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METHODS FOR PRODUCTION LEVELING – TRANSFER FROM LEAN PRODUCTION TO LEAN CONSTRUCTION

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ABSTRACT

Leveling of work packages is a basic requirement for production planning, and an important part of Lean Management. It offers the advantage of a steady utilization of resources and leads to a constant rhythm by using a defined sequence of work packages. Currently leveling of activities in construction processes is mainly applied by defining Takt units and by matching the required workload to the available workforce. Reasons for this are the traditional division of work into trades, interfaces regarding warranties, project based organization, outsourcing, or the lack of optimization of individual activities. Experience shows that apart from this, leveling of construction processes by currently used methods cannot adequately respond to unexpected disruptions. As a consequence resources are overloaded and project execution is delayed. In comparison to this stationary production industries are better equipped to react to disruptions with suitable tools such as the use of additional labor and supermarket delivery systems or through rotating work shifts using a qualification matrix.

This article brings together the results of a theoretical analysis, which investigated the transferability of selected tools for leveling of work processes from stationary production industries to the construction industry. It is determined that a number of tools can be transferred to the construction industry. It is shown how these tools must be adapted to be effectively implemented, and which changes to the basic framework are required in order to achieve this. In the future the results of this analysis must be validated by case studies. For this the required theoretical basis is developed in this paper. The article shows furthermore the potential for increased reliability and a higher efficiency of production systems in the construction industry through a higher degree of leveling activities.

KEYWORDS

Takt, work packages, leveling of work

INTRODUCTION

To realize construction projects in Germany construction works are usually divided between individual trades. Specialized contractors then complete the tasks of these trades. This makes the coordination of individual trades decisive in determining project

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success (Friedrich et al. 2013, 45). A lack of standardization and systemization of the construction process is complicating the planning and coordination of the project. Due to perspectives limited to their own field, the trades only seek to improve their own processes without taking considering other trades. The focus is on individualized optimization to reduce the time taken for one individual trade. In this way an overall optimization of construction projects is seldom achieved. Often a critical-path time plan is used, in which the critical works takes priority.

If construction projects are viewed from the perspective of lean management, the flow of value creation processes is usually referenced (Womack & Jones 2003, 21; Koskela 1992, 38). A continuous pull brings out the most efficient performance. This is caused by applying takting or a pull mechanism. Prior experience is no longer sufficient for planning complex and interdependent execution processes and should be supported with calculations and technical systems. However the acquisition of accurate data is difficult. This presents the challenge of calculating the required effort for small, structured and standardized work packages through which overall harmonization of the construction process can occur. This is required for the complete flow of works. The data as a basis for this must be optimized and verified to repeatedly be reliable across multiple projects.

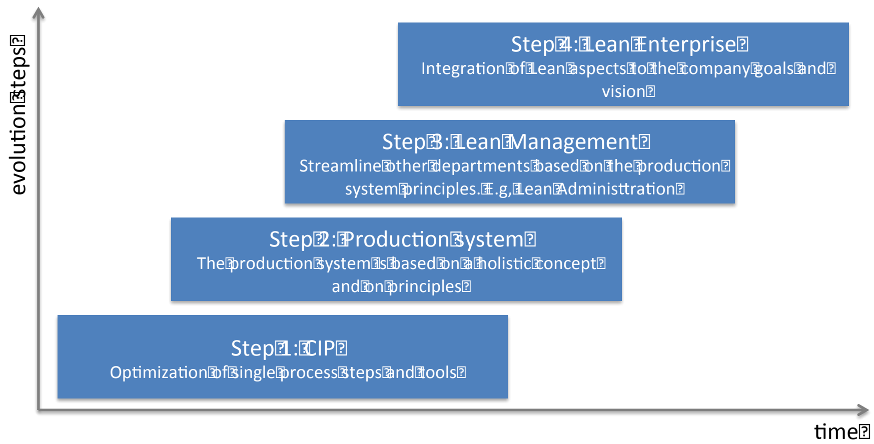

Figure 1: The four steps for "evolution" to a lean enterprise according to Peters (2009, 17)

Figure 1 shows the four steps of an "Evolution" to a lean enterprise according to Peters (2009, 16ff). Here the continuous improvement process is defined as the first step on the way to a lean enterprise. The second step is the development of a production system. On the third step lean management is introduced, where the lean principles are carried over to all divisions of the company (e.g. lean administration). The final step, and goal, is the lean enterprise, which is developed with a clear vision according to lean thinking.

A general contractor and client are mainly on the way toward the second step, the production system. A few companies even have implemented lean in other departments (step 3) without totally fulfilling step 2. Here value creation is set according to significant lean principles such as flow, Takt, pull and zero-defects. However the methods are frequently uncoordinated. Setting and following uniform rules and improving with every project processes and products as can be found in lean production systems is not consistently present in construction projects. This is evident by the variable amount of work within each trade. For example the work package for painting, or technical installations trades often requires a high level of effort, whereas door installation or plastering works have a comparatively smaller amount of effort required.

Optimization should be systematized across a complete production system. This enables all participants a coordinated understanding of the interrelationships. The overall coordination of the individual activities aims for a constant production rhythm (Jap. "heijunka") (Liker & Meier 2004, 47).

The goal of this contribution is a process-near investigation of production leveling in construction to achieve a constant production rhythm. The results will serve as a basis for development of a complete production system for construction contractors. Production leveling is widely used in stationary industries. For this reason the significance of leveling in production in the stationary industries within the framework of lean production will first be investigated. Additionally the current situation in the construction industry will be described and compared in order to derive process-near leveling for construction.

SIGNIFICANCE OF LEVELING

If a value creation process is unevenly loaded, every process step must be set out according to the peak capacity. This leads to an average under-capacity of all process steps, and an uneven loading of individual process steps compared to the peak capacity. Furthermore it reduces the capacity for production planning to react to changes to the production sequence at short notice (Oeltjenbruns 2000; Spath 2003). Within the supply chain the requirements are passed on according to production planning. Trades plan machine and equipment capacities based on peak capacities. This means on average machinery and equipment work are below capacity. In contrast human resources are often planned at short notice according to the urgency of the need to complete the project. Construction workers thereby seldom work to a consistent rhythm. Often they switch between operations that are characterized by being overloaded and in workplaces prone to disruptions. The demands of the uneven loading are passed back up the logistics chain (also known as the "bullwhip effect") (Dyckhoff et al. 2004, 246). Reasons for this are decentralized planning, planning based on prognoses from the past, bundling of order quantities and fear of price fluctuations or supplier bottlenecks (Zäpfel & Wasner 1999, 297 pp.).

To enable uniform production Rother (et al. 2003, 51) recommend production leveling. Leveling means to adjust and smooth out inconsistencies (Dictionary 2016). Ideally this leads to uniform loading and a production rhythm taking all parts into consideration from an overall perspective. Furthermore the ability of a process-near and short notice reaction to disruptions must be achieved.

Leveled production has the following advantages: Value creation is located in a defined and recurring sequence as part of a constant rhythm, resources are evenly used and peak capacities at individual points are reduced; this achieves a higher level of overall effectiveness. Fluctuations in production volumes, stock quantities and lead times are reduced. With the help of process-near procedures, greater flexibility is possible (Oeltjenbruns 2000; Spath 2003). A leveled production program also allows continuous upstream process steps such as external production and in-house production, which minimizes the bullwhip effect. To be able to achieve a leveled production program, the process steps must be considered in detail. With small and controlled steps, feedback loops can be built into the process, so that variations can be detected and potential improvements can be incorporated into the system. This means that where uncertainties in the process increase, individual process steps must be laid out in greater detail and in a more controlled way. Thereby the potential for mistakes will be reduced and the speed of development increased (Minimax-method) (Bösenberg & Metzen 1993, 123ff).

AS-IS SITUATION OF LEVELING AND BARRIERS IN CONSTRUCTION

Some construction contractors in Germany have already introduced a takted production system. The following approaches are applied in practice:

Consolidating the separate working areas: In the framework of Takt planning the working surface areas are divided and organized so that the capacities of the trades are used equally and have sufficient work for the selected Takt. In the stationary production exists a minimal Takt and the Takt time is mostly totally filled out with work (e.g. at Mini nearly 100% of the Takt time of around 70 seconds are used (internal reference). By gaining more reliable performance factors buffers in construction projects should reduced, but at least three to five days of a weekly Takt should be filled out with work. This approach is strongly dependent on the type and form of building and can only be applied to a limited extent.

Dividing the work: If individual tasks require too much effort in relation to the time allocated, the work can be divided according to the classic boundaries between trades. An example is division of the task “finish wall surfaces”. A painter completes this task. In practice this work frequently requires more time than the Takt allocated. However walls are first plastered or primed, and only painted in the next step and therefore two different and specialized teams can be used to better keep to the Takt.

Optimization of individual work steps and work content: If some work steps take longer than others, the can be optimized according to the selected Takt time. An example is the use of better machinery, optimized logistics, or reducing waste during completion of work. A further possibility is a higher level of prefabrication. Due to the conditions of turnkey contracts, this ability to implement these approaches is largely under the control of subcontractors. The potential for the general contractor to utilize these approaches is therefore limited.

Leveling of teams: To equalize the speed of individual responsibilities, the size of teams can be varied. This approach is widely used in practice. There are also limitations as some activities require a minimum number of personnel or a maximum number of personnel cannot be exceeded. An appropriate change to the size of teams is then not possible. For example only a limited number of personnel can work in a small room.

The preliminary approaches listed here offer the possibility to increase leveling and therefore the profitability of the overall system.

Contractors who use these approaches are in a stepped process of development, along which greater leveling of production systems is possible to further increase profitability. An example is shown in Figure 2. Here the utilization of the individual work packages is shown in a takted system. A work package can be made up of one trade, or a combination of multiple trades. From this it can be seen that even in leveled system the utilization of the individual work packages can still be subject to large variations.

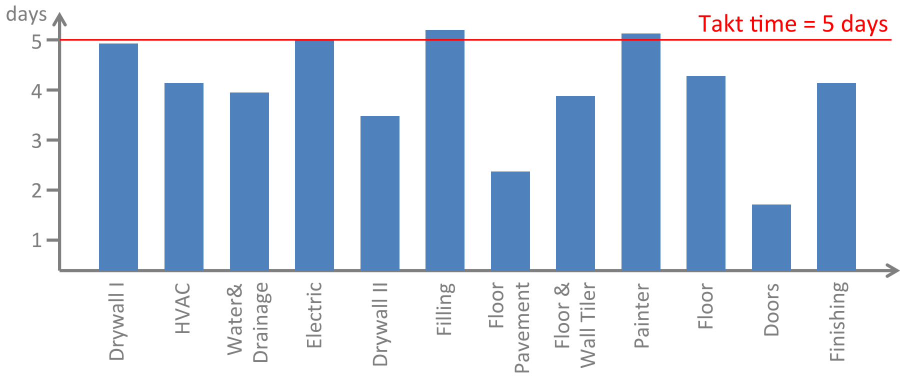

Figure 2: Capacity diagram for an example in practice

The goal is the best possible utilization of the individual work capacities. Measuring the utilization rate of a construction site can assess the quality of production planning. The utilization rate is the weighted average value of utilization of individual work packages. The size of the respective teams is used as a weighting factor to take individual working intensities into account. These figures can be used in future to empirically assess the quality of production planning for construction works.

$$RU_{\text{tot}} = \frac{\sum_1^n (RU_x \times cs_x)}{\sum_1^n cs_x}$$

x: number of work packages 1, …, n

RU_{tot}: total rate of utilization of the production system

RU_x: rate of utilization of a work package

cs_x: crew size of a work package

The calculation of the rate of utilization for each working packages:

$$RU_{\text{x}} = \frac{D_{\text{x}}}{TT} \qquad \text{with } D_{\text{x}} = \frac{V_x \times p_x}{8\left[\frac{h}{d}\right] \times cs_x}$$

D_x: Average duration of work package x [in days]

TT: Takt Time of production system [in days]

V_x: Volume of work of work package x

p_x: performance factor [in hours] of work package x

cs_x: crew size of work package x

Construction has special conditions that must be noted during execution. The following lists the significant unique qualities:

Division into trades: Construction project execution is traditionally divided into highly specialized trades. For example within the framework of takting the trade “Installation of doors” has significantly less work in comparison with other trades, and therefore is not at full capacity. However the door installer is generally not prepared to fit his logistics and services to a new system. With the main goal to improve the overall performance of the project, single trades (like the door installer) cannot be optimized within their work. Their work either can be fragmented over the total construction period or this works are added to other trades.

Warranties/Boundaries between task areas: Between the trades there are clear boundaries between task areas, which are also reflected in providing warranties. Therefore a new organization of tasks due to harmonization is only possible under certain conditions. For example it is not feasible to eliminate the boundaries between tilers and installers of sanitary fittings.

Time-limited cooperation: Due to the time limits based on a contract for works in a project-specific work phase, interest in systematic cooperation and development is limited to a tangible construction site or a tangible project. Scaling effects are rarely implemented.

Outsourcing: Outsourcing and spreading of risks favor short-term project-based thinking. Subcontractors according to the area of responsibility retain potential improvements. Narrow margins often prevent greater investment at the subcontractor level.

Global-Contracting: The integration of turnkey contracts with a functional performance specification favors poorly considered risk allocation. More in-depth consideration, and a detailed understanding of individual processes is no longer necessary from the perspective of the general contractor. On this basis subcontractors are obligated to optimize their own processes – however they lack a total overview of the project.

Optimization of Work Packages: Optimization of work packages is also left to the subcontractors. The general contractor's ability to influence this is severely limited due to the conditions of outsourcing.

Other industries have implemented standardized production systems. These take the framework relevant to the particular field into account. Enterprises have also changed parts of their frameworks to improve their own production systems. A significant part of the new production systems is newly developed methods for production leveling.

LEVELING IN LEAN PRODUCTION

In the stationary industries the goal of leveling is to introduce a uniform production rhythm aligned to customer demand. In reality customer demand is not static. Therefore it is necessary to decouple the production program from customer demand. For this demand must be identified in the first step and categorized according to type, quantity and required resources. For the demand to be met the production must be divided into work processes to be arranged in a suitable chain of production. In a second step production is smoothed out during which templates of the smallest subsets are determined. With an increase in the number of cycles the set-up time must be reduced (Bullinger 2009, 1- 23).

According to Engeström (1987, 217) output can be influenced by subjects (or work stations), objects (or products), instruments, rules, community and work performance. Based on this categorization specific tools and methods from the lean production approach for leveling will be introduced.

Subjects: By changing working capacity, throughput times and thereby also leveling can be influenced. Capacity is made up of *human, machine, and instrument resources* (Schuh & Schmidt 2014, 346).

Objects: Products can be divided between standard products and special customer requests (Glaser et al. 1992, 407). Specific product groups are required by particular customer Takts. These should be identified. Bundling products into *batches* and the length of the planning cycle (also known as "pitch") are significant influencing factors for leveling (Rother & Shook 2008, 51). Short planning cycles together with short throughput times enable the ability to react quickly.

Instruments: To reduce the effort required for control, leveling is supported by the *heijunka-board* (Rother & Shook 2008, 53). The goal of the heijunka-board is to use constant production rhythm to achieve an optimal capacity utilization and the ability to react quickly to customer demands. Using a matrix, planned-demand maps of downstream process steps are used to allocate a Takt and product variant (Brunner 2014, 107). Another instrument is restrictive dimensioning of buffers (Decker 1993, 94). This supports leveling, however is considered waste from the perspective of lean thinking. Material buffers as *product supermarkets* balance out external fluctuations (Rother & Shook 2008, 88). Finally visualization instruments (e.g. shadow-boards, signs) help identifying deviations (Dickmann 2015, 28).

Rules: To allow flexible response to customer demands, *the system (people, machinery and equipment* should be specialized for multiple product variants (Erlach 2010, 72). Furthermore by organizing small batch sizes, quick set-up times and short transport times are made possible.

Community: A team should be flexible with regard to its Takt area. With a *qualifications matrix* every employee is allocated to secondary task areas in addition to their main task area (Dickmann 2015, 62). Thereby appropriate training and up skilling can be planned for the medium to long term.

Work performance: In addition to division into working groups, flexible employees also called jumpers (Jap. "Shojinka") fill some positions (Monden 2012, 159).

A further position is termed *"Water Spider"* (Dickmann 2015, 357). They function as process manager and are responsible for maintaining material stocks to work stations. This splits value-creating and non-value-creating logistical tasks. Time spent on material handling, as well as time spent moving around and searching are reduced. (Fabrizio 2014)

TRANSFER TO THE CONSTRUCTION INDUSTRY

In the following the tools and methods for leveling described will be evaluated from the perspective of lean production and their transferability to construction practices. This qualitative evaluation is according to the subjective judgment of the authors based on experience in practice, and serves as a basis for discussion. This will take the previously discussed framework into account, particularly in reference to the construction industry. The tools and methods will be evaluated according to the criteria of social, economic and technical transferability. The criteria of social transferability include sub-criteria such as "employee acceptance" and "restrictions to working ability". The economic transferability includes the aspects of effort to implement and maintenance costs. The technical transferability is defined according to changes to working processes, contractual considerations and application of IT solutions. The evaluation will be completed on a 1 to 3 scale. If a criteria is defined as not transferrable, it will be marked "--". Table 1 gives and overview of the completed evaluation of the individual tools and methods. The final column shows the total values. This is derived from the sum of the individual evaluations assuming no criterion was evaluated as "not transferable".

Table 1: evaluation of the individual tools and methods

"3" = directly transferable "2" = transferable with minimal effort "1" = only transferable with considerable effort "--" = not transferable	Social transfer-ability	Economic transfer-ability	Technical transfer-ability	Total
Rapid setup/reduction of the resources on hand	1	2	3	6

Small Takt areas (cf. small batches)	2	3	3	8
Implement the Heijunka-Board for takting	2	2	2	6
Partial hand overs as supermarket system	2	1	2	5
Wide spectrum of tasks for workers (qualifications matrix)	3	1	3	7
Fast transfer between Takt areas (cf. fast setup times)	2	2	1	5
Short transport times to construction sites through supermarkets or using local suppliers	2	1	2	5
Involving employees in CIP	3	2	2	7
Implementation of jumpers	2	3	3	8
Implementation of the "Water Spider"	3	2	1	6

As can be seen from Table 1, the tools and methods often cannot be directly transferred, but rather must be adapted. Transferability was not ruled out for any tools. This suggests that that possible transferability should never be ruled out. The following will describe the transferability of the approaches of "implementation of jumpers" and "smaller Takt areas" in greater detail, these being the two approaches, which were scored the highest.

The implementation and use of jumpers is a valuable element of risk minimization and resource leveling in lean production. This approach is easily transferable to construction production however there are some drawbacks in terms of contractual considerations. These will be discussed terms determining contract conditions in the construction industry. There are two possibilities for implementing jumpers. Interdisciplinary/external flexible employees can be deployed at each construction site, and provide assistance to various trades. The second approach is to have jumpers for each trade, which allow leveling of one trade across multiple construction sites. These jumpers are highly specialized in their trade. A drawback is the higher logistical requirements and coordination needed between construction sites. For example one team whose task is door installation, and whose work at one site would be completed in one day would instead be required to work simultaneously across five sites for one week.

As previously mentioned, the requirements for the implementation of smaller Takt areas in the construction industry will be stated. The authors' experience from practice can provide the following purposeful Takt area sizes to fill a weekly Takt: Residential construction approx. 200 m^2, office construction approx. 300-500 m^2 and hotel construction approx. six to eight rooms per week. If a weeklong Takt is selected the waiting times of the individual trades is relatively high. To address this smaller Takt areas and Takt times could be aimed for. The smaller the Takt area, the more short-cycled the inspection points regarding the completion status, quality and security topics are and therefore production areas are completed more efficiently. Examples from practice with short-cycled daily Takts have clearly shown this. This approach is however not transferable to all projects as it is strongly dependent on building geometry. Further advantages are the higher level of control due to the higher number of standardized task interfaces. Finally this form of short-cycled Takt allows a very stable process of supply.

CONCLUSIONS

The analysis of the tools and methods for leveling from lean production show that transfer of various approaches from the production industry is also possible within the conditions of the construction industry. Some tools are directly transferable and offer significant potential. As examples the transferability of two approaches were described in detail. On the way to becoming a lean enterprise the framework of a production system places a high demands on a construction contractors. For further improvements to their production systems under implementation of the methods of leveling, construction firms must have a stronger influence on their operating environment and make adjustments to their business models. Through efficient processes and a stronger competitive position these firms can also become better suited following the influences of their customers. The transfer of the tools and methods discussed here must be tested in practice and validated.

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