IMPLEMENTING TAKT-TIME PLANNING IN CONSTRUCTION TO IMPROVE WORK FLOW

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ABSTRACT

Lean principles, as applied to the construction industry, are known to add value and reduce waste. One of the most critical principles of lean construction is to target continuous work flow in production and reduce variability. Key to achieving this target is producing to takt time which is the work pace or rhythm derived from demand. Takt ensures a continuous flow thus reducing waste. The actual calculation and implementation of takt time for the construction industry however, has been a debatable and ambiguous topic, thus complicating the process of applying takt. The purpose of this paper is to present a systematic method of calculating takt time and aligning various production rates accordingly in a Location Based Management System scenario. In order to achieve this purpose we will examine an infrastructure project as a case study, observe its current state and then improve it by amending production rates to conform to takt time. A flow line visualization planning software, VICO Control, will be used to demonstrate this production rate adjustment. As a result, we expect the outcome to provide proof of how takt time can improve construction workflow and suggest a systematic method of applying takt.

KEYWORDS

Takt time, continuous flow, catch pits, Lean construction work flow

INTRODUCTION

Applying lean principles in construction projects requires the application of a continuous flow as a first step. Creating continuous flow forces the implementation of several lean tools such as visualization and continuous improvement strategies, of which the main prerequisite is takt time (Liker, 2004). We believe that the first requirement for creating a continuous flow is identifying the takt time and producing accordingly. Takt time is the time set for the supply of a certain process and is derived from the customer demand. “It is the heart beat of one piece flow” (Liker, 2004). The benefits that takt time introduces to the project are reducing variability, decreasing the whole project duration and minimizing the cost of the project (Kenley

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et al., 2009). Traditional construction projects adopt Gant Chart plans and schedules. This activity-based management style allocates productivity rates somewhat haphazardly, thus engendering high and low production peaks. Trying to account and correct such peaks in traditional construction behavior entails an unplanned reallocation of resources causing an imbalance of resources (Kenley et al., 2009). This in turn, is believed causes schedule delays and cost overruns, thus driving the majority of construction markets to a severely uncompetitive position when compared with other Lean value-maximizing construction industries.

Basics of lean management pursue waste elimination in production systems (Liker, 2004). Waste can be very costly; thus, its early elimination is necessary to decrease the overall cost. This paves the way for creating continuous flow that allows us to see the problems in advance (Liker, 2004). Therefor flow is fundamental in any lean process that is to be applied. But how do we determine how fast this flow should move? How do we know at which rate should we supply or work at? Takt time is the rate at which the customer demands the product and hence dictating the rate at which production should take place to meet those demands exactly on time without generating unnecessary inventory (Liker, 2004). In other words, Takt time, in terms of construction projects, is the overall progress rate at which all construction activities are ideally supposed to move (Kenley et al.,2009). If we move at a rate faster than takt, job buffers will increase until they are considered excess inventory and thus, waste. However, if we move at a rate slower than takt, activities will take longer than their optimum finishing time and will thus delay successor task causing an insufficient production rate, unable to cater for the client's need.

Takt time can be easily defined in manufacturing where the customer demand can be known through the market. Based on the customer demand and the available working time, the takt time can be deduced. In construction, big question marks are raised when it comes to defining the demand rate. One solution is to find the time available to finish the work and verify it in order to base the demand on it; another is to check the feasibility of improving the capacity of the slowest trade (Frandson et al., 2013). The slowest trade acts as a bottleneck to the process as a whole and slows it down. It is now the job of the system as a whole to work on improving the production rate so that it moves at the same speed as the takt time (Fiallo and Howell, 2012). Another research provides a systematic planning methodology that could be used to determine demand and thus takt (Hamzeh, 2009). Look-ahead planning, as part of the Last Planner system, could be used to set deliverable milestones on the planning timeline. The milestones, acting as deadlines, can then be used as the benchmark from which reverse phase scheduling is performed where activities are distributed accordingly and the production rate of each activity is adjusted within feasible limits to meet the imposed takt time. A study showed how the Last Planner system could ensure that the benefits of takt-based scheduling are realized via its improved socially interactive planning procedure (Seppänen et al., 2010).

In manufacturing we divide work between different stations and see the difference in the rate of production at different stages. In construction, work is categorized by tasks and phases. Having known the tasks required and the resources available, the time required by each trade to complete a certain task is known. Here, the set takt time is the maximum time allowed for a trade at any stage of the project. This is to ensure that all trades move at the same pace towards achieving the final product on time. Additionally, this ensures that overburdening (Muri) is eliminated while optimizing resources.

Traditionally, projects used activity based scheduling that focuses on discrete activities and how they are logically linked together by identifying the critical path. Alternatively, location based management focuses on the flow of resources and production between different tasks (Kenley & Seppänen, 2009). The forecasts given by critical path method (CPM) are based on calculations of the remaining durations available for certain tasks. On the other hand, calculates forecasted based on progress of the project, productivity data and resources available allows more accurate scheduling (Seppänen, et al., 2013). VICO Control software facilitates the transition from activity-based management into location based management. This tool is highly graphical, making waste, time buffers and variations in productions rates highly visual. By looking at a flow line visualization diagram, determination of takt time and most suitable production rate is enhanced.

Findings from the Sutter Health Women's and Children's Center (WCC) show that when takt time and production was managed at daily level, the project was completed in 5 months instead of the planned 11 (Linnik et al., 2013).

Another case compared the productivity and production rate of floor completion time within the same building (i.e.: same site conditions) between Location Based Management System (LBMS) following the flow line visualization management style and traditional ASAP management style. Results show that under LBMS, productivity and production rates were enhanced by 18% and 10% respectively (Evinger et. al, 2013).

Kampi Center building complex in Finland is considered "the biggest project implemented using the LBMS. Results obtained from implementing the LBMS on that project revealed that savings worth millions were made as the contractor was able to deliver the project six months ahead of schedule. Moreover, this case study's results "confirmed that the LBMS can compress large-scale schedules by 10% or more" (Kenley and Seppänen, 2010).

IDENTIFYING TAKT TIME IN CONSTRUCTION PROJECTS

Another process for implementation of continuous flow by using takt time was presented by Frandson et al. (2013) in their paper. The process requires multiple iterations and included the following six phases:

Step 1 - Collect Data: usually done by last planner to identify how, by whom and in what sequence any task should be done.

Step 2 – Divide workstations by zones: Each zone includes all locations that have same production rate for a certain task.

Step 3 – Order by trade: collaborative planning of all parties responsible for executing and designing a certain task.

Step 4 – Balance work equally: identifying bottleneck tasks and improving their production rate in addition to the tasks that need to be slowed down. In our case study this is done using VICO Control tool for drawing a flow line visualization for each task.

Step 5 – Time needed for each trade: first runs are required to determine the duration of each task for future improvement.

Step 6 – Plan according to takt time: control over improved process to take actions in case of variation from established takt time for each task.

FLOW LINE VISUALIZATION:

Planning of construction projects is traditionally done using CPM techniques that are often expressed in the form of Gantt charts. But such representations have failed to show flow and linkages between tasks. Excessive activity float times in a CPM diagram are not shown by Gantt charts (Melles and Welling, 1996).

We can notice however, that in flow line representations, buffers can be clearly seen as well as the overcrowding of two task crews in one location. Figure 1 below shows a representation of unbalanced production process using a flow line visualization.

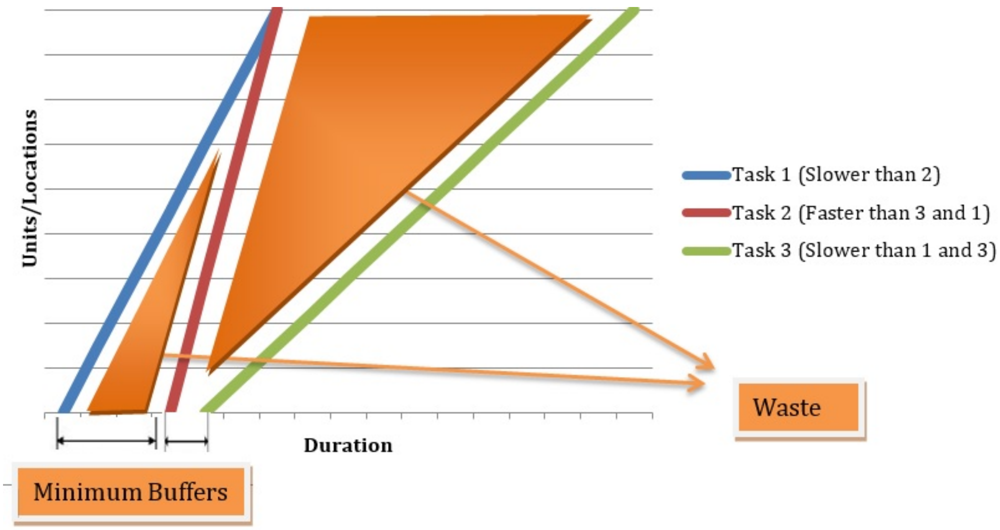

Figure 1: Unbalanced production process

METHODOLOGY

To put theory in practice, we examined a case study on which takt time identification and planning adjustments could be shown. The selected case was suitable as it picks a project which has fallen way behind schedule, thus giving opportunity for takt time flow line visualization -based planning to propose solutions after portraying the potential benefits. For simplicity, only specific tasks and activities pertaining to the project's substructure were chosen for this study. Detailed interviews with the contractor, project manager, and site engineer were performed to obtain information regarding task details, crew productivities, cash flow approximations, and other information required. We used VICO Control software as a planning tool that helped us represent the current state work schedule from the data obtained. Flow line visualization plans helped us induce adjustments to current activity production rates and eventually calculate the project's takt time. The adjusted tasks and activities were represented in a form of an flow line visualization schedule following takt.

Furthermore, optimum resource allocation curves were generated from the flow line visualization schedule. Finally, the mentioned outputs and deliverables were discussed and analyzed, displaying the impact of takt time planning on this sample project.

CASE STUDY

The project is comprised of a 3000m2 area for 300 apartments and 170 retail stores. It is around two years behind the schedule and there is a desperate need to finish as soon as possible. This study focuses mainly on laying down the sub-structure piping and sewage system (catch pits). Our study encompasses the construction process beginning with excavations and ending with 600 catch pits connecting the piping system for the whole project. This case study was optimum for this paper because its construction tasks were repetitive to a significance degree. This methodology might otherwise be limited for more complex construction projects with many non-repetitive tasks. Table 1 summarizes the tasks included in the project.

Table 1: current approach

Task	Consumption per person (hour per meter)	Production rate (meters per day)	Duration (days)	No. of Labors in crew	No. of crews	Notes
Surveying	1	24	33	3	1	-
Excavation	0.7	57.14	17	5	1	Depth of 1 meter
Cleaning & preparations	2	20	48	5	1	Hand tools required instead of excavator due to proximity to building
Scaffolding of catch pits	2.5	12.8	74	2	2	Catch pits are too narrow limiting crew size to 2
Casting	0.5	64	15	4	1	-
Pipes	A&C: 2.3 B:1.6	13.9	68	2	2	Zone B located on sloped region
Catch pit covers and level	1.9	16.8	56	2	2	Figure 3
Backfill	0.5	48	19.8	3	1	-

The total length of the pipes to be inserted is 950 meters. For ease of study we divided them into three zones. The zones are according to the elevation with respect to the sea level (zone A the lowest elevation, zone B the highest). Zone A consists of 450 meters, zone B 300 meters and zone C 200, as shown in figure 2 below.

Figure 2: The 3 zones of the project

Figure 3: Picture displaying site catch pits

Based on the method being currently used, we analyzed the production rate as shown in table 1 and figure 4. The current method is "as soon as possible", an option in LBMS that starts activities as soon as possible rather than delaying their start dates to achieve continuous flow.

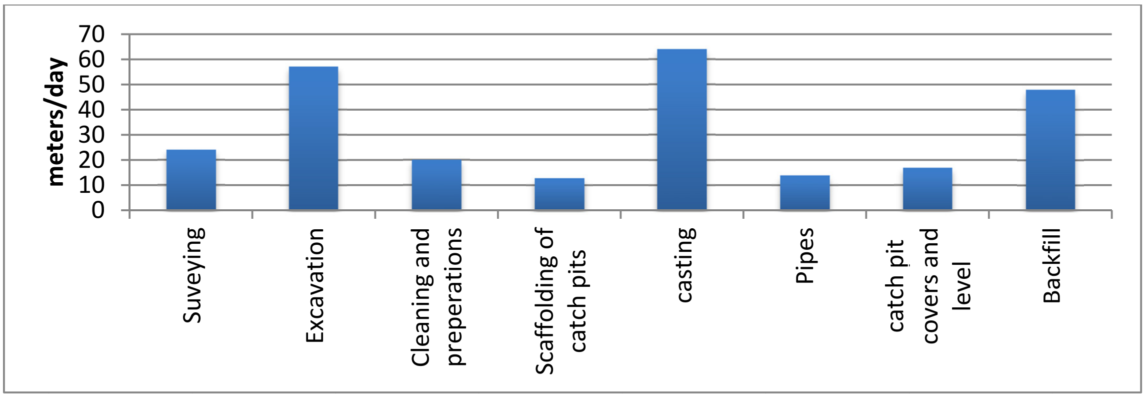

Figure 4: Production Rate of the current approach

From figure 4 above, we can see the large variations in production rates between the different tasks. We can also identify that we have several bottlenecks, the main two being scaffolding and the pipe works. The current approach seems to waste so much time and it takes 105 days to complete the works. According to the project manager; this working methodology tries to cut on expenses of temporary construction resources (i.e: wood needed for scaffolding) on account of extra time wasted. Therefore he only provides two crews for scaffolding, which causes the bottleneck we see in the figure above. This causes the delay of all the trades that come after the scaffolding.

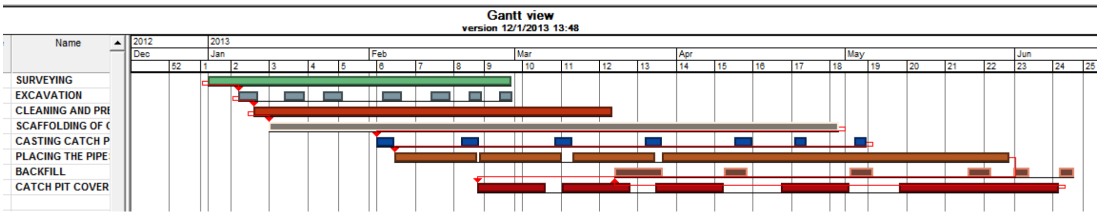

Figure 5: Gant chart of the current approach

The current method is shown in the Gant chart in fig. 5. This chart shows that the process is moving in the right order and time. It does not show the production rate of each task. If we try to generate a flow line visualization fig. 5, we can see the change in production rate between the different tasks as shown in fig. 6. We can also notice the waste in the current method. The flow line figure displays how some of the activities are experiencing disruptions due to the relatively slower production rate of their predecessors. These disruptions eventually cause time wastes and a deviation from ideality.

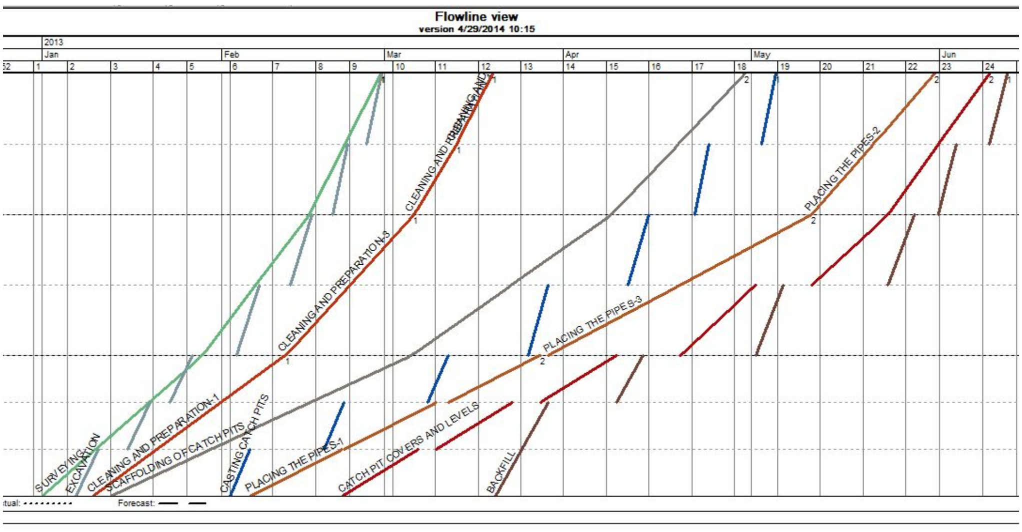

Figure 6: Flow line visualization of the current approach

RESULTS

To avoid delay, we applied takt time to the process. The tasks were made as repetitive as possible with minor buffers. The same team will move from zone to zone doing the same tasks without disruptions. This will save on resources and enhance productivity.

We used VICO Control in order to achieve takt time. Two stages were involved; the first stage had no changes in the resources, and thus production rate. Activities were aligned according to pace such that all activities are continuously effective from the moment they begin, up to their ending time. Second stage was adjusted according to takt time.

STAGE ONE

This stage aims to make all tasks continuous with no disruptions whatsoever. This is done by delaying the start dates of fast activities such that the disruptions are eliminated and time wastes between the tasks are shown. This is shown by the gaps between the lines in fig. 7. The next step is to make adjustments for each task so that they move at a rate that minimizes the waste. This rate should ideally be the takt time, however we tried to approach takt time as much as possible within the boundaries of feasibility.

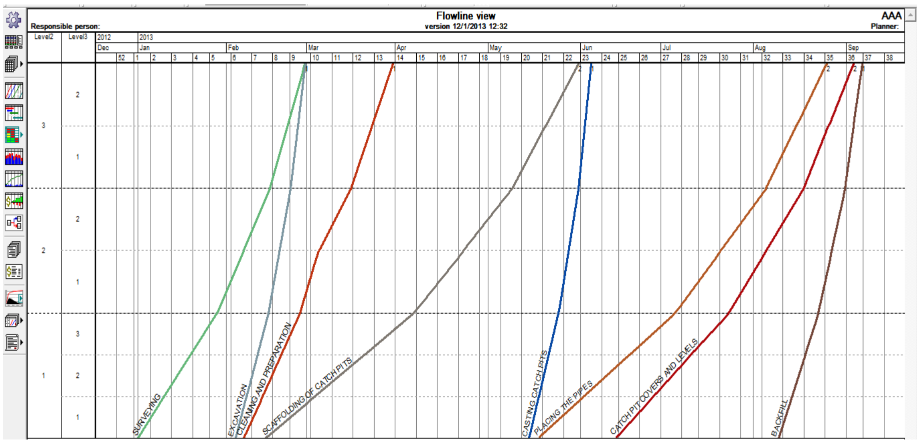

Figure 7: Flow line visualization for uninterrupted flow

Stage Two (Adjustments)

1. Due to the relative small size of the land, there is no need to have more than 2 members in a crew. To make the process faster, 1 crew is not enough; furthermore, more equipment are needed for surveying. We changed from (1 crew, 3 laborers) to (3 crews, 2 laborers).

2. Decrease the number of workers on excavation from 5 to 4 workers.

3. In cleaning and preparation, we changed crews from 1 to 3 and the laborers from 5 to 4.

4. To increase the productivity of scaffolding, which was a bottleneck, we added 3 extra crews of more skilled labor. Moving the production rate from 13 to 47. This of course is based on the assumption that this small increase in labor (6 laborers) would not have a negative effect on the individual productivity of laborers (manhours/unit) as suggested by Seppänen, Evinger & Mouflard (2014). Other adjustments of higher labor additions are expected to otherwise do so. This adjustment requires a change from traditional thinking that entails cutting down on short term costs while losing long term benefits. i.e.: the contractor would need to purchase extra scaffolding in order to allow the extra laborers to produce. This short term increase in costs is expected to be off-setted by long term savings represented by saved liquidated damages and overheads due to the shorter schedule.

5. We added 3 crews of skilled labor to the team working on the pipes and covers. In zone B the production rate decreases, therefore the extra crew will target this area.

Table 2: Takt time approach

Task	Consumption per person (hr/m)	Production rate (m/day)	Duration (days)	No. of Labors in 1 crew	No. of crews
Surveying	1	48	20	2	3
Excavation	0.7	45.7	20.8	4	1
Cleaning & preparations	2	48	19.9	4	3
Scaffolding of catch pits	1.7	47	20	2	5
Casting	0.5	48	20	3	1
Pipes	1.7	48.63	20	2	5
Catch pit covers and level	1.7	47	19	2	5
Backfill	0.5	48	20	3	1

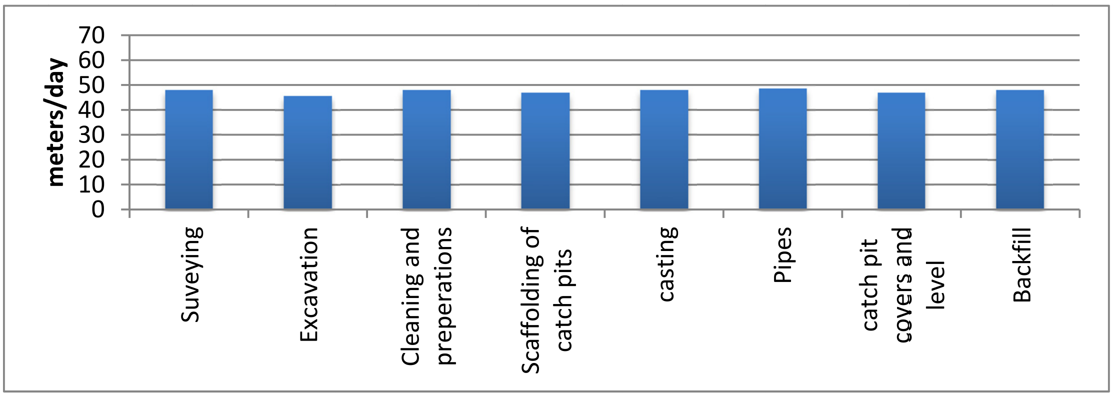

Figure 8: Production rate of takt time approach

The study revealed that a convenient takt time would be 48 meters/day. This means that the task completion will take 54 days instead of 105 days allowing time savings of about 50%. In the new process, resources are distributed in a more synchronized way. Figure 9 below shows how the various activities should progress when following takt. Notice how the slopes of all activity lines are equal. This prevents activities from experiencing disruptions as flow is now continuous. This continuous workflow also displays advantages when it comes to human power resource allocation as explained later. It is also notable from figure 9 below how buffers are optimized where the large spaces between the activity lines are decreased notably.

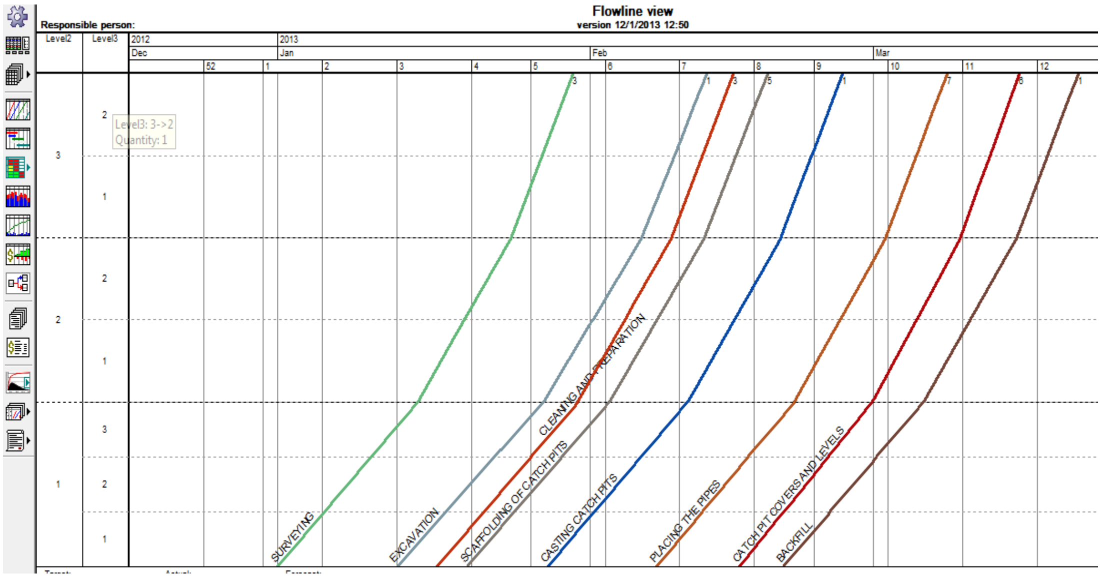

Figure 9: flow line visualization of takt time approach

Figure 10 below depicts the human resources graph for the current state work flow prior to the suggested takt time based adjustments. It is noticeable how there is a lot of 'hiring and firing' in terms of labor employment, where laborers that are assigned to perform a specific task are urged to perform a portion of the task and then stop to continue at a later stage. This is known to be an indicator of poor management because 'hiring and firing' is a source of time and material waste due to the fact that productivity is negatively impacted when laborers experience multi disruptions in their workflow.

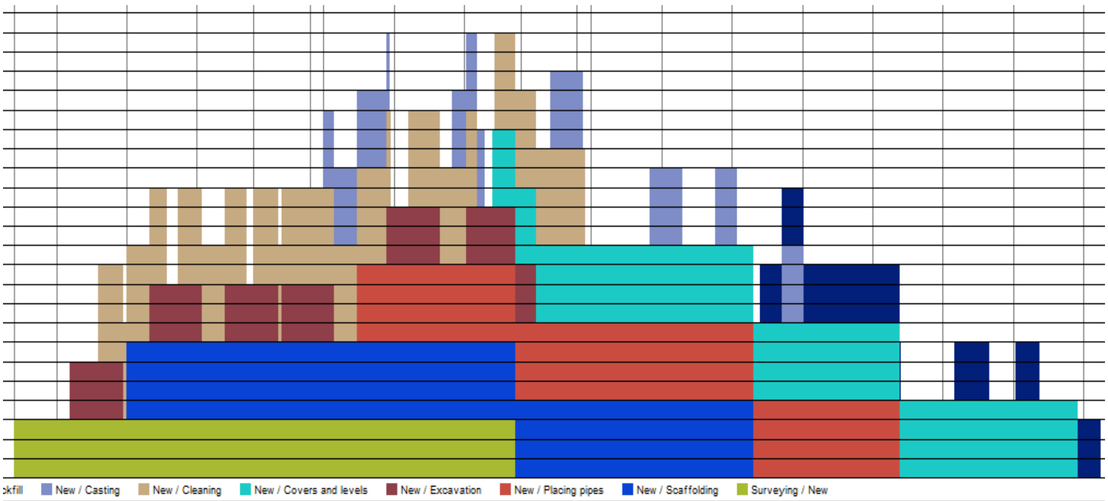

Figure10: Distribution of resources of the current approach

After a new working schedule has been suggested which complies to takt time restrictions, the following resource allocation graph is displayed in figure 11. We can see how 'hiring and firing' has been drastically reduced, where most crews begin their assigned tasks and continue working on site until the task is complete. This allows for a better time utilization and a higher realized value.

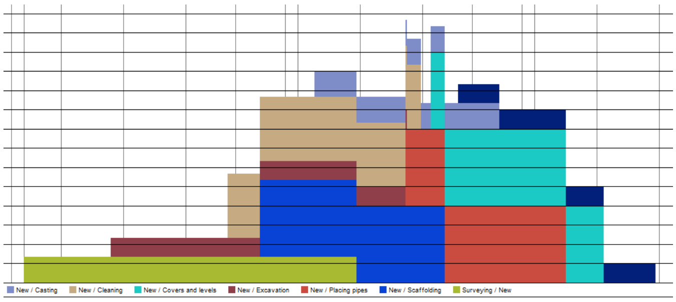

Figure 10: Distribution of resources of the takt time approach

CONCLUSIONS

As time and cost optimization within the construction industry is becoming more crucial for its success, new planning and scheduling methodologies are suggested for implementation. This paper presented a systematic method of applying takt time planning based on location based management ideology. A local small-medium sized project was used as a sample case study. This case study was optimum for this paper because its construction tasks were repetitive to a significance degree. This methodology might otherwise be limited for more complex construction projects with many non-repetitive tasks. Tasks were initially represented according to the current working style and large time wastes in terms of excess time buffers were found. Moreover, an unbalanced resource allocation curve was noted. After that, two steps were made to reach production according to takt time: (1) implementation of phased production instead of 'as-soon-as-possible' keeping resources constant. (2) Aligning of production rates of different tasks and setting them equal to the applied takt time. Results show that the overall project duration after the mentioned amendments has become 54 days after being 105 days according to the current traditional working style, thus reducing the project duration by approximately 50%. Moreover, a smoother resource allocation curve was obtained as generated from the new takt time based schedule. Case study results shows that producing to takt time helps in establishing a continuous flow and consequently, less waste, shorter duration, and thus, less cost.

To wind up, this study has shown that producing to takt time can help decrease wasteful time and inventory buffers with the help of flow line visualization techniques that makes determining the takt time easier and the buffers highly visuals.

This study has presented a systematic methodology of determining and applying takt time to project planning processes. It has also established that using takt time to pace production reduces waste. Future research could expand on this topic by testing the methodology and applicability of finding and applying takt in large scale projects

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