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Continuous Improvements at Operator Level

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Abstract: Few empirical studies have previously reported on the implementation of takt planning and utilizing Deming cycles (PDCA) to control construction workflows continuously. This paper presents a case study from the offshore renewable industry, closely related to construction. The paper aims to develop and evaluate a conceptual model combining takt planning and the Deming cycle within the offshore wind construction environment. The conceptual model has through interactions with construction experts been modified for a visual board implementation, covering two alternative processes with a fixed number of technicians per performing team. The knowledge base for the conceptual model is based on Takt planning implementation from the lean construction community and PDCA implementation from the lean production community. The main contribution of this paper is the development and evaluation of the conceptual model combining takt planning and the Deming cycle in a construction environment. This conceptual model has potential implications in the construction and refurbishment industry.

Keywords: Construction, Deming cycles, offshore wind, planning, takt

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1. Introduction - Offshore Wind Turbine Construction

Projects for turbine manufacturers begin with a contract negotiation as customers choose the turbine's expected power output. The project team then formulates the design, in particular, the relationship between cabling, foundation, and turbines. Meanwhile, the larger installation vessels are booked for installing foundations and turbines, which account for a large portion of total construction costs. When these parameters are defined, production starts and components are sent to a designated harbor port facility (Irawan et al., 2017). Here towers, nacelles, and blades are prepared for later offshore installation by large jack-up vessels (Barlow et al., 2014). Then the turbines are set in production and handed over to operations by the commissioning teams. Previous studies have focused on offshore wind project planning (Barlow et al., 2018; Lacal-Arántegui et al., 2018). Alla et al. (2013) detailed the overall project planning, including cabling, foundations, and turbines. Backe and Haugland (2017) investigated port and vessel configurations, emphasizing potential weather-based effects. Ursavas (2017) further developed the understanding of offshore wind farm installation planning and how changing weather conditions are crucial in calculations. Neither of these planning methods considers the teams, their performance, or continuous improvements.

Wind turbine construction entails repetitive tasks that have small differences, similar to Heinonen and Seppänen (2016) case study on a cruise ship cabin refurbishment. They can be seen as standard products or modules that are manufactured and later constructed within the project-based production domain. Modulization has received increasing attention in construction (Peltokorpi et al., 2018), and the increased standardization makes it ideal for takt planning. The non-land location of offshore wind projects increases the importance of continuous improvements and a thorough plan. Liker and Meier (2006) described a combination of the Deming cycle and takt planning as an approach to reach continuous improvements in the car manufacturing industry (Liker 2004). Frandson et al. (2013) developed an understanding of takt in a construction setting with repetitive activities, which is also done in location-based scheduling (Seppänen, 2014).

Wind farm installation planning is an established topic from a critical path perspective, but takt does not have the footing in this area that it does in manufacturing (Liker, 2004) or construction (Frandson and Tommelein, 2014).

Neither takt nor the Deming cycle (Deming, 2000) has previously been applied to the planning of offshore wind farm construction. We evaluate the installation and commissioning processes for turbines in an offshore construction project through the implementation of takt and PDCA in a combined conceptual model and its achieved results. We present the project and the results from the application of the lean methods. Finally, we compare results with current takt literature and discuss implications for lean construction. For academics and practitioners, this paper offers a conceptual model for takt planning and PDCA combined in a construction environment.

2. Case study

The case study was developed within the pragmatic paradigm (Creswell, 2014) following Hevner et al. (2004) guidelines for developing and evaluating an artifact within an environment mold (Simon, 1996). The center of Fig. 1 shows the model containing the artifact also mentioned as a conceptual model. The left side is the project environment being the mold from within the offshore wind domain. The right side of the figure shows the background which was addressed in the introduction. The evaluation of the model was conducted as a field study based on Yin (2014). With the field study approach, the interviews and observations developed the understanding of the conceptual model. These findings, where triangulated with the manual data entries and progress, logs for the individual processes.

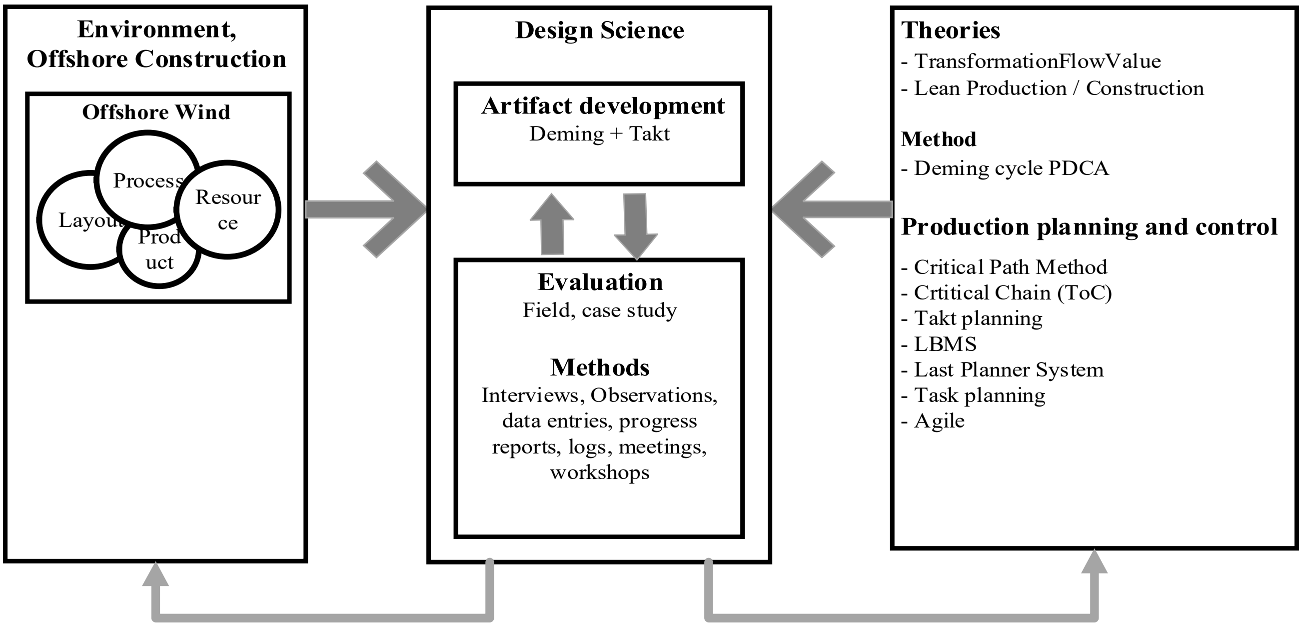

Fig. 1. Design science model for artifact development

2.1 Case Project

The case data was collected with the cooperation of an offshore wind turbine construction site in the German sector of the Baltic Sea. Teams are brought together for the specific purpose of executing this specific project for a known client, making project organization temporary, fulfilling a contract as turbine manufacturer and supplier with an expected power output above 360 megawatts for the final wind farm. The project team previously planned the construction works and generated takt workflows, to understand risks and find areas for improvement. They aim to meet contractual targets for the various processes and milestones in the project. The first selected process for this case study is part of the offshore installation requiring a large jack-up vessel (Barlow et al., 2014). The daily vessel charter costs approximately 200,000 EUR. A contractual target is 18 hours of lead time per installation process run through during the entire project. The second process is part of the commissioning requiring a walk to work vessel. The daily vessel charter is valued at approximately 30,000 EUR. The contractual goal for each turbine is 8 hours of lead time. The installation vessel defines the takt, and the vessel charter costs provide motivation to continuously improve processes. This makes the vessel and equipment the main cost drivers during the offshore project phases. For commissioning the vessel equipment is not partially defining the takt, here the technicians and processes are defining for the productivity. The number of available vessel cabins limits the number of technicians during the voyage and processes. The processes studied here are repetitive, similar to takt operations seen in manufacturing and construction.

During the installation, the components are moved to their final assembly positions via the vessel crane, and the technicians traverse the product as if it were a high-rise building. The workstations are defined by the interface assembly points of the turbine: foundation - tower, the tower - nacelle, nacelle - blades. Later the commissioning teams go through the product without the support of a vessel and finalizes these interfaces mentioned. The process planning and control system includes the following four steps, which will be covered in more detail below:

- Standard installation process workflows
- Standard commissioning process workflows
- Conceptual model combining takt and PDCA
- Operational roles and responsibilities

2.2 Existing Workflow

The workflows are process maps defining the planned activities with durations for the team of technicians executing the construction process together. Each full run-through is considered an actual duration and here referred to as a lead time. The formalized workflows are based on the takt planning methodology and had previously been mapped and organized. They are based on the team of multiskilled technicians working together, while Frandson et al. (2013) organized it by trade. The takt system here is developed on a team level, similar to the structure described by Frandson et al. (2014). The turbine installation and commissioning processes have low variation and complexity, which enables organizing activities among specialists and a systematic application of the processes across the board. The installation locations are defined by the vessel deck or main components-foundation, tower, nacelle, and blades-but these are not directly reflected in individual workflows. Whereas for commissioning the locations are defined by the main components as their vessel is not engaged in the actual processes but more a mean of transportation. Each row is divided by the team roles and gives a clear illustration of the tasks and the order in which the role must perform them. The role and location columns could potentially be exchanged. If locations mattered more to the overall project planning methods such as location-based scheduling (Kenley and Seppänen, 2010), this would require considerations of the operational level and trades. Fig. 2 shows the timeline at the top and then gives the time stamps for when the activities are scheduled to be completed by the individual technicians. Task headlines and durations are shown in the schedule, and if more than one technician is required for individual activities, this would be reflected by similar task descriptions. Color coding could also offer an easy overview of the processes for the technicians and managers. The project teams are familiarized with this way of working, enabling further development of a conceptual model.

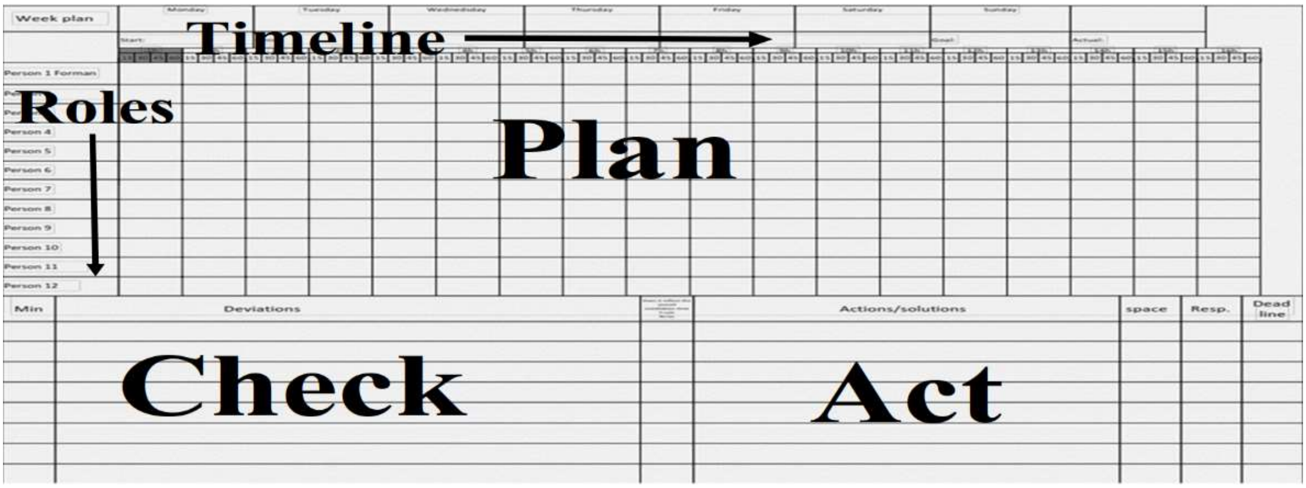

Fig. 2. Takt visual board design with the PDCA

2.3 Conceptual Model Development

The following section shows the findings and development of the conceptual model for combining takt planning and the Deming cycle in a visual board solution intended for the team levels. This was done with the understanding of the activities and structuring these between the individual roles as described above. The Deming cycle (Deming 2000), also called the Plan-Do-Check-Act (PDCA) cycle, has been widely used in industry standards and management systems (ISO 2018; Liker, 2004).

- Plan-describing how and what, ensuring processes are aligned with the objectives.

- Do-performing the processes or tasks according to the plan.

- Check-measuring performance, deviations and results of the processes compared to the plan.

- Act-acting to eliminate deviations or improve existing processes.

PDCA has been used to improve work processes, manage issues, and improve the business or organization. (Liker and Meier, 2006) have also offered the steps as drivers of continuous improvements and the key to a learning culture (Frandson et al., 2014). The PDCA utilization, in this case, was motivated by the continuous improvement potentials and understanding of whether and how this could impact workflow durations. The decision process was streamlined, as teams and shifts in between could use PDCA to communicate and to structure meetings concerning deviations, improvements, or corrections in the flow. A workshop with the operational team was set up to uncover the potentials and to further understand how the workflows in combination with PDCA could be displayed for the teams.

The case owner agreed to create a visual, revisable solution for the daily team interactions that could help them make decisions. During the workshop, visual management was discussed in the construction context, referring to “why” manufacturing had opted for visual management (VM) through years. Koskela et al. (2018) argued that “Mental operations, such as communication and decision-making are strictly seen waste in production; they are not adding value to the customer. Through VM, communication and decision-making can be sped up.” The operational team agreed to build the conceptual model around their current workflows and with an organized way to handle deviations or improvements. The result of the workshop is illustrated in Fig. 2. The fields are shown in Fig. 2 and marked as “check” and “act,” which both relate to the PDCA cycle (Deming, 2000; Liker, 2004). These inputs are used to adjust the workflow if required and to reduce the waste in the daily operations by making deviations visible for operators. Fig. 2 is then illustrated in Fig. 3, which comes from the case project. Here the operators’ tasks are organized and the visual display of the workflow is then, as shown in Fig. 4, combined with rows for deviations marked “check” on the left and actions marked “act” on the right. Between these is a yes/no column for whether the deviations affect the lead time. Float in the schedule does not affect the schedule and is marked as “N.” “Y” is considered similar to stopping a production line and affects lead time. Next to the actions, a “space” column illustrates the affected location. The following columns organize the solution owner (responsible) and deadlines for the action. Individual rows ensure that actions, deviations, etc., are linearly connected.

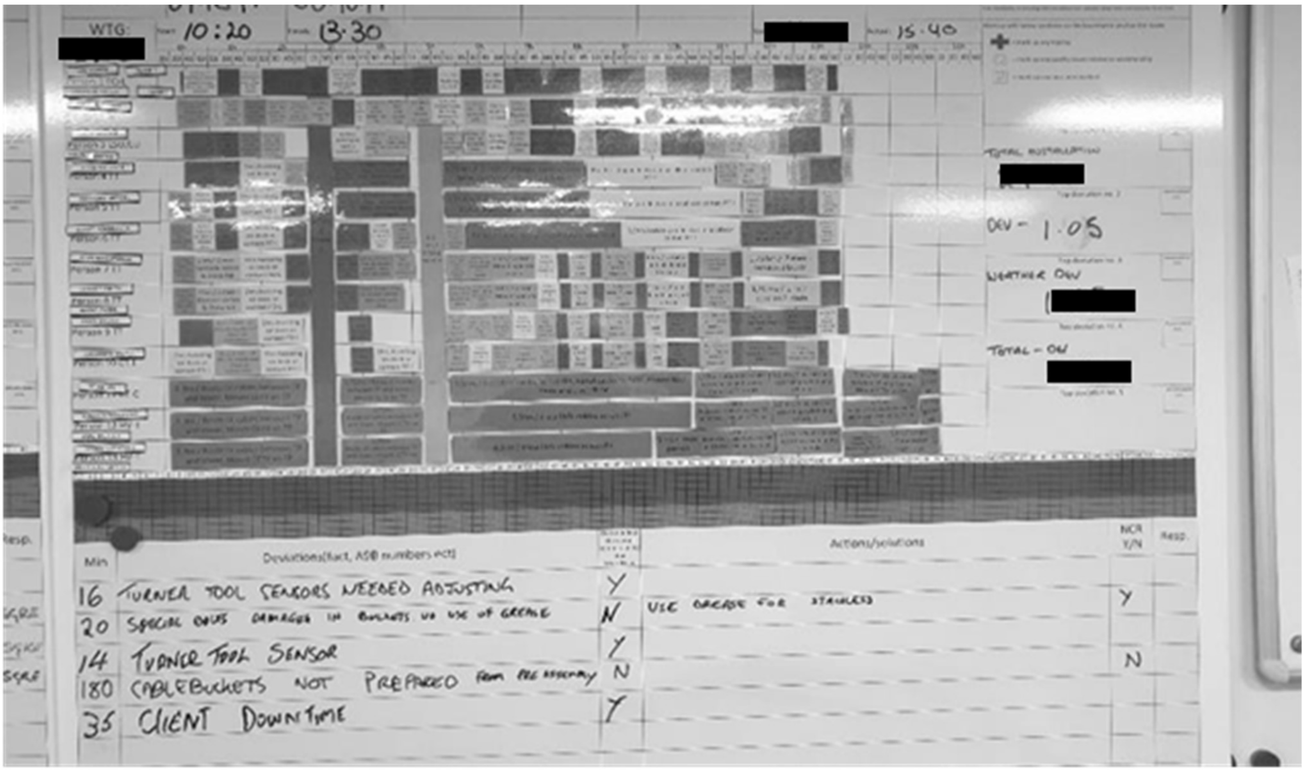

Fig. 3. Takt table picture from implementation

2.4 Resources and Responsibilities

The installation supervisor coordinates team and vessel interfaces such as technicians, crane operators, deckhands, master, and client representatives. Commissioning supervisors have similar coordination responsibilities but do not have to engage with crane operators or deckhands regularly. The supervisor also handles the interface for the project organization, logistics, equipment, and tools. At the beginning and end of each shift, the operative supervisors briefing and debrief the team about their performance and occurrences through the shift. The supervisor follows up on deviations and actions and helps the foremen apply any changes to the workflows.

The foreman is responsible for organizing and leading the team. This involves several specialized roles, such as mechanical, electrical, or specialized operators. Together these technicians form a united workforce, which in comparison with construction would require carpenters, electricians, bricklayers, and plumbers to be engaged at the same time and work together as a team. Each individual’s competences, trade, and profile determine his or her role. Picture 1 shows the technician’s day-to-day tasks during the construction phase. While performing tasks, team members take note of possible obstructions or streamlining possibilities, which are registered as deviations. These deviations are listed in the “check” area, and following each shift, the team is debriefed about performance, issues, and suggestions. The board offers a visual overview and provides traceability for the incoming shift, streamlining decisions for them as they have a clear overview of the situation and any recent developments.

3. Achieved Results

The case owner agreed to implement the conceptual model and subsequent performance measures. Operational managers conducted these performance measures and took pictures (Fig. 3) of the visual board after each run-through for both installation and commissioning.

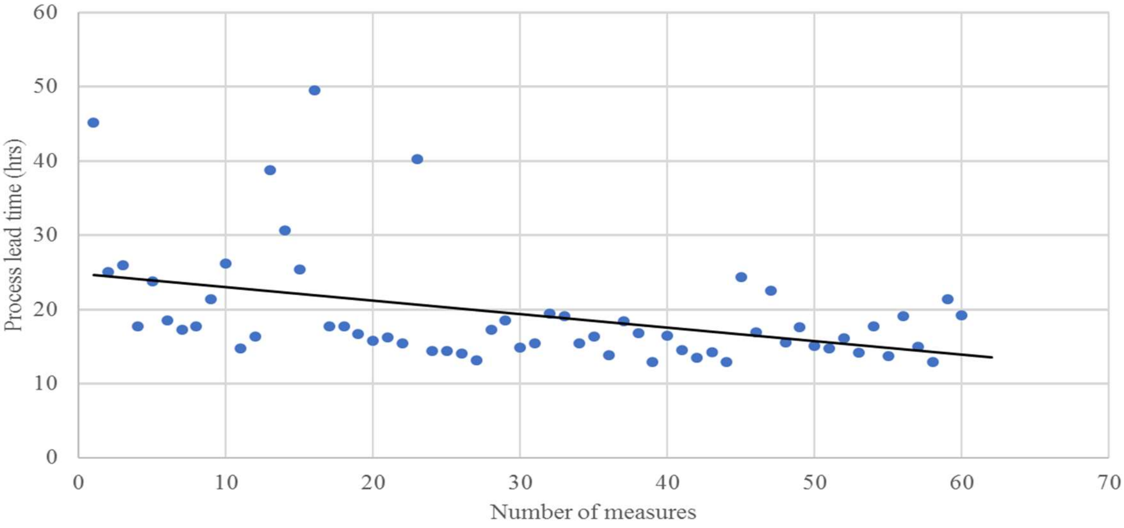

Fig. 4. Registered process lead time with trendline for installation

The data for both processes are presented here in scatter diagrams with a trendline. The lead or cycle times for the installation process include preparations, lifting operations, main component assembly, and ensuring the turbine main components are fully assembled for the commissioning teams offshore. Each process run-through for the installation was cleaned for adverse weather delay registrations, which were not covered by the contract. Fig. 4 illustrates the multiple lead times for the installation processes registered during the case study. The trendline shows a downward shift, from 22 to 16 hours lead time, giving a 28 percent reduction by using this conceptual model with takt time planning of the activities in this phase. Fig. 5 illustrates the commissioning lead times including preparation, completion activities, testing and commissioning the electrical equipment ensuring the turbines are ready for power production. Similarly, to the installation process, the commissioning lead times were cleaned for weather delay registrations and waiting time between locations.

The trendline here shows a shift from 11 to 6 hours lead time, or a 46 percent reduction, through the use of this model in this phase.

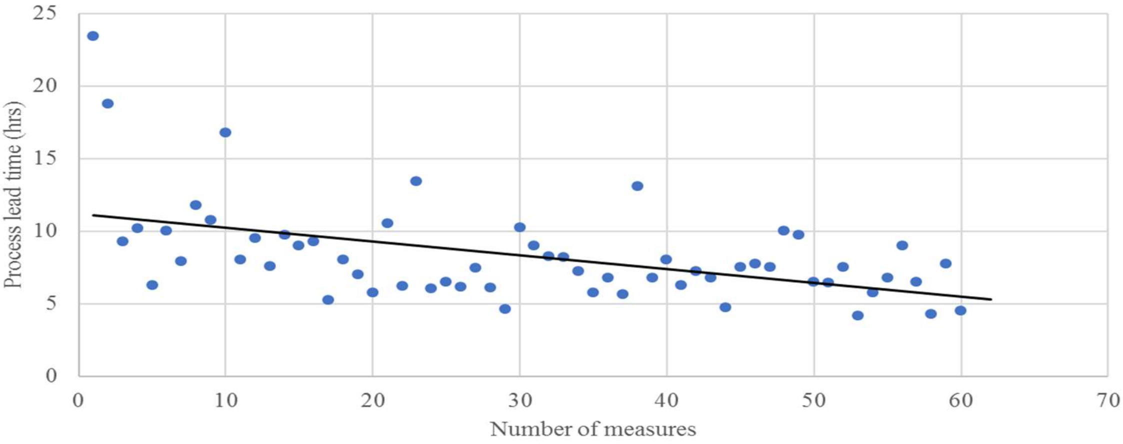

Fig. 5. Registered process lead time with trendline for commissioning

These lead time reductions were generated through stabilization of the workflow, by continuously adapting minor improvement adjustments and removing obstacles in the flow. Every deviation was registered on the board and transferred to an excel register for later follow up and potential analysis of occurring errors. These data registration could be used to improve future project executions.

4. Discussion

4.1 Workflow Comparison

Wind turbine construction is similar to construction in multiple aspects: project-based production, pre-fab elements, and fixed position manufacturing. This is also reflected in the external conditions of the turbine construction sites being subject to weather conditions (Alla et al., 2013; Ursavas, 2017), which is also seen within regular construction (Koskela, 1999). These flow conditions enable the workflows and performance of the teams if they are prepared, no matter if constructing wind turbines or pre-fab buildings. It could be argued that the preconditions would enable the workflows proactively through lookahead planning as described by Ballard and Howell (1997) but this would require further investigation. Here these conditions were handled as they occurred during the project, learning from it but in a reactive manner. The possibility of eliminating the workflow variations here only emphasizes the importance of ensuring workflow readiness prior to each turbine installation. Tommelein and Riley (1999) described the deviations in the workflows as variabilities for the construction flow. The foundation for the wind turbine construction here was the formalized workflow illustrated in Fig. 3, which defined the movements through the products of multiple trades as one team. In the construction trades are organized separately and move through the products (Tommelein and Riley, 1999). Frandson et al. (2013) showed how takt from a construction perspective divides the trades into zones and segregated trade teams.

4.2 Takt Results in Comparison to Construction Takt Results

Chauhan et al. (2018) argue for prefabrication and takt as a way of industrializing the construction industry. This could be argued to support takt applied in offshore wind construction with its multiple identical components and products in each project. Results revealing cycle time reductions between 28-46%. In comparison to Heinonen and Seppänen (2016) who achieved a 73% cycle time reduction during the refurbishment of 126 identical cruise ship cabins. Indicating that the potential is being greater than achieved here, which could be related to learning curves as presented by Thomas et al. (1986) for construction productivity. It could also be addressed as continuous improvements, which were intended. The results revealed improvements on individual turbine levels, not on a project level where Frandson et al. (2013) for instance showed takt and daily management leading to 5 months completion instead of the original 11 months planned. It could be argued that further investigation would be required to understand how proactiveness or logistic control would impact the results in offshore wind. For instance, the cruise ship refurbishment chose to control the logistics to reach their results. Emdanat et al. (2016) on the other hand argued for the integration of Last Planner and takt in the construction domain.

4.3 Combined Takt and PDCA Implications

The conceptual model offered implications as a way to visually display PDCA with different types of plans. In addition to applications for process meetings like week plans and lookaheads (Ballard, 2000), the check areas could be adapted further with the flow conditions for planning and control purposes. This allows technicians and site management to increase focus on changes or variabilities that impact the workflow. It could also be argued that the registration of deviations allows technicians to help stabilize the flow if takt time is not achieved, giving them a voice. Similarly, the foremen, as part of the Last Planner System (Ballard, 1999), can coordinate and collaborate on their process plan across trades based on the master and phase plan. The check and act parts of the boards could similarly to obstacles and challenges be brought to the surface during lookahead planning, simplifying decisions for managers and peers during repetitive planning sessions. Additionally, a combination of takt and PDCA can be used as a continuous method for improving the parade of trades through workflow improvements, encouraging alternative approaches and methods. From a technological perspective, it would also be possible to adapt these findings to digital solutions eliminating the need for excel entries of deviations and actions.

5. Conclusion

This case showed a positive relation between takt and PDCA in a construction environment. The measures showed a downward tendency in the process lead times for the teams, though it was not possible to clearly determine whether this was related to the increased focus on the deviations or the learning curve. However, the decrease in lead times of more than 28 percent is notable. Neither impact on decision-making nor time between a deviation and its solution was registered. Further development can extend the conceptual model to various levels of site management. Using planning and control as an opportunity for learning proactively. The field study also showed that the utilization of visual management can be beneficial for the construction domain.

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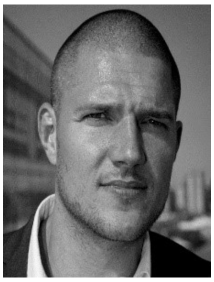

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