tool named Schedule Planner created by Vico Software (an integrated location based scheduling system with flowline). The software tool provides the option of integrating quantity takeoff information from a model with project locations and create highly optimized schedule. One of the visuals that this tool can produce is a flowline view. This view divides the project into zones (which are the 'locations' in the LBMS concept) and shows all the tasks in the zone. Rather than a bar that is common in a Gantt chart, an task is shown by a sloped line with the bottom of the line at the start date and the top of the line at the end date resulting in lines of various slopes. The tasks that are longer, and thus have slower production rates, have flatter slopes. Another advantage of this visual tool is that the tasks that are happening at the same time in the same zone are shown physically on top of one another. Large gaps between lines indicate down time in a zone (as marked by the double-headed arrows in Figure 3). The tasks can have a responsible party assigned to them and when the view is filtered by responsible party, it is readily apparent where that crew might be over or under-allocated to work throughout the project.

The project team on the healthcare project could have been benefitted from using a schedule based on LBMS concept than the traditional CPM taking advantage of the repetitive tasks in the patient rooms and restrooms. By creating a schedule based on LBMS concept, the project could have used production rates of the different crews to ensure continuous resource utilization. Using the TTA in conjunction with the LBMS schedule, the takt time of the sequence could have been identified based on the production rates and quantities of individual tasks. TTA could have specifically compared the production rates of the individual tasks, and identified the pace setting tasks of the schedule at hand. Looking at Figure 3, it is evident that tasks such as ‘Water – OH & Wall’, ‘Cast Iron – OH & Wall’, and ‘Tape/bed/texture/paint’ were critical in setting the pace of the schedule. However, the criticality of these tasks in setting the pace of the overall schedule is not apparent from the CPM schedule shown in Figure 2 (where the millwork tasks are shown as critical). The LBMS schedule, being visually revealing clearly shows which tasks have the slowest production rate and thus are setting the pace that other tasks need to work around the pace setters. Figure 3 also shows certain overlaps that are counterintuitive (shown by circling the sequence in Figure 3) and depicts the crews’ down time conspicuously. For instance, the down time can be observed after ‘Pull wires’, ‘VCT’, and ‘Misc. Specialties.’The pace setting tasks can be adjusted based on the demand of the succeeding tasks or overall completion of the project. The authors did not attempt to rezone the floorplan based on the quantity data, which is the ideal approach to identify locations in LBMS and perform subsequent TTA.

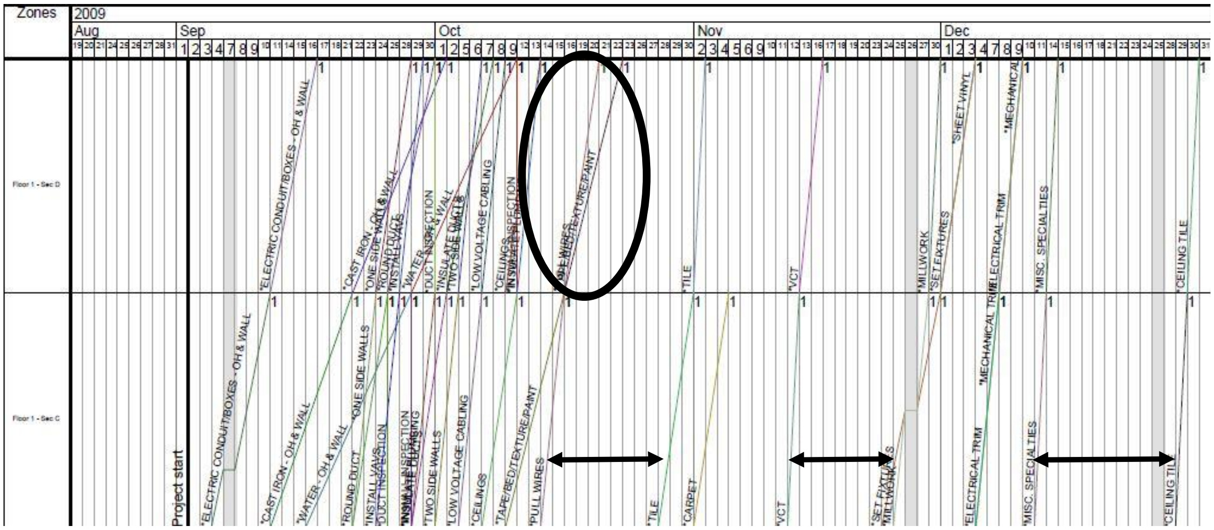


Figure 3: Completion Schedule for Sections C & D Using Flow Line View

Had the project team on the healthcare project used a tool such as this, it would have been immediately apparent that breaking the schedule down based solely on how the architectural plans were divided was not a good method for analyzing the schedule. It would have been clear that a new unit of analysis was needed. This new unit of analysis would have helped the team to better allocate crews to various parts of the project. Figure 3 shows a reworking of the schedule with a flowline view. It is broken into the same sections (“zones” in flowline view nomenclature) that the project team originally used. Some problems are apparent that were not so in the original schedule view. The clumping and overlap of work in the early portion and large gaps later on is clear in the flowline view. For instance, the overlap of tasks such as ‘pull wire’ with ‘tape/paint’ is apparent in the flowline view of Figure 3. Further filtering by trade shows a scattered use of crews that is not efficient. Many problems could have been caught earlier with a visual tool such as this.

Context for the Premortem Analysis

The authors chose a large housing project that is currently under construction in the southern U.S. for the premortem analysis. The 260,000 five-story building includes three distinct building segments. The east and west wings are primarily composed of occupant rooms and both wings come together in the central building segment which is a dining facility. The construction management-at-risk project has a contract value of approximately $100,000,000. The project team makes use of CPM scheduling but also relies heavily on lean processes such as pull planning and planned percent complete analysis. The project team divided the building into five distinct zones, two are in each wing and the fifth is the central dining facility. A sketch of the building and planned flow of work for the east and west wings is shown in Figure 4.

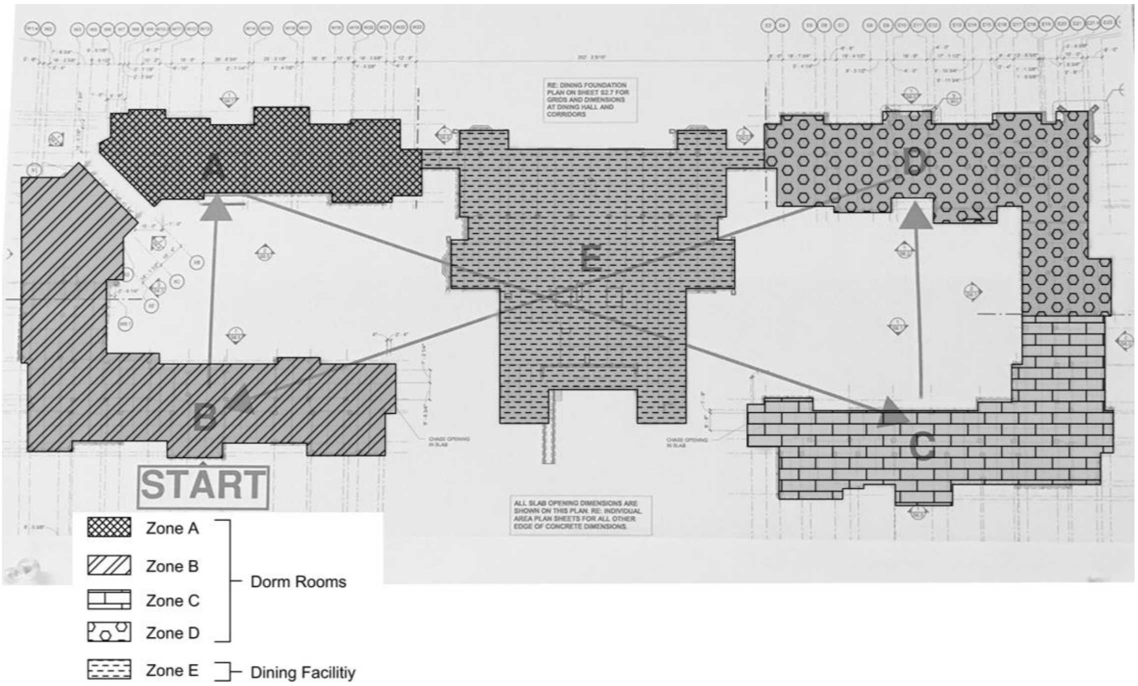


Figure 4: Building Footprint Indicating Zones and Planned Workflow

Premortem: Analyzing the Schedule

In this instance, a challenge that the project team has encountered has been the level of detail that they receive in the pull planning sessions. In the postmortem example, the project team had too little detail due to an improper breakdown of the project. On this project, the team is at times receiving a level of detail that is more than what is required for updating the schedule. For example, the project team may get information on the installation of VAV boxes that has multiple sub-tasks. Instead of the detailed list of sub-tasks, the project team can be benefitted from handoff information. Handoff, in this context, refers to when a product or item “changes hands” between trades. With handoff information, the project team can coordinate when a new crew can move into a location to begin the next piece of the work. Additionally, handoff information helps to establish expectations and simplifies the process of managing where crews are working in the building and where there might be down time for specific crews. This ability to manage down time is crucial especially in an environment where labor is in short supply.

Using a version of the project schedule based on handoff dates, the authors developed another schedule using the flowline view. With this tool, it is apparent where there are potential conflicts and overlaps of trades. However, since the level of detail has been adjusted from that provided by workers in pull planning sessions, it is easier to track where the individual trades are working throughout the project and enables better maximization of crew production while minimizing down time. For example, the schedule view clearly indicates a gap of two weeks between ceiling installation in Zone A and Zone C. With this fact highlighted, the project team can make decisions on how to best manage the ceiling crew's time. In keeping with continuous resource usage concept, the team can choose to not start the ceiling work in zone A so that the crew doesn't have to experience down time and suffer a productivity loss. This is in contrast to traditional CPM techniques that encourage completing work as soon as it is possible to do to. Figure 5 shows the flow line view for zones A and C with the ceiling being the final task in each zone.

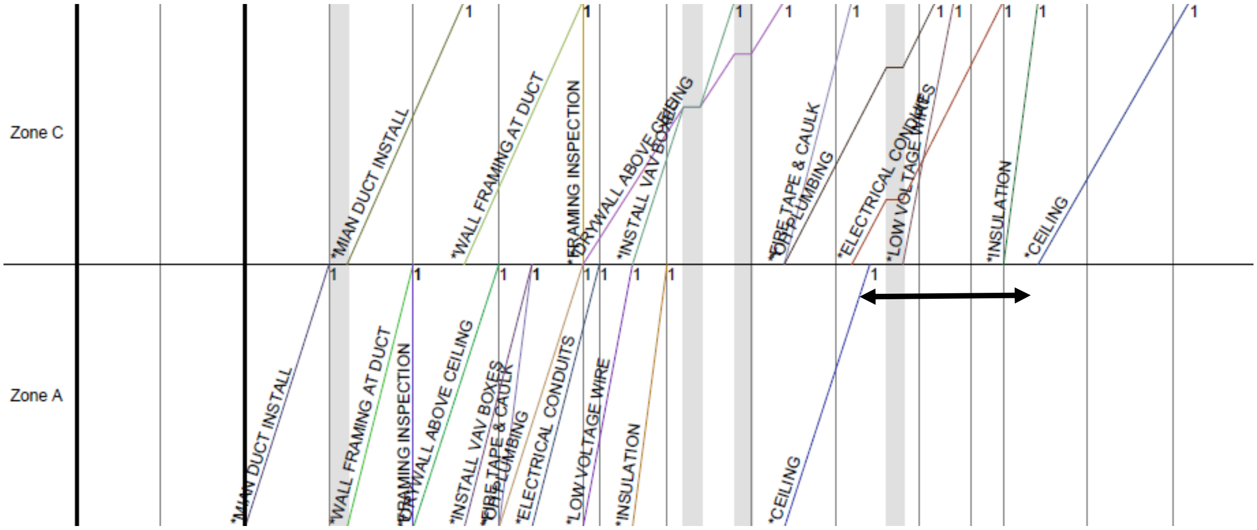


Figure 5: Flowline View of Zones A & C for Housing Project

Conclusions

Optimizing construction schedules for maximizing project performance is becoming more crucial with increased competition and globalization of the construction market. A paradigm shift from project planning to production planning is one such system optimization approach. In an attempt to improve the existing planning and control processes utilized in the industry, this paper presented a systematic method of applying takt time and location based planning. While none of these techniques are new to the construction industry with their earlier applications dating back to the Empire State Building project, much effort has been invested to formalize the techniques. Two projects with distinct characteristics have been presented - one where traditional CPM planning and control was used and another project that is utilizing pull scheduling and the Last Planner System. While neither of the projects used LBMS in reality, the authors decided to recreate the schedules of the two projects using the location based schedules and apply TTA concepts. The intent of this procedure was to ascertain whether opportunities for improvement can be identified using these alternative methods. The flowline view of the recreated schedules exposed tasks that were represented according to the CPM logic and large time wastes in terms of excess time buffers. Overcrowding and large unwanted time buffers in both of the projects were clearly evident from the flowline schedules. Although the recreated schedules were not resource loaded, the authors could infer based on experience that the current situation would result in unbalanced resource allocation. Looking at the flowlines, the slopes of which essentially represent the production rate of the individual tasks, it is possible to identify the pacesetter of the schedule for the individual zones. In ideal scenarios the planner can use the takt time to adjust the other tasks to replicate the slope of the pacesetter task. As a result, it can be expected that a smoother resource allocation curve will result that will enable continuous flow. Existing study shows that producing to takt time helps in establishing a continuous flow and consequently, less waste, shorter duration, and thus, less cost (Yassine at al. 2014).

To summarize, the paper presents anecdotal evidence that planning to takt time can decrease time waste and facilitate smooth usage of resources. The flow line view of the location based schedule helps to visualize the overcrowding and downtime of the crews. Future research can expand on this topic by applying LBMS and TTA on similar projects and documenting the improvements.

References

Fiallo, M. and Howell, G. (2012). “Using Production system design and takt time to improve project performance.” Proceedings 20th Annual Conference of the Int’l. Group for Lean Construction (IGLC 20), San Diego, CA, USA.

Frandson, A., Berghede, K., and Tommelein, I. (2013). “Takt-time planning for construction of exterior cladding.” Proceedings 21st Annual Conf. of the Int’l. Group for Lean Constr. (IGLC 21), Fortaleza, Brazil.

Ghosh, S., and Robson, K. F. (2015). “Analyzing the Empire State Building Project from the Perspective of Lean Delivery System—A Descriptive Case Study.” International Journal of Construction Education and Research, 11(4), 257-267.

Harris, R.B. and Ioannou P.G., (1998). “Scheduling Projects with Repeating Tasks.” Journal of Constr. Eng. Manage., 124 (4), 269-278.

Kenley, R. and Seppänen, O., (2010). “Location-based Management System for Construction: Planning, Scheduling and Control.” London and New York: Spon Press.

Koskela, L. (1992). “Application of the new production philosophy to construction.” Stanford, CA: Stanford University.

Linnik, M., Berghede, K., and Ballard, G. (2013). “An experiment in takt-time planning applied to non-repetitive work.” Proceedings of 21st Annual Conf. of the Int’l. Group for Lean Constr. (IGLC 21), Fortaleza, Brazil.

Lumsden, P., (1968). “The Line of Balance Method.” Oxford: Pergamon Press.

Mariz, R., Picchi, F., and Granja, A. (2013). “Application of standardized work in Franki Piles concrete work.” Proceedings of 21st Annual Conf. of the Int’l. Group for Lean Constr. (IGLC 21), Fortaleza, Brazil.

Mohr, W., (1979). “Project management and control (in the building industry).” Dept. of Architecture and Building, Univ. of Melbourne.

Rooke, J., Koskela, L., Howell, G. and Kagioglou, M. (2012). “Developing production theory: what issues need to be taken into consideration?” Proceedings of 20th Annual Conf. Int’l. Group Lean Constr. (IGLC 20), San Diego, CA, USA.

Velarde, G.J., Saloni, D.E., van Dyk, H., and Giunta, M. (2009). “Process flow improvement proposal using lean manufacturing philosophy and simulation techniques on a modular home manufacturer.” Lean Constr. Journal, 5 (1) 77-93.

Wardell, C. (2003). “Build by numbers.” Builder Magazine, January 1, pp. 1-6.

Yassine, T., Bacha, M. B. S., Fayek, F., & Hamzeh, F. (2014). Implementing Takt-Time Planning in Construction to Improve Work Flow. Proceedings of 22nd Annual Conf. Int’l. Group Lean Constr. (IGLC 22), Oslo, Norway.