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Applying Work Measurements to Identifying Productivity Potentials: The Case of Prefabricated Concrete Elements

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Abstract

Determining productivity targets based on actual potential for productivity improvement; is essential for fostering continuous improvement. Developing realistic and work specific productivity targets has proven a huge challenge in on-site construction. The present research exemplifies how work measurement techniques can be used to identify improvement potential and develop such targets. Two work measurement techniques; work sampling and continuous time study have been applied during a five day period, where the installation of prefabricated concrete elements have been observed at a single project case. The study revealed high fluctuations in daily utilization and productivity rates; moreover, a strong relationship between direct work and productivity at work task level were identified ($R^2 = .827$). Additionally, four managerial strategies for improving productivity were identified: 1) Enhance production start and stops, 2) Improve flows, 3) Optimize utilization of manning and avoid absenteeism 4) Shield the production from weather. To develop a realistic productivity target, the observed productivity day-curves have been modified, by adjusting for effects of variation and declines in productivity, revealing an improvement potential of 19.4%. The present study demonstrates how realistic productivity targets can be developed, to support managers' and managerial decisions and thus act as a starting point for continuous improvement.

Keywords: Work sampling, continuous time, productivity targets, goal setting, continuous improvement, construction management

Introduction

Productivity is often defined as a ratio between production output and production input (Hanna, et al. 2005; Johari and Jha 2020). Output and input can be measured in different ways, because the construction progress is labor dependent, the input is often hours or man-hours. Thus, the work pace of the labor force is viewed as the determining factor of whether the project will be completed on schedule or not.

Productivity output can be either a direct measurable output as completed square meters or number of joints welded or a more general measurement such as value creation (Hwang et al. 2020). While the number of complete square meters per hour is easy to measure it is difficult to compare across disciplines. Oppositely, value creation per hour is difficult to measure but easy to compare across disciplines.

In general, the construction sector has issues with delivering projects within budget and on time (Love et al. 2005; Larsen et al. 2018; Lindhard et al. 2020). Productivity, cost- and time performance are linked together where a higher productivity will reduce the time spent on the

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project which again will reduce cost of both labor and equipment and vice versa. Managing cost, time and productivity is complex as the performance is difficult, because it is affected by many varying factors (Wyke et al. 2023), but crucial important as it is directly affecting project success (Leo and Walker 1998). Moreover, regarding reduced labor- and equipment cost; as labor and equipment are two out of the three primary cost components (third being material) (Hanna et al. 2005), they constitute a substantial part of the total cost. In summary, higher productivity levels will have a substantial effect on both time and cost performance which translate into an improved profitability of the project contractors and an increased chance of delivering the project on time and budget (Rojas and Aramvareekul 2003).

In the Lean Construction approach, productivity is increased by focusing on improving the flow of work and reducing waste (Ballard 2000). Production variation is creating interruptions and delays in the workflow and is a major cause to waste (Lindhard et al. 2019; Salhab et al. 2022). Therefore, the workflow is sought stabilized, this is done by 1) optimizing and establishing a good work sequence, 2) using pull planning to ensure that resources (materials, materiel, labor) are present when needed, 3) removing production constraints and only plan with ‘ready’ activities, 4) making sure that activity durations are realistic (Ballard and Howell 1998).

In order to ensure an efficient budget and cost control, project managers need to be informed on the project’s current performance and stage (Abou Ibrahim et al. 2019). During the work, the project management team has the responsibility to make sure that plans and schedules are followed. Production follow-up is an important control element to provide input for plan and schedules (Meiling et al. 2014). Because the construction productivity targets are experience based, and mainly focused on creating a fit between workload and capacity to make realistic future plans and schedules, the productivity levels are kept at a status quo. In accordance with Goal Setting Theory, difficult but well specified goals can be applied to increase the performance levels and harvest the productivity potential in the construction industry. No current research has demonstrated how to identify such production targets.

The present research builds on the existing body of knowledge by exemplifying how work measurements can be applied to estimate productivity potentials. The presented research shows a proof of concept to how well specified and realistic productivity targets can be formed to foster continuous improvement. The development of production targets is of high relevance for site managers or other construction professionals responsible for the on-site productivity performance.

Background

A good approach to develop production targets is to ensure that the target follows the SMART goal approach, where the targets are Specific, Measurable, Ambitious, Relevant and Time-sensitive (Sahin and Mahbod 2007). In order to be ambitious but tangible, targets need to be created with outset in the feedback from actual performance levels, which are identified through following up on production performance (Marginson et al. 2014). Production follow-up can be carried out in several different ways. Typically, it is a simple comparison of actual productivity or progress and forecasted productivity or progress, but it can also be based on on-site follow-ups, where the actual production flow is monitored. On-site observations reveal

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the actual work processes and labor utilization and help in revealing waste and potentials (Gong et al. 2011).

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On-site Work Measuring

Different approaches to structured work measurements exist, a commonly used approach is work sampling where labor utilization is identified by examining *direct work* rates (Jenkins 2004, Hajikazemi et al. 2017), where direct work is understood as direct production, including only activities directly adding value to the product (Neve et al. 2020). An alternative to work sampling is the continuous time approach, where the duration of activities are directly measured. While there exists a direct relationship between the duration of activities (continuous time) and productivity the relationship between direct work (work sampling) and productivity has been heavily discussed (Thomas et al. 1984; Jenkins 2004; Chang et al. 2015). The major part finds that there is a correlation between the time spent on direct work and labor productivity, while a minor part, mainly represented by Thomas (1991), argues that direct work is simply an expression of how time is utilized and this does not reflect the pace, or productivity. Despite strong support for the existence of a relationship some uncertainty still exists, this is apparent when comparing the statements in related research (Josephson and Bjorkman 2013; Chang et al. 2015).

Even to critics of the relationship between DW and productivity, work sampling is found beneficial, because presenting work sampling data to project managers and craftsmen can stimulate discussions and reflections on how to improve productivity output (Thomas 1991, Josephson and Bjorkman 2013).

The present study fully acknowledges the findings from Thomas (1991), and agrees that work sampling is simply a registration whether craftsmen seem busy and not a measurement of if they are productive. Despite this, it is not unrealistic to assume that some relationship could exist between spending more time on direct work and the productivity level. A universal relationship might not exist, but the relationship will depend on a number of technological and organizational factors, including design data, material properties, location factors, construction method and procedures, equipment factors, labor factors and social factors (Herbsman and Ellis 1990).

Productivity Targets

Targets are essential for fostering productivity improvement (Ofori et al. 2020). The Goal Setting Theory shows that when creating difficult but specific goals or productivity targets, task performance is increased both at an individual and at an organizational level (Loche and Latham 2006). Goal Setting Theory has its outset in motivational theory and explains how goals are shaping performance by urging people to do their best (Difendorff and Seaton 2015). Feedback is important for creating realistic targets, while realistic targets are important for creating goal commitment which leads to increased task commitment and group cohesion and is a key ingredient for creating an effective team (Franz et al. 2017). The importance of goal setting is supported by Ghanbaripour et al. (2020), who looked into critical success factors to subway constructions and identified goal setting as the most important factor.

In construction, productivity improvement targets have primarily been developed as overall targets stating an aim of improving productivity with a specific percentage (Kenley 2014). General targets do easily become either unrealistic or too easy to meet and will often be regarded irrelevant by the work crews (Lingard et al. 2001). Moreover, as goals affects behavior, setting the bar to high creates a depleting and demotivating work atmosphere,

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resulting in either reduced commitment and poor performance or unethical behavior where cutting corners are necessary for goal-achievement (Welsh and Ordóñez 2014, Pollitt 2013). To make good productivity targets the actual work being performed must be considered (Kenley 2014). Traditionally, performance feedback consists of measurement of actual productivity rates or productivity costs, these measurements can easily be used to make managerial adjustments in manning or to modify the schedule and provides a direct input to future tenders and the calculation of cost and performance. Unfortunately, actual performance is not a good future performance target, because it is not ambitions (cf. SMART goals) and does not create incentive for continuous improvement, but keeps the performance level at a status quo. Productivity targets need to be based on actual potential, which is very challenging to identify, this is why setting SMART productivity targets remains a huge challenge in on-site construction (Hanna et al. 2005).

Research Problem

To take a step towards closing this gap in knowledge, the present research aim is to show how case specific productivity target can be developed with outset in production feedback from work measurement techniques such as work sampling or continuous time. In summary, the present research aims to add to the body of knowledge by answering the research question:

How can work measuring be used for identifying improvement potential and for creating realistic productivity targets to foster continuous improvement?

To answer this question, several research objectives were identified. 1) The current level of knowledge within target setting and work measuring as introduced in the background section. 2) Identifying a work task suitable for exemplifying the development of productivity targets, 3) Preparing templates, identifying the case, and conducting the data sampling, 4) Identifying an appropriate approach to analyzing data and to identify production potentials, and 5) Concluding and making recommendations based on the findings.

In the data analysis, the productivity targets are created by using day-curves to predict production potentials by stabilizing the production output by avoiding flow interruptions and reducing variations and fluctuations. The target development is based on either continuous time or work sampling measurement, while continuous time identifies work specific productivity rates and is best suitable for repetitive works, work sampling identifies direct work rates which can be cross compared, the process of data analysis is elaborated in the methods section where the highlights is shown in Figure 1.

As continuous time and work sampling are supplementing each other, the direct relationship between direct work rates and productivity becomes important. Previous studies have tried to establish a general relationship, by compiling data points from multiple observations covering entire projects (Thomas et al. 1984, Allmon et al. 2000). Thus, a second scope of the present research is to add on to the body of knowledge by, in contrast to existing research, studying the relationship between direct work and productivity from a single work task view.

The research aims are reached within the scope of a single case study research following the installation of prefabricated concrete elements. Using a single case study design brings in certain benefits regarding the detail level of the data but also certain limitations especially regarding the generalization of the identified production target at work level.

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In the methods section, it is explained how the time measurement study is conducted and how data is analyzed. The results are presenting the measurements, coupling work sampling to productivity, and exemplifying how to use time measurement to create productivity targets. Afterwards the findings are discussed with a focus on the applicability of the developed production targets. The discussion is followed by a conclusion summarizing the most important findings as well as the research limitations.

Method

The present study is based on a single case study approach observing five entire work days of on-site installation of prefabricated concrete elements at a construction project in Denmark. The installation of prefabricated elements is chosen because of its repetitiveness.

The single case study approach chosen because it allows for and in-depth focus on the case and work process observed; thus, resulting in more detailed knowledge and understanding of the data including both the actual work but also the surrounding factors captured through on-site observations c.f. (Yin 2012; Gustafsson 2017). Moreover, by studying a single, specific and repeating work task completed by the same work crew and with the same supporting elements (tools, machinery and technological support), impact of external influencing factors are removed, the hope is therefore to identify a stronger relationship between direct work and productivity than in previous works.

Because a single work task is followed, the findings can be supplemented with on-site observations, which together with day curves are used for identifying causes to productivity fluctuations. This adds additional but case specific knowledge of where a site-manager should focus to reduce waste and optimize the production workflow.

The data-collection consists of a work study consisting of two different work measurement techniques: work sampling and continuous time. The two techniques are applied simultaneously by having two different teams observing the production workflow. The findings are supplemented with field notes when relevant. By simultaneously studying the production workflow using two different methods, the findings can be directly compared. This research design was chosen because it increases research reliability because a comparison quickly will reveal any inconsistencies.

The observation teams consisted of three master students from the construction management education in Aalborg University. The students were both taught and instructed in the applied techniques. Moreover, templates to each sampling technique were prepared to simplify the registrations, ensure data consistency, and minimize the risk of mistakes. Finally, their registrations were continually evaluated, and findings discussed to reveal possible mistakes as early as possible. The evaluation led to an early modification of the templates, but all registrations were approved.

To compare the work measurements the daily observations are compiled into 15 minutes intervals where both the direct work level (work sampling study) and the productivity levels (continuous time study) are calculated. The generated data points are then mapped with

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respect to time and represent the productivity day-curves. With outset in the actual performance an optimized day-curve is generated by reducing fluctuations and variations in productivity. The optimized day-curve represent the productivity target and the improvement potentials can then be calculated. The research methodology is illustrated in Figure 1.

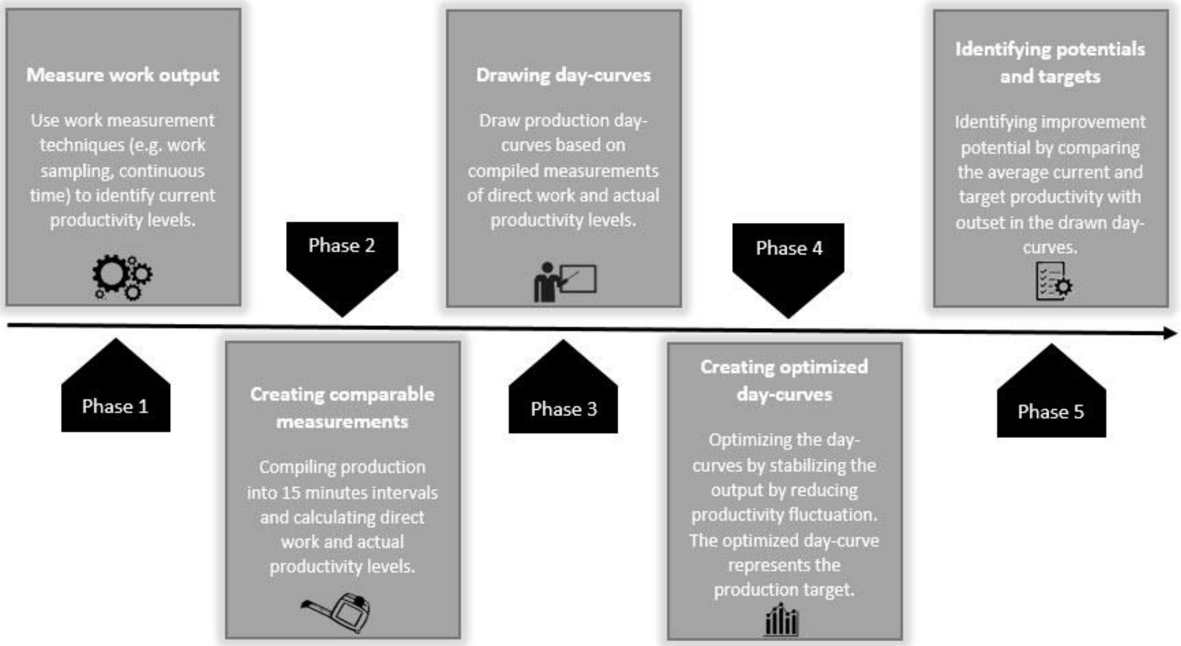

Figure 1: Research Methodology

Work Sampling

The work sampling method has been applied to collect data about how time is utilized by the observed work crew. The registration of activities is carried out every five minutes, and is based on what the workers are doing at the instant of registration (Gong et al. 2011).

The number of categories used in work sampling have been increasing, to draw a more detailed picture of how time is spent. In early studies, the work sampling have primarily been divided into direct work and non-productive work, this was later expanded to include direct work, supportive work and non-productive work while resent studies, have applied six or seven categories (Gong et al. 2011). In this work sampling study the following seven categories have been applied: Direct Work, Talking, Preparation, Transport, Walking, Gone and Waiting. The definition of the seven categories and their relationship to direct, supportive and non-productive work is shown in Table 1.

Table 1. A definition to the seven work sampling categories used in the present study.

Category	Overall category	Definition
Direct work	Productive	Time spent on production activities.
Talking	Supportive	Time spent on discussing drawings or problems or work at hand. The category also includes private conversations.

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Preparation	Supportive	Time spent on preparing the work for instance setting up machinery, taking measurements or cleaning.
Transport	Supportive	Time spent on moving materials or equipment around the site
Walking	Non-productive	Time spent on walking without moving material or equipment
Gone	Non-productive	Time spent away from work-site, for instance at personal breaks.
Waiting	Non-productive	Time spent on waiting on co-workers or for information.

The production workflow of the installation of concrete elements was observed for five entire work days, resulting in 464 observations. To minimize fragmentation of the work process and to strengthen the data points (Thomas et al. 1990), the observations have later been grouped in clusters of 3 corresponding to 15 minutes intervals.

Continuous time study

To identify actual productivity levels, a continuous time study has been conducted. A continuous time study is effective when observing a short repetitive work cycle (Peer 1986), and therefore fits well to observing the installation of concrete elements. The study has been conducted based on direct observations, where a stop-watch has been used to measure the process cycle time. During the five work days of observations, the installation of 117 prefabricated concrete elements were measured.

The overall work process, which is explained in section 3.1, has been split into: On-Rigging, Lifting, Installation, Of-Rigging, and Return time, the sub-processes are explained in Table 2.

Table 2. A definition to the five key work processes in the installation of the prefabricated concrete elements.

Sub-process	Process starting time	Process description
On-Rigging	The rigger receives the chain	Receiving the chain, and rigging the element
Lifting	The element is lifted from the ground	Lifting the element and maneuvering it into its place.
Installation	The element hits the chocking	Attaching the two struts to the element and the flooring
Of-Rigging	The fitter begin to release the chain	Releasing the element from the chain.
Return time	The chain is freed from the element	Returning the chain to the rigger.

The process workflow is regarded as a linear process, thus no overlapping activities have been included in the measurement. Besides, no overlapping activities of significance were registered during the data sampling. Thus, the data sample contains is a simple measurement of time spent from handover to handover during the five sub-processes. The sum of the sub-processes gives the process lead time.

With outset in the process lead time, the productivity of the work crew has been calculated in intervals of 15 minutes to allow for comparison between the work sampling.

Ensuring data-consistency

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The dataset consisted of observations of both direct work rates and the related productivity measured in installed concrete elements per hour. Observations were carried out at a construction site where the production of installation of concrete elements was observed in five whole work days resulting in 162 observations. After removing observations made when coming late, during breaks or when leaving early (direct work and productivity levels at 0), the sample included 129 observations. Because the observations of direct work and productivity were carried out simultaneously, it was possible to link the observations. The observations are well above the rule of thumb criteria for regression set by Green (1991) at 104 plus the number of predictors (1), thus 105.

Linear regression is based on the assumption of normality. The z-score approach has been applied, the results are shown in Table 3. The calculated z-scores of the distribution skewness and kurtosis should at a sample size above 50 and below 300 these z-scores should be below 3.29 (Field 2009; Kim 2013).

Table 3. The normality test: z-scores of the skewness and kurtosis.

	z-Skewness	z-Kurtosis
Productivity	-.62	.26
Direct Work	1.72	-.25

In conclusion, the observations have satisfactory levels of skewness and kurtosis and pass the normality test, despite that the data do not look normally distribution when making a visual inspection of the histograms. Besides, despite the requirement of normality when performing a linear regression, Schimdt and Finan (2018) found that in sample sizes above 10 observations per variable, the regression tends to perform well despite violating the normality requirement. In conclusion the data is found to behave normally distributed.

The dataset has been examined for outliers. First the observations have been looked through point by point, where all datasets were found complete. Afterwards a visual check has been applied by looking at boxplots generated from SPSS. This process revealed no outliers. Finally, during the regression, standardized residuals have been calculated to identify outliers. According to Field (2009), standardized residuals with an absolute value above 3.29 should be considered excluded. Moreover, only 1 % of the standardized residuals with an absolute value should exceed 2.58 and only 5% should exceed an absolute value at 1.96. A point by point examination of the calculated standardized residuals is shown in Table 4.

Table 4. Identified standardized residuals from the regression between direct work and productivity.

	Min	Max	Mean	Above 3.29	Above 2.58	Above1.96
Standard residuals	-2.24	2.54	.00	0 (.00 %)	0 (.00%)	5 (3.88%)

As Table 4 reveals, the standardized residuals give no cause for regarding any of the remaining observations as outliers.

Finally, the data have been examined for influential observations, this to ensure that the regression model is stable across the sample. Cook’s distance has been applied to provide a measurement of the overall influence of the single observation. According to Cook and

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Weisberg (1982), distances above 1 are causing concern. The maximum identified Cook's distance is .29, thus the regression model is found to be stable.

Case narrative

The present study followed the on-site installation of prefabricated concrete elements at a construction project in Denmark. The project consists of one u-shaped, four to six floor building containing in total 12,043 m^2. Of these, 9,532 m^2 is used for construction of 91 apartments, 1,893 m^2 is used for 65 parking spaces, and 618 m^2 is used for bicycle parking, storage and technical installations.

The study followed the installation of prefabricated concrete elements. The installation crew consisted of five to seven workers, this included one rigger, two to three fitters and two to three concreters. The crew started the workday at 07.00 in the morning and ended at 15.00. They had two primary breaks of 30 minutes, one from 08.45-09.15 and one from 12.00-12.30. Moreover, to gain flexibility of the production workflow, breaks and day-end were adjustable.

The work process

The elements were received on flats allowing the rigger to work from lift. At arrival the elements were received and prepared for rigging by the rigger. The elements were fitted with embedded lifting brackets, where the rigger had to attach the crane's lifting hook. The element was then lifted by the crane operator and moved to the place for installation.

The fitters started by making the work site ready for the reception of the element. The preparation included attachment of personal fall protection and removal of general fall protection (to make room for the element). The element struts were pre-delivered to the site to smoothen the process. When ready, the element was received and the element was maneuvered to fit the locking iron and the element was lowered to its chock. The fitters then attached the two struts in the element and the floor. After installation, the fitter used his ladder to reach the lifting brackets and released the chain. Finally, the crane operator returned the crane to the fitter and the process was repeated. Meanwhile the concreters casted the foundation under the element.

Results

The production workflow for prefabricated concrete elements have been followed for five work days. In Figure 2 the observed day curves and the average day curve are shown. The day curves illustrate how time is spent by the work crew. For simplification reasons, the day curves only contain the three major categories: Productive, Supportive and Non-Productive, while the average day curve contains all seven categories.

The day curves illustrate that there is a huge variation in how time is utilized both during the work day but also between work days. The differences have some effect on how fast productivity increases or decreases when looking at the average day curve. Despite the differences some general aspects have been observed:

1. It takes time to start and stop the production in relation to having a highly efficient process. This relates to start-ups in the morning, stop and starts between breaks, and

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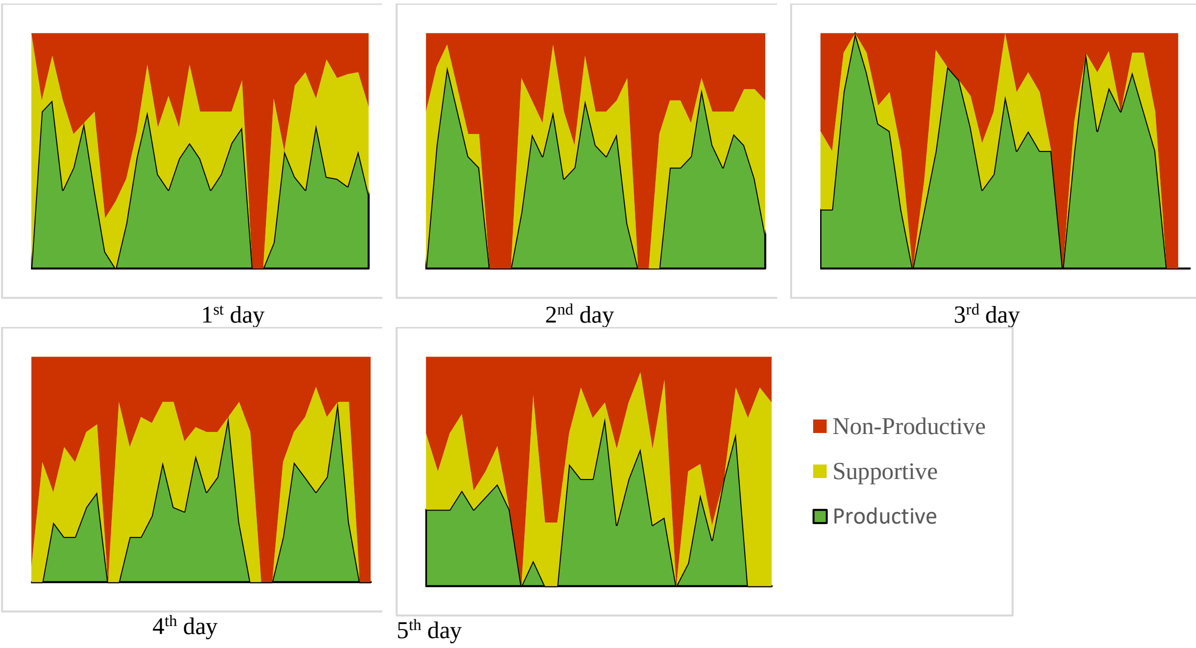
packing up in the evening. This tendency is supported by Hasse et al. (2020) and Hwang et al. (2020).

2. Material and equipment restrictions affect the production flow. Maintenance of the crane by changing the lifting chain or running out of materials e.g. concrete, chocks or elements, using the crane as a hoist all interrupted the production flow. While running out of elements often determined the placement of the breaks and caused the crew to leave early or late.
3. Manning conditions affected the production flow. Starting late, longer or shorter breaks and leaving early or late all affected the production workflow. Most often the work day was organized in relation to the production where the presence of elements often were the determining factor. Flexibility in placement of breaks and variation in the duration affects the steepness of the start and stop phase, when looking at the general result, because it is based on averages.
4. Weather also affected the crew size. Bad weather caused the number of fitters and concreters to be increased from two to three.



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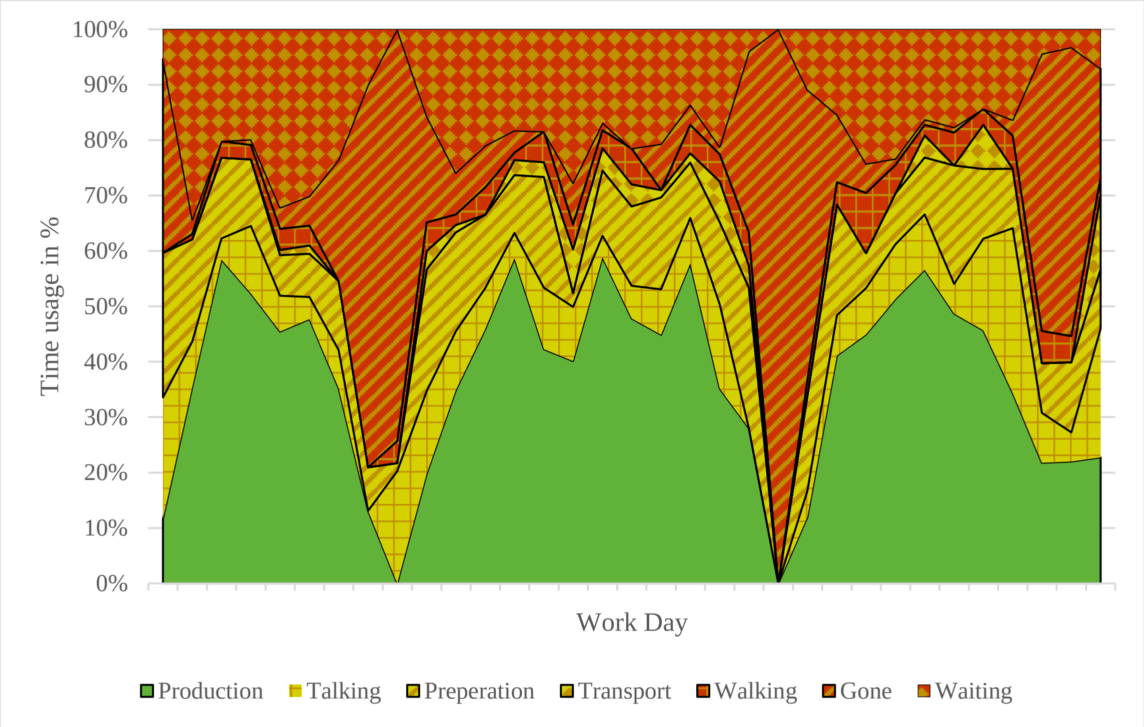

Average

Figure 2. Findings of the Work Sampling Study

As illustrated in Figure 2, the time utilization varies a lot during the work day. The average production peaks, with a direct work rate at around the 60% level, while the mean is much lower. To identify the expected mean, a one-sample t-test is conducted. The values have been cleared form the effect of shifting working hours and breaks, thus having no production during the break is not included in the measures. The result is shown in Table 5.

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Table 5. Calculation of expected mean and identification of confidence interval to the work sample study.

	Expected Mean	Sig	95 % confidence interval		Std. deviation
			Lower	Higher	
Direct Work	.420	.000	.383	.457	.223
Productive	*.420*	*.000*	*.383*	*.457*	*.223*
Talking	.104	.000	.081	.128	.012
Preparation	.146	.000	.123	.170	.012
Transport	.021	.000	.012	.031	.005
Total Supportive	*.272*	*.000*	*.239*	*.305*	*.198*
Walking	.041	.000	.030	.052	.006
Gone	.074	.000	.049	.100	.013
Waiting	.193	.000	.169	.217	.012
Total Non-productive	*.308*	*.000*	*.280*	*.336*	*.169*

Thus on average 42.0 % of the time usage is found productive, 27.2 % is found supportive and 30.8 % is found non-productive. An average of 42.0 % is very much in accordance with Hwang et al. (2020), who conducted a work study including several different work disciplines, here concrete works in general, had an average productive time at 43.13 %.

Productive vs. productivity

There is an essential difference between seeming productive (direct work) and working with high productivity (Thomas 1991; Josephson and Bjorkman 2013). Nevertheless, the assumption of a relationship between the two is not far-fetched. The significance of this relationship in this specific construction case is tested by coupling the work sampling data with the data from the continuous time study. To remove external influential factors the work study focuses on a single repeating task completed by the same basic crew and with the same supporting elements. Moreover, the two work measurement techniques are carried out simultaneously to measure the exact same production flow.

The expected mean productivity has been identified using a one-sample t-test. The result is presented in Table 6 and reveals a mean productivity at 3.322 elements per hour.

Table 6. Calculation of expected mean and identification of confidence interval to the productivity observed in the continuous time study.

	Expected Mean	Sig	95 % confidence interval		Std. deviation
			Lower	Higher	
Productivity	*3.322*	*.000*	*3.061*	*3.583*	*1.572*

The coupled findings of time spent on direct work and productivity is shown in Figure 3. In the observed cases, it can be confirmed that some sort of relationship exists. Thus, when looking at the repeating task of installing prefabricated concrete elements, the productivity is peaking when the crew members seem productive, thus when direct work is high.

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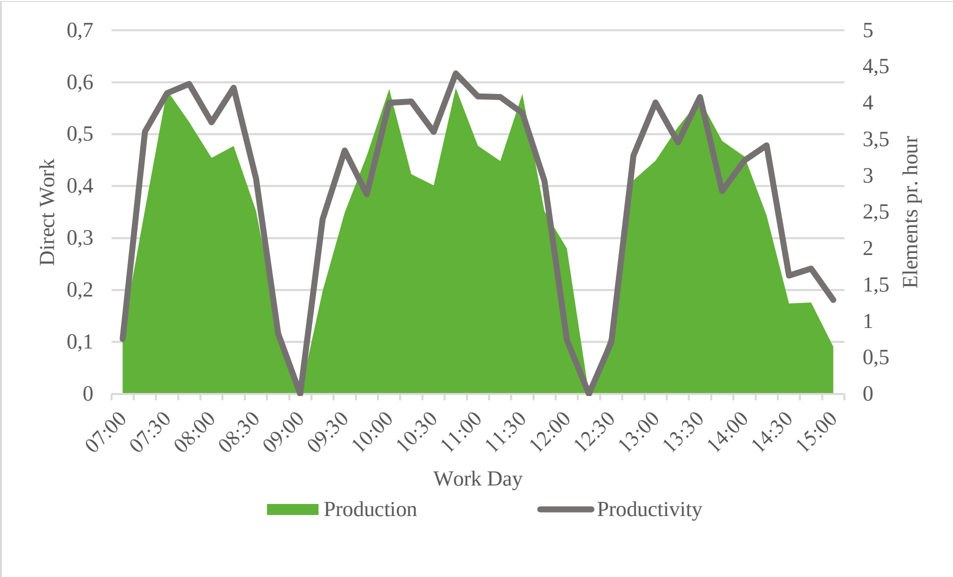

Figure 3. The average productive time coupled to the average productivity

To confirm and determine the relationship between seeming productive (direct work) and productivity a regression test between the two data samples is carried out. The findings are shown in Table 7, and within the present case, confirms the relationship. Actually there is a very strong relationship where the identified coefficient of determination (R^2) is at .827, bearing in mind that Cohen (1988) defined a large effect as R^2 = .25.

Table 7. Linear regression and ANOVA test for the relationship between direct work (DW) and Productivity (Pr). * Significant at the 5 % level.

N	R^2	Linear model	95 % confidence interval		ANOVA p-Value*
			Lower bound	Upper bound	
129	.827	Pr = 7.031 · DW	6.469	7.593	.000

The coefficient of determination (R^2) is a measurement of how much variance in the dependent variable (productivity) is explained by a second and independent variable (direct work). Thus, the findings show that 82.7 % of the variance in productivity can be explained by seemingly being productive.

A plot of the observations and actual fit is shown in Figure 4. The plot reveals that the observations are balanced around the identified linear model, thus the model represents a fine expected mean, even though the residuals often are quite large (but still within an acceptable range c.f. Table 4).

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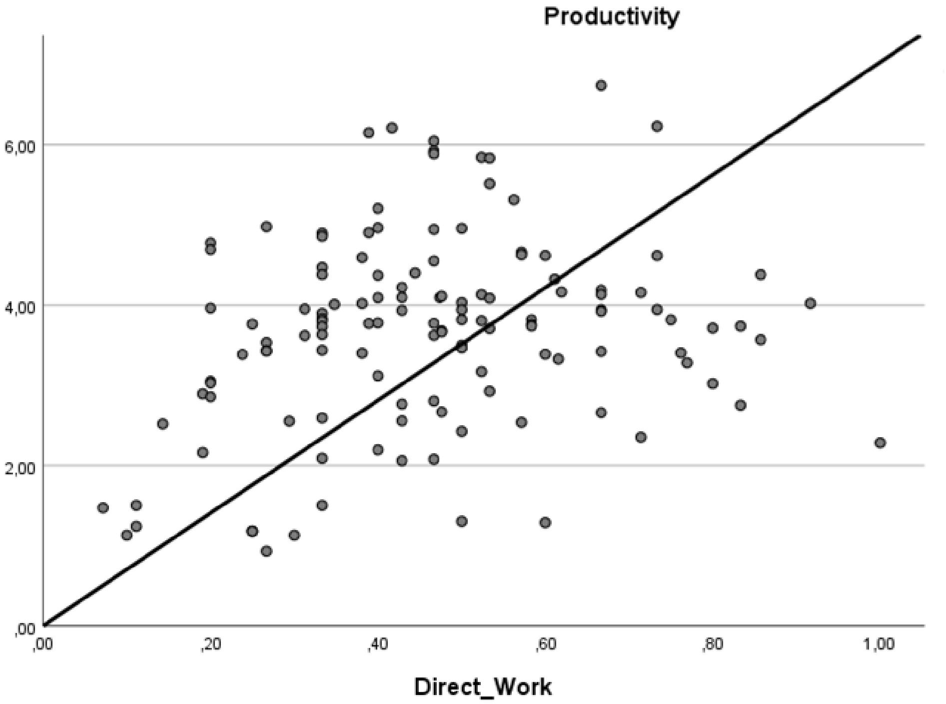

Figure 4. The linear model fitted to the observations of the relationship between productivity and direct work.

Using flow optimization to identify productivity targets

Even though the production flow can be improved it is not possible to reach a direct work rate anyway near the 100 % level. Supporting activities are necessary for keeping a high production rate and making a high quality product. Even non-productive time cannot be avoided, keeping in mind how the process of installing prefabricated concrete elements currently is designed. In the process, the crane is the limiting factor, thus the workers will naturally have to wait for the crane resulting in supporting or non-productive time.

In an attempt to identify the optimal production workflow for this specific installation of prefabricated concrete elements, the average day curves for direct work and productivity have been modified by removing variation, resulting in an optimized day. The low direct work and productivity areas in the day curves are removed and the productivity potential is revealed. To generate a realistic productivity target the low areas have been replaced by highest observed average. The start and stop phase have been adjusted by using the best average measurement as a target, while the high productive phase has been adjusted by using the highest average productivity as a target. The result is shown in Figure 5.

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Figure 5. Optimized day curves for direct work and productivity.

The optimized production flow generates a productivity target with an increased mean direct work rate at .522 which is an improvement at .102 corresponding to 24.3%. Looking at the actual productivity, the optimized production flow increases the productivity target to 3.966 elements per hour, which is an improvement at .644 elements per hour corresponding to 19.4%.

The optimized day curve represents the upper limit for the production flow. Despite that direct work or productivity rates can be higher. The highest measured direct work rate is 1 which is 69.9% higher than the value applied for the high productive phase, while the highest measured productivity rate is 6.74 elements per hour which is 53.0% higher than the value applied for the high productive phase.

The optimized day curve represents an upper limit to productivity, and an ambitious goal which meets the SMART goal criteria. The day curves bring attention to the loss in productivity which occurs during start and stop and when the production flow is interrupted, avoiding these losses needs to be a focus in order to achieve the goal.

Discussion

If actual productivity can be measured, why bother to observe direct work levels? In simple cases productivity can be directly measured by either measuring the time usage per unit or by measuring output quantities. The problem emerges when trying to measure and compare productivity of multiple activities of different disciplines and with different outputs.

One approach has been to measure value creation per input. The value creation is often expressed as value added and is the difference between the sales value of the completed work and the expenses: raw materials, labor etc. (Lieberman, Kang 2008). Even though value creation per input can be compared across activities and disciplines, we cannot necessarily expect that the added value of electrical works has to be the same as for concrete works. Despite both processes being highly effective, marked effects will have a huge effect on both

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purchase and sales prices. Therefore, direct work has been suggested as a measurement for productivity, even though direct work only is stating whether workers seem active or not.

The relationship between direct work and productivity

The regression analysis confirms, when removing other influencing factors, that there, in the observed cases exists a strong relationship between direct work rates and productivity (R^2 = .83) at work-task level. It is important to notice that the identified relationship between direct work and productivity (R^2 = .83), only relates to the specific work task of installing prefabricated concrete elements, at the observed project.

When looking into previous research it looks like there exists a general relationship, which is becoming stronger as the examined activities are becoming more specific. Liou and Borcherding (1986) studied the same type of task, and found (R^2) .64; Handa and Abdalla (1989) studied the same type of work, and found (R^2) between .35 and .45. Thomas (1991) compared different types of work and found (R^2) between .00 and .59 and finally, Hasse et al. (2020) studied macro trends and found (R^2) .20.

Despite the identified and strong relationship between direct work and productivity at work-task level, direct work rates do not seem to be a good predictor of general productivity, because the relationship quickly becomes weak when looking across disciplines. Even though direct work is not suitable as a predictor, it is still an influencing factor and can be used as an indicator to whether productivity is high. Moreover, improving direct work rates will overall have a positive effect on productivity.

The benefits of on-site observations

Observing direct work rates through work sampling brings other observations into play, and can help identify productivity inhibitors. This could both be specific on-site observations (like material or equipment restrictions) or by data-analysis. The day curves can help identify when productivity seems low and the supportive and non-productive categories can help reveal how time was spent and to identify productivity inhibitors. Moreover, presenting and discussing the sampled data can create discussions and reflections that improve productivity (Josephson and Bjorkman 2013).

The on-site observations can, combined with Lean thinking, be used to rethink the process to improve flow and reduce waste (Slomp et al. 2009). In relation to the observations made for the process of installing prefabricated concrete elements:

1) The time to start and stop the production can be reduced by identifying waste and improving the work sequence for instance by applying Value Stream Mapping. 2) The flows of material, equipment can be improved by improving the work sequence, by using pull planning and by focusing on removing production constraints, for instance by applying Last Planner System. 3) High levels of absenteeism is related to high levels of labor turnover which is caused by low job satisfaction (Porter and Steers 1973). Goal setting can be used to foster motivation and increase job commitment. Lean Construction also has the potential to improve job satisfaction, this because improved job-satisfaction comes from a well-planned and smooth workflow and not from job enrichment (Nahmens et al. 2012). A smooth workflow entails reduced variations which also improves utilization of manning and leads to

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improved productivity. Last Planner System is aiming to improve construction planning by reducing inflow variation. 4) The influence of weather can be reduced by shielding the production, or as today by increasing manning, using overtime or as in Last Planner System keeping a buffer of ready work.

The identified optimal state from the case observation is based on the current process, an improved process will enable the achievement of even higher optimal direct work and productivity rates.

Developing and applying productivity targets

Having realistic targets is important to foster continuous improvement (Prather 2005). The developed targets are based on an optimum productivity which is identified by studying and removing variation in day-curves to improve the workflow and reduce waste. In the studied case, the optimum productivity is set to peak at 4.4 elements per hour, with an average daily production rate at 4.0 elements per hour or 28 elements per workday, when, as observed, working 7-hours a day excluding breaks. Although, the production rate will vary from site to site, the variation caused by the influencing factors is expected to be small, for similar processes of installation of prefabricated concrete elements. Even so, the location of the crane and the design of the building would have an impact on the crane's lifting time. With this in mind, the identified optimum productivity can with caution still be used as a target for the production rate for future installations of prefabricated concrete elements.

The development of production targets is directly applicable to managers, as it provides input to the upper productivity potential. Even though the developed target is attainable it is very ambitious. Moreover, the day-curves and optimized day-coves can be a good approach to foster discussions with work crews and visualize wastes and potentials to create a sense of urgency. Involving the crew and letting them participate and contribute to the change strategy will foster motivation and increase goal commitment which is crucial in order to ensure goal achievement and consolidate the change (Leong et. al 2008). During the discussions, it is important to as one unit align expectations, efforts and rewards and to face up to the fact that reaching the overall targets is a long process of continuous improvement. To maintain momentum, and avoid any negative effects of too ambitious goals, the improvement process should therefore, in accordance with change management theory, be divided into small steps to generate wins which can be celebrated along the process.

Finally, the exemplified procedure for using work measuring and productivity day-curves to identify productivity improvement potential and setting productivity targets can be repeated for any type of work, and can be an important approach for construction professionals to initiate continuous improvement at work crew level.

Conclusion

Productivity targets are a necessity for fostering continuous improvement, and should be based on work specific improvement potential. Identifying this potential has proven difficult, which is why targets typically have been developed as overall aims of specific percentage gains. These overall targets have a tendency to become demotivating and regarded irrelevant by the work crews. Good productivity targets must be based on the actual work and the

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potential, therefore, the present study exemplifies how work measurement techniques can be used to develop such targets.

The process of installing prefabricated concrete elements were observed using a work sampling and a continuous time approach simultaneously. To identify the relevance of using direct work as a predictor its relationship to productivity at work task level was examined. By following a well-defined and repeating work task the influence of external factors have been minimized. A strong relationship (R^2 = .83) between direct work and productivity has been established by combining the observations from the work sampling and the continuous time study.

The work sampling study itself revealed an average direct work rate at 42.0%, while 27.2 % of the work time were spent on supporting activities and 30.8 % were spent on non-productive activities, while the continuous time study revealed an average productivity of 3.322 installed concrete elements per hour. Based on the work studies day curves were developed, they revealed huge fluctuations in time usage and productivity. On-site observations revealed four areas where the process workflow could be improved. This can be achieved by rethinking the process and applying Lean Construction methods to improve flow and reduce waste. The four areas were: 1) Reducing the time to start and stop the production, 2) Improve material, equipment flows, 3) Optimize utilization of manning and avoid absenteeism and 4) Shield the production from the influence of weather.

Creating realistic productivity targets are difficult but important for fostering productivity improvement. It has been exemplified how observations, in the form of idealized day curves, where production variation is removed, can be used to identify the improvement potential which can be used as a productivity target for managers’ . The optimized day curves represent upper limits of productivity, which in the observed case yield an improvement of direct work by potentially 24.3%, which, in turn, potentially improves production flow by 19.4%. The actually observed day curves yielded a mean value for direct work of 42.0%, thus confirming earlier studies of concrete work activities.

The study is limited to a single case study following a specific work crew carrying out a specific work task on a single construction site in Denmark. This limits the findings to be case specific and not directly generalizable across projects and trades. The approach of using work measurements to identify productivity targets is directly applicable for site managers as a starting point for continuous improvement.

In future research the same work task can be studied in different projects and with different work crews to identify differences and similarities within the same task. Moreover, different tasks can be studied to make it possible to identify patterns and generalize the findings. Finally, it can be studied if there is a relationship between the complexity of the work task, the direct work and productivity level and the improvement potential.

Data availability:

Data generated or analyzed during the study are available from the corresponding author by reasonable request.

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