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TAKT TIME PLANNING IN CRUISE SHIP CABIN REFURBISHMENT: LESSONS FOR LEAN CONSTRUCTION

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ABSTRACT

Takt time planning has recently received a lot of attention in lean construction community. However, very few empirical results have been reported. This paper presents a takt time planning case study from a closely related industry, cruise ship cabin refurbishment. The results of lean implementation in the case company have been very good, including productivity increase to 380% of baseline, WIP decrease of 99%, quality defect decrease of 99% and project lead time reduction of 73%. The paper reviews the process used and compares and contrasts the takt time method implemented by case company and the process proposed for construction in previous lean construction conferences. The implemented takt time method was found to be similar to the method proposed in previous lean construction conferences but it includes several additional process steps such as explicitly considering material logistics and garbage collection and real-time data collection. The main differences between project types are in logistics setup and business drivers impacting desire to cut lead time over improving resource efficiency. Interestingly, cycle time reduction achieved both goals in the case company. The contribution of this paper is to show the benefits of takt time planning and to propose additional components to takt time planning process.

KEYWORDS

Takt time planning, logistics, flow, work in progress

INTRODUCTION

Takt time planning has its origins in lean manufacturing based on setting production rates to match the demand rate (e.g., Hopp and Spearman, 2008). The theory has been adapted for construction by Frandson and Tommelein (2014) but there are several earlier practical implementations (e.g. Court et al. 2005; Court et al. 2006). Takt time planning has a lot of similarities with Location Based Management System (LBMS, see comparison of the two methods in Frandson, Seppänen and Tommelein, 2015). Some empirical results have been reported for LBMS (for example, Seppänen 2009) but so far few empirical results have been reported for takt time planning. LBMS empirical results are focussed on metrics such as project duration, number of production problems, production rates and productivity but ignore important lean metrics of Work-in-Progress and cycle time.

In this paper, we will describe a case study of a cruise ship cabin refurbishment contractor, who have implemented takt time planning in a project type very similar to construction and have gained impressive results. The process of the company is described in detail and numerical results of key lean performance indicators are presented. Finally, the process is

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compared and contrasted with the processes of Takt time planning method proposed for construction and implications for lean construction are discussed.

CASE STUDY

CASE COMPANY

I.S Mäkinen Oy is a Finnish turnkey contractor specialized in cruise ship cabin refurbishment. Typical projects are executed in two to four weeks for a project of 300 – 1,500 cabins with a workforce of 100-280 technicians. Cabin refurbishments contracts are typically from three to ten million USD. Cycle time is critical because the opportunity cost for the Owner of one day of docking can be one or two million USD, depending on the time of year, location and vessel class. Because of huge opportunity costs, there has been strong external pressure for I.S Mäkinen to decrease cycle times or lose business. This has served as a strong motivator to radically improve processes by implementing lean and takt time planning. I.S Mäkinen started Lean development in 2012 and the results have been extremely good.

CRUISE SHIP CABIN REFURBISHMENT PROJECTS

A typical cabin refurbishment project scope includes changing the carpet, TV and soft goods but extensive scopes can include changing everything from lighting to wall finishes. Because of high opportunity costs to the owner, there are late delivery penalties for the contractor of 1.5% of contract value per day, up to a maximum of five days (7.5%). The damage of delay to the Owner is far greater than the maximum late delivery penalty which makes the relationship damage more important than money. Cost of labor is around 30% of total project cost in the industry, so any improvements in productivity can result in significant project cost decreases.

Before implementation of lean, batch processing was used. Materials were moved in and out of ship in large batches using a huge crane. Workers started cabins as soon as possible and the production rates were not synchronized. To avoid penalties, overtime in the final stages of each project was common, accounting for 10-20% of project hours. Typical results of the traditional process included finishing a batch of 35 cabins each day. A good contractor would finish the project on time with a few hundred minor quality punchlist items, ranging from wrong color of silicon in the bathroom to minor carpet cutting errors or a missing ottoman in the cabin.

Problems of the traditional way of mass refurbishment have been low production, difficulty of managing quality, bad visibility of project progress and excessive space requirements.

IMPLEMENTED LEAN PROCESS

The Lean process setup is very similar to a production line, where products stay in place and the workers move. This line is called a construction train. The work stations are called wagons, where multiple people work. Foreman is called a train driver. The production system design includes three steps:

- Defining standard work flow within construction train
- Defining logistics
- Defining management roles and responsibilities.

These steps are elaborated below.

Defining Standard Work Flow Within Construction Train

Standard work flow definition starts with customer's project specification which includes the scope of work within each cabin. Each scope line item is then broken down into a set of tasks, for example demolition, smoothening of surfaces, painting or outfitting. Each task gets a workload value in man minutes per cabin. It could also be man minutes per item but it is more intuitive to think in terms of whole cabins. Ideally, the values should come from a library of measurements from previous projects. However, when the project specification includes items whose resource loads are difficult to derive from previous measurements, they are at least educated guesses, which can be based on mock-up cabin experience.

Cabin type and scope can vary. This variance can be dealt with multiple ways, depending on the frequency and amplitude of variance. If the frequency is small and amplitude moderate, for example accessible cabins for persons using wheelchairs are bigger and have more furniture and special devices, it may be best to use a separate task force to do these cabins completely outside of the takt schedule, or do only the additional work over standard cabin scope outside the takt schedule. If both frequency and amplitude are moderate or high, for example cabin suites compared to standard cabins, separate trains may be required or they can be scheduled last in the sequence with a longer takt time and different standard workflow.

Takt time is the time system has available to produce one cabin. It is calculated roughly as the time available per cabin:

[(project duration x net daily working time) – single unit lead time] / (number of cabins -1)

If the takt time becomes very small with this formula and the waste ratio of moving from cabin to cabin, compared to value adding time inside the cabin is unfavourable, i.e. with under 10 minute takt time, additional construction train may be added and the takt time doubled for each train.

Single unit lead time will get an accurate value later in the process but at this point it is possible to get an estimate of minimum single unit lead time by dividing the total man minutes by crew size per cabin, and adding the drying times on the critical path (i.e. levelling h + waterstop h + tiling h + grouting h]. The optimal crew size per cabin is usually around 3 for standard cabins with one person working in the wet unit and two on living unit side. In reality, the optimal crew size varies for each task.

Tasks need to be organized by logical and resource dependencies before they can be bundled into wagons which are the standard sets of tasks repeated every takt time by the same crew. Optimal resources are now defined for the actual bundle of tasks. The combination of tasks needs to have a shorter lead time (Sum of tasks' resource loads in man minutes / headcount) than the takt time with some buffer to cover for variance. The size of this buffer is an optimization problem balancing resource efficiency and flow stability similar to any production environment.

Drying time may require some empty wagons, where no work is done. Night time drying can be utilized only if the drying time is required to be longer than gross daily working time, to be valid for every takt of the day. This limitation can cause a false temptation towards bigger batches, where night time drying time is easier to utilize. Drying time must be smaller than the number of empty wagons multiplied by takt time. If the number of empty wagons is more than the daily production rate, the night time length can be included in the calculation. Figure 1 shows a takt time schedule of 15 wagons for one day.

Train:	1		**TD:**	Mr. XY		**SM:**	Mr Paul Deschenes			**Date:**	4.4.16	**Version**	21.3.16	11:53			**Takt time**
Start time	7:00 AM	**End time:**	7:20 PM														**0:25**
Date	**Time Start**	Wagon 1	Wagon 2	Wagon 3	Wagon 4	Wagon 5	Wagon 6	Wagon 7	Wagon 8	Wagon 9	Wagon 10	Wagon 11	Wagon 12	Wagon 13	Wagon 14	Wagon 15	Comments
4.4.2016 7:00		7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	7086	7088	
4.4.2016 7:25		7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	7086	
4.4.2016 7:50		7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	7084	
4.4.2016 8:15		7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	7082	
4.4.2016 8:40		7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	7080	
BREAK 09:05 - 09:20																	
4.4.2016 9:20		7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	7078	
4.4.2016 9:45		7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	7076	
4.4.2016 10:10		7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	7074	
4.4.2016 10:35		7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	7072	
4.4.2016 11:00		7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	7070	
BREAK 11:25 - 12:10																	
4.4.2016 12:10		7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	7064	
4.4.2016 12:35		7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	7062	
4.4.2016 13:00		7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	7060	
4.4.2016 13:25		7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	7058	
4.4.2016 13:50		7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	7056	
BREAK 14:15 - 14:30																	
4.4.2016 14:30		7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	7054	
4.4.2016 14:55		7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	7048	
4.4.2016 15:20		7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	7046	
4.4.2016 15:45		7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	7044	
4.4.2016 16:10		7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	7042	
4.4.2016 16:35		7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	7038	
BREAK 17:00 - 17:15																	
4.4.2016 17:15		7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	7036	
4.4.2016 17:40		7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	7034	
4.4.2016 18:05		7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	7032	
4.4.2016 18:30		7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	7030	
4.4.2016 18:55		7040	7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	7028	
4.4.2016 19:20		7050	7040	7043	7001	7000	7008	7010	7012	7014	7016	7018	7020	7022	7024	7026	

Figure 1: Daily takt time schedule of 15 wagons. The takt time in this example is 25 minutes.

After the value adding work has been organized into wagons, the next step is to define material delivery and garbage collection points. If the takt time is very short compared to material delivery time accuracy, material delivery may also need to be an empty wagon where no work is done.

Defining logistics

Logistics planning process involves at least planning the material sequencing for long haul material shipment, material delivery routes off- and onboard and takt time scheduling for JIT deliveries. Ideally for efficiency, all material required for the project should be sequenced for one-piece flow in the first point of packing. This means packaging all the items needed for one cabin together so that they require minimum handling as late as possible on site. However, for logistics cost efficiency, bigger batches may optimize long haul logistic costs with better packaging ratio in order to require fewer sea containers and trucks. A good compromise is to ship long haul items in batches and to pick the materials to be delivered on board Just in Time outside the ship. If material picking is done on-board the ship, a lot of space is consumed and fire load is added on-board. Items are shipped in at least two containers to decrease the risk of losing a container for a few days, which sometimes happens on big shipyards.

One-piece flow and JIT deliveries require that materials are moved for the needs of one cabin, exactly when the material is needed, every takt time. Delivery trolleys are used to move materials onboard through the corridors. All routes of these trolleys need to go in the same direction to avoid passing on narrow ship corridors. Material delivery trolleys may be used for demolition garbage transportation, so it is convenient to design the logistical route so that it aligns with construction direction and material can be delivered just before picking up garbage. Rather than using the traditional huge crane to haul materials, it is better to use a flat gangway connecting off-board material handling point to ship's service corridor so that material trolleys can flow in and out of ship on each takt time. Figure 2 shows a picture of a material trolley.

Figure 2. Material delivery trolley and sea containers in Singapore

Logistics flow may get interrupted by accidental power shutdowns, miscommunication between contractors etc. so some material delivery safety buffers are required as close to cabins as possible. They should be just large enough to cover the length of probable material delivery interruptions divided by takt time.

Materials get picked for one cabin each takt time, just enough in advance for delivery to the cabin. This advance time is calculated as delivery lead time rounded to the next takt time plus material buffers times takt time. Takt time schedule defines the entry and exit times of each wagon to each cabin and logistics scheduling. The spreadsheet gets heavy to update manually, so a parametric scheduling tool based on Excel, is used to automate takt time scheduling.

Management roles and responsibilities

Foremen are called train drivers. They oversee the wagons, ensuring that they follow construction direction, meet takt time and pass quality standards. It is the job of the train driver to call for countermeasures immediately if any one of these is at risk. The management focus shifts throughout the project. During production ramp-up, it is most important to ensure that everyone is having enough time to complete the set of tasks defined for the wagon in standard work flow. Deviations can be corrected by advising on correct working methods, changing or adding resources or changing tasks from a busy wagon to a less busy wagon, keeping in mind the dependencies between tasks and skills required by each task. If takt times are short (e.g. 15 minutes rather than 30 – 180 minutes), a co-driver is often appointed for each wagon focusing on quality and correct task execution methods. In these projects, the driver can have a “sergeant” profile with less construction experience and the co-driver can be an experienced construction foreman with ability to inspect quality and advise on working methods.

Logistics manager oversees the material flow to construction site and manages the logistics team, which is around 10-25% of the total workforce depending on the efficiency of the logistics setup. Logistics foremen oversee material picking and corridor logistics and participate in material handling.

Management meetings are held daily. Key Performance Indicators and their standards are defined for each project (i.e. quality, schedule, safety, tidiness, flow). They are measured continuously. Root causes of deviations are analysed immediately, countermeasures are defined and their results are monitored. Android tablets are used for recording wagons cycle times against takt time, and the data is analysed using Minitab statistical analysis for finding a better line balance.

ACHIEVED RESULTS

The results have been extremely good. Table 1 shows the comparison between Royal Caribbean Cruise Lines previous contractor in 2011 and Explorer of the Seas project in April 2015. Quality defects decreased to practically zero. I.S Makinen was able to deliver a zero punchlist project four times in a row in 2014-2015 which is an exceptional result in the industry. The good quality results from very short single cabin lead time. Final inspections can start within a few hours of construction start when completed cabins start to be delivered to the Owner. The Owner can give final instructions very early, ensuring that quality errors do not get repeated in all cabins. These instructions can range from silicone installation affecting the hygiene of the cabin or incorrect location of the toilet brush which can become a problem when multiplied by a 1,000 cabins.

Productivity increased to 380% of baseline compared to traditional process. This has resulted in a significant cost benefit, because the manpower cost accounts typically for 30% of total project cost in the industry. The productivity increase from I.S Makinen’s first takt time project in 2012 to the last one with similar scope (Explorer of the Seas) has been 57% but when the impacts of over-time work (no overtime in Explorer project, compared to 10-20% overtime in EN project), the productivity improvement has been closer to 80%.

WIP decreased by 99% which is the enabler for all other results. Traditionally, the first cabins were handed off to the Owner on the third to last day of a refurbishment project of 150 men working 12 h days, 7 days a week for three weeks, equalling 32,400 hours of work in process. Makinen refurbishment train delivers the first cabin to the Owner right after single unit lead time, which can be as small as three hours, and then the remaining cabins in takt time. 150 men working for three hours equals 450 hours of work-in-process.

Most importantly, project lead times reduced by 73%. The speed increased from 35 cabins a day in 2011 batch production to 62 cabins a day in the first one piece flow project in 2012 and to 126 on the last project with similar scope in 2015. This has increased the flow efficiency value to the Owner, enabling bigger scopes to be executed within standard dry docking schedule without need to increase out of service time.

DISCUSSION

COMPARISON OF PROJECT TYPES

Cruise ship cabin refurbishment is similar to building construction in many respects. The labor component and tasks performed are very similar to finishing trades in a construction project. Both project types have space as a critical resource and, in contrast with manufacturing, workers move through locations to perform work.

The differences are related to scope, duration and amount of activities, amount of subcontracting used, logistics setup, risk factors and variability, business case drivers and contractual requirements. In terms of scope and duration, building construction projects are multi-year projects (in contrast with a few weeks in this case study) and each trade can work in an area for a week or longer (in contrast with 15-180 minutes in this case study). The typical contractual set-up in building construction has a high percentage of the work delivered by specialized subcontractors whereas in the case study all employees were directly controlled by the case company. The building construction industry is very fragmented and there are a lot of operations with few opportunities for moving scope from one wagon to the next. In terms of logistics, building construction sites typically have much more space inside and subcontractors are often responsible for their own deliveries, making it hard to coordinate deliveries for individual locations. There are many uncertainty factors for building construction that do not exist in cruise ship refurbishment, for example weather risks and uncertainty related to design and requirements. Owners are not aggressively requiring lead time reductions, tending to settle for market cost and market duration, whereas the case company would have gone out of business unless they radically changed processes. Finally, the typical lump-sum environment decreases transparency and decreases the desire to improve productivity because the benefits of any process improvement can go to other parties in the process.

Table 1: Comparison of results between the previous contractor using traditional process, the first takt time project of Makinen and the last project with similar scope

Results	**2011**	**2012**	**2015**
	Baseline, previous contractor	First Makinen one piece flow project	Latest Makinen project with similar scope
Production rate (cabins/day)	35	62	126
Scope, proportional	100%	100%	130%
Manning (proportional)	100%	100%	140%
Resource efficiency (man hours per cabin)	100%	56%	26%
Quality	Hundreds of small to medium defects	Hundreds of small to medium defects	No claims for the last four projects
Logistics, cleanliness, order and safety	Random material, waste and people movement with long waiting times	Most materials and waste with JIT movement, roles and discipline developing	Materials, waste and people move JIT with minimum buffers
Risks	Day level scheduling, with +-10% overal accuracy	Minute level scheduling and full transparency, still many missed takts and train seizes	Minute level scheduling and full transparency. No interruptions to production flow
WIP Max	20 man years	200 man hours	200 man hours
Source:	(Douglas 2016)	Own data	Own data

Although the differences seem great, many of these differences have been self-imposed by construction industry. The differences related to scope and duration do not really matter because they impact the scale of planning only. The problem of fragmentation is currently being solved with new contract forms emphasizing collaboration and rewarding innovation. Different risk factors can easily be taken into account with the same approach as described here related to material delivery uncertainties.

COMPARISON OF PROCESSES

The process in this case study and the process described for construction (Frandson, Berghede and Tommelein 2013; Frandson and Tommelein 2014) have several similarities and differences. The overall approach is pretty well aligned and is based on having a standard duration for each trade/wagon in a location but there are many important differences which will be discussed next.

Setting the takt time in this case study is a mathematical exercise depending on the number of cabins, scope (man-minutes / cabin) and project duration (mandated by the Owner). Frandson, Berghede and Tommelein (2013) define two alternatives to define the overall takt time. The first one is based on duration to complete work and the second is to consider available resources, identify the bottleneck, study if the bottleneck's rate can be improved and use the improved rate as the achievable demand rate. The second option is elaborated and seems to be preferred by the authors. For the case company, it is impossible to compromise on customer's lead time due to Owner's high opportunity cost. It forces the team to always find a way to achieve the required lead time.

Locations are very clear in cabin refurbishment projects and their scope is not highly variable. In building construction, the locations are collaboratively defined with the specialty trades based on their preferred work-flows based on batches of work that take the same time for each trade to complete (Frandson, Berghede and Tommelein 2013). The sequence is collaboratively designed with the subcontractors. Subcontractors may have to compromise in order to achieve the project goals. In this cabin refurbishment project case, these compromises are not required because all workers are directly controlled by the contractor.

Balancing the work is based on man-minutes in the cabin refurbishment case study and durations in the Takt time planning approach (Frandson, Berghede and Tommelein 2013). Durations are used in construction probably because of the lack of availability of detailed productivity data. However, man-minutes per cabin make it possible to calculate crew sizes to achieve a given duration which is not possible based on duration. This may result in tighter takt times and improve learning from one project to the next. Both approaches call for a capacity buffer, scheduling less work than required to allow for variation.

Logistics get a lot of attention in this case study but have not been discussed extensively in Takt time planning approach for construction. Logistical constraints are likely to be larger in cabin refurbishment but similar approaches could be implemented in construction.

COMPARISON OF RESULTS

Very few case studies of takt time planning report empirical results. Frandson, Berghede and Tommelein (2013) report that the duration of exteriors decreased from 11 months to five months but they do not report the impact on quality or Work-in-Progress. The results from this case study show that it is possible to achieve huge benefits in terms of quality, productivity, work-in-progress and cycle time. The benefits keep increasing through experience, demonstrated by the improvement between the first takt time planning project to the latest of similar scope.

IMPLICATIONS TO LEAN CONSTRUCTION

This case study illustrates what impacts a thorough lean transformation can have in a production process which is close to construction. Although there are several important differences between ship cabin refurbishment and building construction, the production systems are roughly analogous and it is possible to see the potential benefit of implementing location-based techniques. The external pressure to reduce lead times was a huge factor forcing the case company to overhaul their processes. External pressure of such magnitude is currently missing from construction.

CONCLUSIONS

Takt time planning process has been described in Lean Construction conferences but few empirical data have been reported. This case study shows the huge potential of improvement by implementing location-based techniques in a similar production system. The case company was able to reduce cycle times by 73%, quality defects by 99% and Work-in-Progress by 99%. Although differences in production systems may make the same magnitude of results difficult to achieve in building construction, they show that the improvement goals set in construction have been too low, perhaps due to lack of external pressure. Future research is required to calculate similar metrics in construction projects and compare and contrast the findings with these results.

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