Faloughi, M., Linnik, M. and Murphy, D., 2015. WIP Design in a Construction Project Using Takt Time Planning. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 163-172, available at www.iglc.net

# WIP DESIGN IN A CONSTRUCTION PROJECT USING TAKT TIME PLANNING

**Mazen Faloughi[1], Meeli Linnik[2], Dan Murphy[3], and Adam G. Frandson[4]**

## ABSTRACT

Work in process (WIP) is a well understood and used metric in the management of manufacturing processes. However, this is not the case when it comes to production planning in non-repetitive construction projects. Moreover, there are different understandings of WIP depending on the management personnel using it (financial managers vs. production planners for example). The aim of this paper is to study how WIP can be defined in the context of a construction project so that it can easily be identified, visualized, and managed without having to resort to simulation models or advanced software tools. The authors present a case study where Takt time thinking is used to identify and handle different types of WIP and improve construction workflow. The challenge is to minimize both 'work waiting on workers' and 'workers waiting on work' by determining suitable work area sizes, and having an adequate work backlog. The case study shows how in some cases, areas are separated and sized so that WIP between tasks can be reduced, and in others so that WIP can be maintained as a buffer because reducing it is less of a concern.

## KEYWORDS

Takt time planning, WIP, production system design.

## INTRODUCTION

Work in process (WIP) is often neglected as a design parameter in the construction industry. Due to the recent increase in the popularity of location based schedule representations (mainly in the Lean Construction community), excessive WIP in construction projects has become more visible to planners and as a result the issue has become more evident. This paper addresses the problem by first defining WIP and introducing the theory behind the concept, then discussing how it can be applied to construction projects. The authors draw support from previous research done about WIP in construction projects and how it is managed. Then, in an attempt to fill the gap found in the literature, the authors propose a less technical but more visual and

[1] Graduate Student, Civil and Envir. Engrg. Dep.t, Univ. of California, Berkeley, CA, USA, mazen@berkeley.edu

[2] Production Engineer, The Boldt Company, The Replacement Hospital at St. Luke's Campus Project, 555 San Jose Ave, San Francisco, CA, USA, meeli.linnik@boldt.com

[3] Production Manager, The Boldt Company, The Replacement Hospital at St. Luke's Campus Project, 555 San Jose Ave, San Francisco, CA, USA, dan.murphy@boldt.com

[4] PhD Student, Civil and Envir. Engrg. Dept., Univ. of California, Berkeley, CA, USA, afrandson@berkeley.edu

practical WIP management methodology. A case study project using Takt time planning (TTP), the Last Planner System™ (LPS), and careful WIP management is used as an example to show how the methodology is applied on a large scale hospital project in California.

## WHAT IS WIP?

As the name suggests, any unfinished work (or area not being worked on) falling between the start and end points of a production routing is considered WIP (Little, 2011). In manufacturing and assembly line production, Little's Law for queueing systems expresses WIP as a function of the cycle time (CT) and the throughput rate (TH). The law says that the average number of units in a queue (WIP) is equal to the product of the average processing time and the average arrival rate (Little, 2011). Thus:

$$WIP = TH.CT \tag{1}$$

In the field of construction management, this concept is currently applied by financial managers, real estate developers, and house building contractors to determine how many projects to start in a given time period (Wardell, 2003). In this case, WIP is the number or houses (or projects) under construction, the processing time is the average house completion time, and the number of house starts is the average arrival rate (Gharaie, Blismas and Wakefield, 2012). Managers can determine how many projects to start in a given time period so that the company can achieve an even-flow production.

However, this method of computing and managing WIP is too high level when the goal is optimizing the construction of a single non-repetitive project and reducing waste in the process. This goal can be achieved by first representing construction schedules in a way that enables construction planners to identify WIP, and then integrating WIP (and the duration for which it stays as WIP) as an additional management parameter in the construction production system design.

## WHY IS WIP ABUNDANT IN CONSTRUCTION PROJECTS?

The problem outlined by many before (Koskela, 1992; Ballard et al., 2001; Arbulu 2006 and others) is that production system design is generally neglected in the construction industry. According to Tommelein (1998) and Arbulu (2006), different construction teams refer to the construction schedule and "push" their production accordingly without having some sort of feedback mechanism between the interdependent parties. Because the production rates of each party are different and variable, this eventually results in large amounts of WIP between the handoffs. This leads to lost time, tied up capital, and an increased chance of having damaged work before the next trade moves in. The solutions illustrated by Tommelein (1998) and Arbulu (2006) consist of moving from "push" scheduling systems to "pull" driven scheduling or using CONWIP systems to limit the amount of WIP that can be accumulated between stations. The authors believe that one of the main reasons behind excess WIP in construction projects is the fact that, when the critical path method (CPM) schedule is used to push the production, it is easy for planners to overlook WIP and perhaps perceive the duration for which it exists as a desirable "float" in their schedule. In this case, management does not identify where WIP is occurring or may even treat it as a desired feature. Therefore, it is important that construction planners are easily able to identify and visualize WIP so that they can plan accordingly.

# IDENTIFYING WIP IN A CONSTRUCTION PROJECT

Previous research has focused on WIP design and management methodologies for repetitive projects through discrete event simulation modelling (González, Alarcón and Gazmuri, 2006) or by using Rational Commitment Model (RCM) equations (González et al., 2008). This paper discusses how WIP can be identified and managed when the use of simulation tools is not practical, and a more visual and less technical method is required.

In order to design WIP for a production system we must first define the different types of WIP that can be analysed depending on the adopted perspective:

- **WIP for consecutive tasks:** In this case, WIP can be separated into two categories:
  **1)** WIP within handoffs also known as the production batch, this type of WIP can be used as a design parameter when balancing work between trades. It is closely tied with the methodology of the work done within a trade's scope. It is the minimum possible transfer batch. Refer to Figure 1 for an example of how the methodology affects the production batch size.
  **2)** WIP between handoffs also known as the transfer batch, this type of WIP is related to whether the unfinished product is handed off to the next task right after the first task is competed, or if there is a waiting time or buffer between the two tasks (Figure 2). In many cases this WIP is a product of not levelling the workflow between processing stations (eg. framer needs 5 weeks to finish Level 2 but plumber needs 7 weeks)
- **WIP in the supply chain:** In this case, WIP is measured by the amount of unprocessed off-site manufactured units specifically for each trade (e.g. rebar, prefab components, etc.) between each of the production phases such as procurement, fabrication, assembly, delivery, material stocking, and installation (Arbulu, 2006). As the team is striving to align all these phases to production areas, we realize the importance of sequencing all these phases to production plan. For example, it is not reasonable to deliver Area 3 material before Area 2 material when the intent is to work on Area 2 before Area 3. The just-in-time (JIT) concept is followed with conscious sizing of WIP.
- **WIP for construction phases:** When using different planning methods but especially location based management system (LBMS) and Takt time planning, the plan is usually developed phase by phase (e.g., Foundations & Shoring Phase, Exterior Phase, Interior High Overhead MEP Phase, Interior Framing Phase etc.) for practical purposes. In our experience, due to the different types of work, different phases can have different area structures to which the work is controlled. In order to minimize waste, creating area structures so that the transition from one area structure to another creates the

least possible amount of WIP is important. With unthoughtful planning the team can increase the project's duration and not gain any value from this.

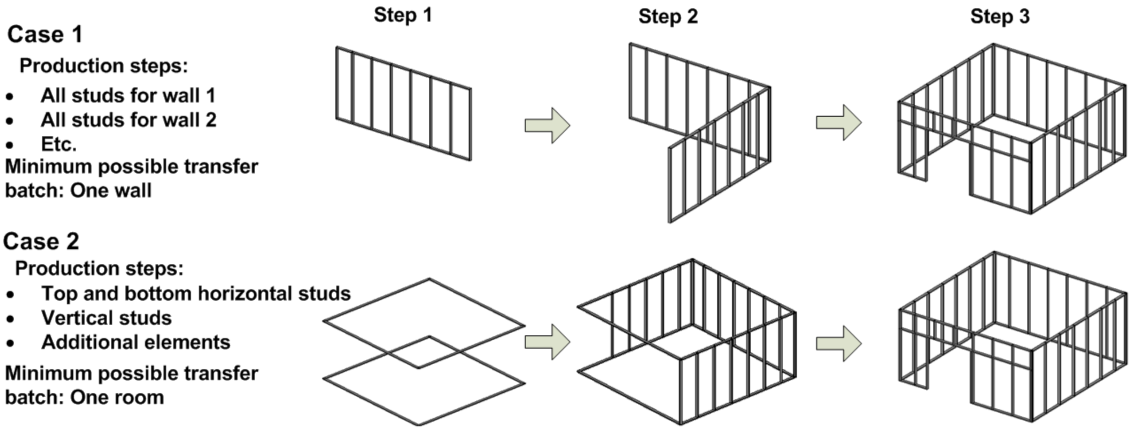


*Figure 1: The work process of installing the studs for a drywall in a room affects the possible amount of WIP within a handoff*

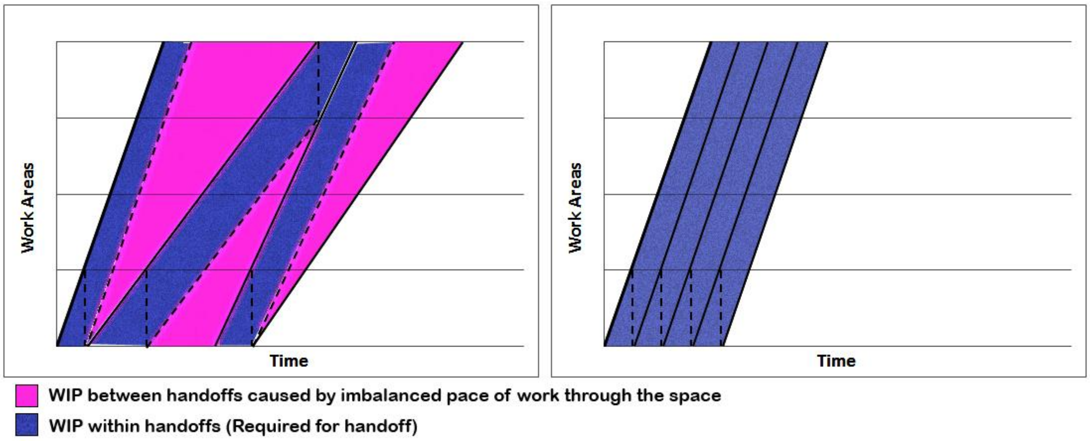


*Figure 2: Graphic representation of WIP between handoffs vs. WIP within handoffs. The right graph shows the most efficient scenario where all WIP between handoffs is eliminated by making the production rates for all tasks equal.*

# CASE STUDY: DESIGNING WIP FOR A CONSTRUCTION PROJECT

## OVERVIEW

The case study project is a 7 story, 21,300 square meters acute care hospital project in California. The project site is located in the middle of a busy city and on an existing hospital campus. The Last Planner System® (LPS) is used to its full extent as the team believes that it is the right approach to increase commitment reliability, measure and improve percent plan complete (PPC), and achieve several other values. However, in order to better optimize the design of the production system and obtain a more continuous flow for the majority of trades, the team has added additional layers of planning and WIP analysis to the usual LPS methodology (Figure 3).

Figure 3 is a visual that is displayed on the project planning wall so that employees and visitors are familiar with the planning phases. All levels of LPS are covered (incl. constraint removal, make-ready work, analysing metrics, etc.). The phase "Production Optimization" is added as a transition step between the phase planning phase and the lookahead planning phase. During this phase, the production team works collaboratively with trades to figure out improvement opportunities and develop a Takt time plan before getting to the make-ready lookahead planning phase.

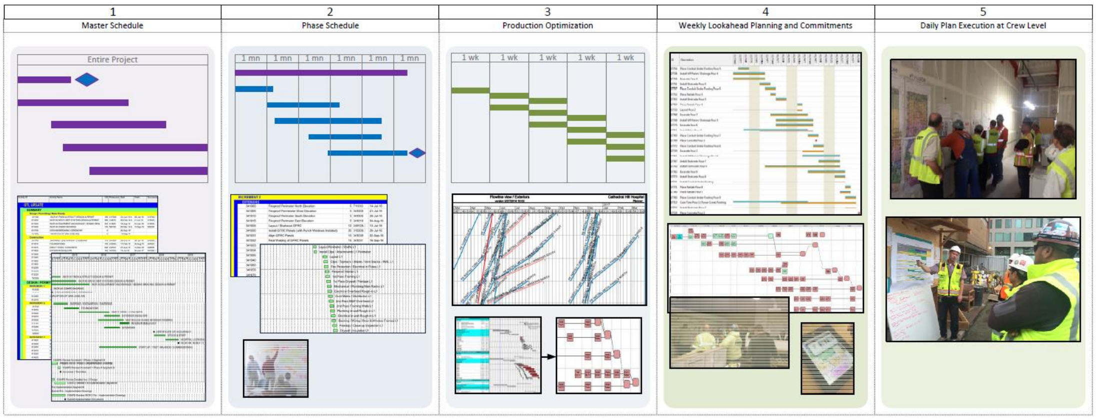


*Figure 3: Visual that team uses to explain different levels of planning.*

The team's experience has led them to conclude that traditional schedule representations, such as CPM diagrams and Gantt Charts, make it hard to identify and manage WIP. The LPS adds value as planning is done collaboratively in phases, constraints are removed (work is "made ready"), and the reliability of the plan is increased with last planner's weekly or daily reliable commitments. However whether the production plan is well optimized or not, is not addressed by the LPS. Therefore additional planning steps that specifically address the management of WIP are needed in order to get the full benefits. WIP needs to be studied for the project as a whole and the team cannot afford leaving its management to each trade leader or area superintendent independently.

Takt time planning is a main component of the 'production optimization' phase in our case study project. The following section explains the Takt time planning process and how it is used in the case study project.

## TAKT TIME PLANNING

Takt time planning uses a location-breakdown structure with the objective to make work flow continuously. It is designed to have a sequence of trades working in pre-defined areas using the same amount of time (Takt time) in each area. In order to design a Takt time plan the sequence of trades and their activities is designed by a collaborative pull plan, data is gathered to understand crew sizes and durations planned by trades, and all the transfer batch cycle times in a phase are set the same (Frandson, Seppänen and Tommelein, in press). In the case study project, the Takt time is 5 days. As a concept, Takt time planning can be used to reduce WIP both between hand-offs and for each trade. But Takt time planning also aligns procurement, fabrication, and supply flow closely to the plan to reduce WIP in the supply chain. This can be done until the desired project throughput is reached without having to incur excessive costs. 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' (Linnik, Berghede and Ballard, 2013). This paper again emphasizes that the focus of the process is the same. Linnik, Berghede and Ballard (2013) offer a more elaborate description of the Takt time planning process. Therefore, only a brief explanation is given in this paper due to length requirements.

During the ‘production optimization’ phase, the planning team deals with two different types of work: 1) Work that can easily be planned in the Takt time strategy because it is relatively easy to balance the workflow among the different trades (which includes the majority of the work on the project) and 2) work in parts of an area (operating rooms, kitchens, etc.) where the work “density” makes it difficult to allocate under the regular sequence (the amount of onsite labor is significantly out of balance with the amount for other crews or other areas of the same floor).

## WIP BETWEEN HANDOFFS (INSIDE ONE PHASE OF WORK)

The majority of activities for the case study project are planned using Takt time planning. The production team will have a collaborative pull planning session to define the high level sequence for one phase of work. Also, each trade will submit building plan “color-ups” that indicate how they are planning to work through a certain space (e.g., Level 2), and their crew size. The production team will analyse the pull plan and color-up information, work with trades to develop an area structure for the phase and balance everyone’s labor count (Figure 4).

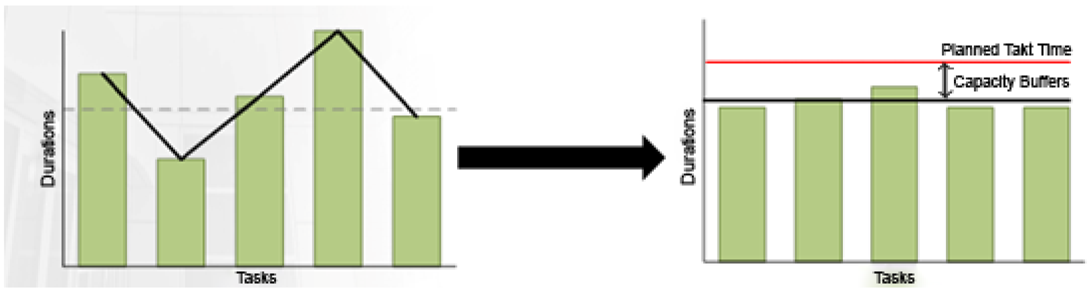


*Figure 4: First, the task durations for different trades are not equal. In order to create a Takt time plan, trades are asked to modify their work methods (e.g., more prefab) or crew size to match the Takt time (defined work cycle time) in each area.*

Usually the result of this approach is no trade stacking, reduced manpower on site, reduced Phase duration and minimal WIP between handoffs inside the phase. Figure 5 illustrates an example Takt time phase.

By balancing manpower as shown with Figure 5, WIP is minimized between consecutive tasks (e.g., red task and yellow task). The methodology for this type of planning is to find the bottleneck trade in the sequence, work collaboratively to make them faster and then match all the other trades pace to bottleneck trade. The idea is that any trade working faster than the bottleneck trade is not adding value but only creating additional WIP for the project.

This method of planning doesn’t require advanced analysis tools, and can be done easily in Excel or even just drafting the flow on a piece of paper. It just requires awareness and understanding of the concept.

The team is using visual representations as shown in Figure 6 (SOG stands for slab on grade) to analyse WIP, see if there is continuous flow for each trade, check for crew idle times (labelled (1) in Figure 6), and examine overlaps where the crew is shown to be working in two areas at same time (labelled (2) is Figure 6).

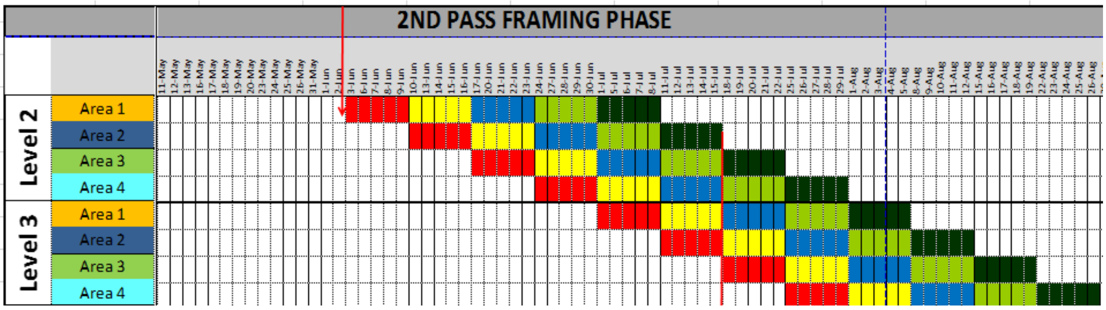


*Figure 5: 2nd and 3rd floor of 2nd Pass Framing Phase. Each color represents a specific trade's scope of work in that phase.*

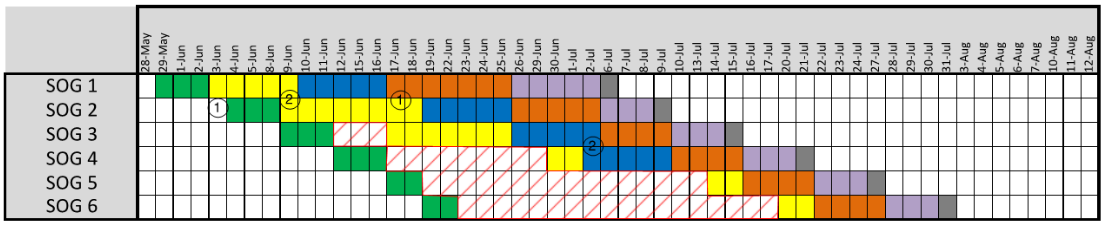


*Figure 6: Graphic representation of WIP for work areas Dates are on x-axis, area structures on y-axis, different tasks are represented with different colors, and WIP is shown with the hatch*

## WIP BETWEEN PHASES OF WORK

Different phases of work may require different area structures because of the differences in work methodologies. For example the overhead MEP scope requires larger areas to accommodate installation and testing of their racks and other components than the framing and in-wall trades require. The team is carefully examining transitions between phases, as different cycle times per phase can result in large amounts of WIP. The team analysed inter-phase WIP for three interior phases and developed four different scenarios for a collaborative discussion and review. Figure 7 shows the original plan for these phases and Figure 8 shows the strategy that the team chose. As a result of this analysis the team saved 5 weeks out of the original schedule while reducing manpower on site, levelling out crew sizes, and reducing WIP between phases. The scenario shown in Figure 7 was considered the better option (25 vs 30 days during which an area is considered WIP on level 7) before the third phase was included in the planning window. However, when the three phases were studied together, it became clear that the scenario shown in Figure 8 was the best in terms of minimizing overall waiting (duration during which there is WIP between phases) in the system (Figure 8).

It can be seen from figures 2, 5, 6, 7 and 8 that a simple change in how the plan is visualized, i.e. using flow lines instead of traditional Gantt charts or critical path method (CPM) network diagrams, easily makes the planner aware of different types of WIP in the system and their quantities. Figures 5, 6, and 7 show a flow line schedule representation method that also integrates some of the features of a traditional Gantt chart and is extensively used by the production team in the case study project.

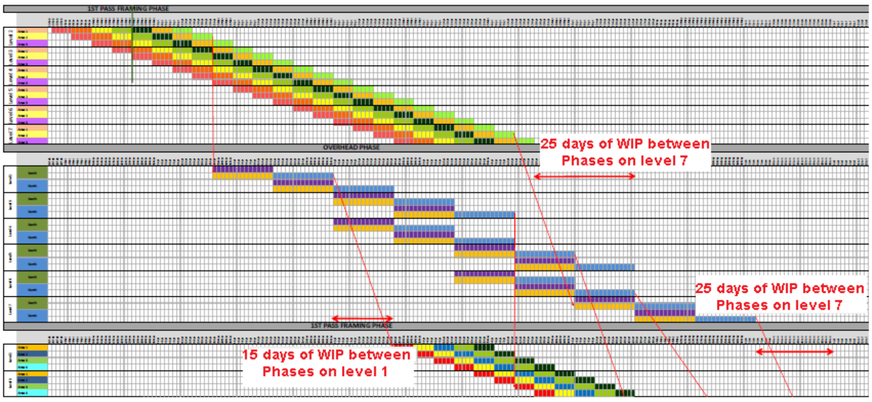


*Figure 7: Original Plan for three phases of interior work (1st pass framing, overhead phase, 2nd Pass Framing Phase). Overhead phase is taking place at two floors simultaniously to release work for 1st pass framing phase that has a shorter cycle time. WIP discovered in several areas through simple analysis.*

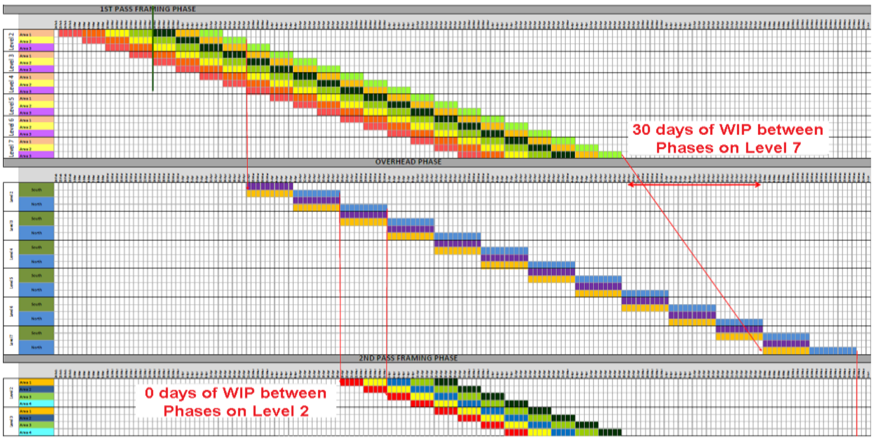


*Figure 8: Best choice of suggested 4 options for three Phases of interior work (1st pass framing, overhead phase, 2nd Pass Framing Phase). WIP reduced based on team collaboration and 5 weeks of time saved compared to original plan.*

## WIP INSIDE HANDOFFS

The optimum handoff size can be different for different phases. The larger the area (in terms of square meters or worker days) one trade is handing off to next trade the more WIP there is in the handoff itself (bigger transfer batch). The team has found that a 5 day handoff period is the most convenient for the case study project and has delineated the work zones accordingly. While this may be increasing the amount of WIP inside handoffs, the team has decided that it (1) provides the amount of flexibility needed to keep the plan reliable and (2) sets a standard duration so that handoff dates and durations are not constantly changing as the project progresses. For many trades, the production team has to fully understand the scope of the work, the adopted process, and the effect of crew size on production rate before determining the area size. Most importantly, the crew has to be completely done with their area before handing it off to another crew by the end of their Takt time production duration (5 days in this case). Though it may sometimes seem that this 5 day Takt is creating unnecessary WIP, the team has found that it has led to great reductions to both overall WIP and project duration when compared to traditional planning methods. Crews know that they will always be working on a structured area for 5 days undisturbed before having to hand it off, and therefore do not have to account for unexpected interruptions by other trades in their plans and increase their contingencies.

### WIP IN THE SUPPLY CHAIN

The team is minimizing WIP in the supply chain by aligning the whole delivery system to the designed Takt time strategy. In other words, if material for Area 1 is needed first then the fabrication or kitting for Area 1 is done first. Delivery rules to the site demand that deliveries have to: follow the order of the production strategy, arrive on site in batches containing one structured area worth of material, and be labelled to match with the area structure. Deliveries to the site originally come from either the fabrication facility or third party vendors. In order to deal with the variability that could come from these sources and make sure the delivery rules are applied, the team makes use of the nearby project warehouse. This ensures that a just-in-time pull delivery system can be implemented on site without disturbing the production processes of the fabrication facility or third party vendors. In addition, the production team cooperates with some of the key suppliers to synchronize fabrication to the pull of the project.

## CONCLUSIONS

This paper discusses a method of managing WIP in a construction project using Takt time planning. The authors emphasize the importance of using an adequate visual representation of the production plan so that WIP becomes more evident and planners become more aware of the problem. The preferred schedule representation in the case study project consists of a table-based flow line chart using Excel spreadsheet format that also resembles a traditional Gantt chart so that it is more familiar to construction personnel. The purpose of managing WIP in construction projects is to minimize both ‘work waiting on workers’ and ‘workers waiting on work’. In practice, it is difficult to simultaneously minimize these two types of waste and planners often have to minimize one at the expense of minimizing the other. The authors treat minimizing ‘work waiting on workers’ as a priority because they believe it has led to better results in their previous projects and current case study project as well. Until the two types of waste are eliminated, workers waiting on work can perhaps use their time to take care of their workable backlog, or more importantly, study how their process can be improved for the rest of the project. In this way, the team gets the opportunity to minimize yet another type of waste which is ‘unused employee creativity’. In contrast, work waiting on workers does not leave any opportunities for workers to think about their process and come up with ways to improve their plans and processes because they are too busy catching up. In addition there is an increased risk of damage to trade work and tied up capital. Having a constant handoff duration (Takt time) as the project progresses may introduce extra WIP and ‘work waiting on workers’ in some parts of the project where work is easier for some trades. However, the benefits of having a simple and predictable schedule where crews always know that they can work uninterrupted in a structured area for a given duration before handing it off and moving to the next possibly outweigh the disadvantages. By using the methods described in the paper the team has been able to minimize different types of WIP and thereby achieve an estimated 20% compression of the initial schedule. In addition to this, there is added value in making the process very simple to understand for all team members. By making all the participants in the production aware of WIP and how it should be managed so that the whole project benefits, it has become easier for the team to plan and coordinate with the different trades.

## ACKNOWLEDGMENTS

We would like to thank Prof. Iris Tommelein, Glenn Ballard, Will Lichtig, and the anonymous reviewers from IGLC for their feedback on this paper.

## REFERENCES

Arbulu, R., 2006. Application of PULL and CONWIP in Construction Production Systems. In: *Proc. 14th Ann. Conf. of the Int'l Group for Lean Construction*. Santiago, Chile, July 25-27.

Ballard, G., Koskela, L., Howell, G. and Zabelle, T., 2001. Production System Design in Construction. In: *Proc. 9th Ann. Conf. of the Int'l Group for Lean Construction.* Singapore, July 17-22.

Frandson, A.G., Seppänen, O. and Tommelein, I.D., in press. Comparison between the Location based management system and Takt time planning. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31.

Gharaie, E., Blismas, N. and Wakefield, R., 2012. Little's Law for the U.S House Building Industry. In: *Proc. 20th Ann. Conf. of the Int'l Group for Lean Construction.* San Diego, USA, July 17-22.

González, V., Alarcón, L.F. and Gazmuri, P., 2006. Design of Work in Process Buffers in Repetitive Building Projects: A Case Study. In: *Proc. 14th Ann. Conf. of the Int'l Group for Lean Construction*. Santiago, Chile, July 25-27.

González, V., Alarcon, L.F., Maturana, S., Bustamante, J.A. and Mundaca, F., 2008. Work-in-Process Buffer Management Using the Rational Commitment Model in Repetitive Projects. In: *Proc. 16th Ann. Conf. of the Int'l Group for Lean Construction.* Manchester, UK, July 14-18.

Koskela, L., 1992. *Application of the New Production Philosophy to Construction*. Technical Report. Stanford, CA : CIFE, Stanford University.

Linnik, M., Berghede, K. and Ballard, G., 2013. An Experiment in Takt Time Planning Applied to Non-Repetitive Work. In: *Proc. 21st Ann. Conf. of the Int'l Group for Lean Construction*. Fortaleza. Brazil, July 31- August 2.

Little, J.D.C., 2011. Little's law as viewed on its 50th anniversary. *Operations Research*, 59(3), pp.536-549.

Tommelein, I.D., 1998. Pull-driven Scheduling for Pipe-Spool Installation: Simulation of Lean Construction Technique. ASCE, J. Constr. Eng. Manage., 124(4), pp.279–288.

Wardell, C., 2003. Build By Numbers. *BUILDER Magazine*, [online] Available at: <http://www.builderonline.com/article/build-by-numbers_o> [Accessed 3 Mars 2015].