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IDENTIFYING THE IMPACT ON LABOR PRODUCTIVITY FROM DESIGN CHOICES THROUGH WORK SAMPLING

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ABSTRACT

Productivity within construction and production is about the relationship between earned value and input of resource value. Researchers have dominantly focused on measuring how the hours are spent categorically in relation to the total amount of hours spent in order to understand productivity. Little has been done to investigate how the decision before execution affects productivity or process durations. Through a case study investigating assembly of cables at numerous locations with similar configurations, two companies are asked to install and terminate cables between switchgear. Their technical design solutions are compared, as the exterior around these is considered homogenous. This allows an understanding of how two design choices affect productivity and process durations. The results show how the design affects the productivity, where both contractors achieve a 25 % value-adding work, while the durations are significantly different- up to a 94 % difference at times. The results are contributing to the practical understanding of technical solutions and how the processes are thought into the design, The results contribute to the literature by raising the question of whether our quality management systems are adequately attuned to this situation.

KEYWORDS

Process, productivity, time compression, waste, work sampling

INTRODUCTION

For decades, construction has had an interest in understanding labor productivity on the national, project, and individual levels (Neve et al. 2020A; Neve et al. 2020B). As measuring productivity requires data from both earned value as output and the value of resource use as input, it is resource-demanding to collect productivity data. Therefore, researchers are searching for other variables that can be used as predictor variables for construction labor productivity. One of these is direct work, which is the share of work time that is used for value-adding activities. Neve et al. (2020A) showed that the relationship between direct work and labor productivity on the national level is statistically significant. Neve et al. (2020B) investigated the same relationship on a

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project level and found in detail the relationship between value-adding and non-value-adding activities and how these impact the productivity through the lenses of transformation-flow-value (Koskela 2000). This relates to the understanding of what causes the activities to be delayed or postponed, which Koskela (1999) addresses as preconditions that need to be met for a task to be healthy, and where Sanni-Anibire et al. (2020) see it as delaying factors, which are factors related to material things (tools, equipment, paperwork, materials etc.) and immaterial circumstances (communication, information, weather etc.). Talking about these delays, Hopp and Spearman (1996) saw the delays as flow and process-time variability, where construction has had a tendency to focus on the process time variability as it is what delays a process that has already started (Bertelsen et al. 2007; Lerche et al. 2020). Multiple investigations have tried to understand the delaying factors and productivity on both individual and systemic levels, dominantly utilizing surveys as their primary source of evidence. But limited knowledge exists about what leads to either the process duration or productivity from a design perspective, and even less is known about how design choices impact the productivity.

This research project investigates the impact of systemic decisions on the individual-level performance. The research question to uncover this is how do the design decisions impact project labor performance? To answer this, this paper first provides insights into the relevant literature and presents the productivity measuring methods from the construction domain. The method section describes case selection, how data was obtained, and how analysis provides results. Last, the discussion explains how the results relate to the relevant literature, providing implications to both practitioners and the literature.

DESIGN IN CONSTRUCTION

From the conceptual understanding of transformation, flow, and value (TFV) (Koskela 2000), it becomes evident that the processes are related to the value. It is known how design is part of the value generation but focusing on the cost reveals that little is known about the effects of either design or managerial decisions on construction productivity. In the design process, the value concept relates to effectiveness and can be incorporated by means of value management methodologies (Wandahl 2004). Whereas in the execution phase, the value concept is about efficiency and buildability, which is addressed in Value Engineering methodologies (Wandahl 2004). This can then be seen from various perspectives, and often it becomes an aim of reducing cost and limiting budget overruns, but as addressed by Koskela et al. (1997), there is more to it than just design management. Not limiting quality to the operator's level but understanding that these can also stem from the managerial level as the design decisions occur long before the operators are introduced on the project. There should be a focus on meeting customer requirements in a trade-off with the objective and schedule goals, which aligns with quality management (Koskela et al. 2019). Ballard et al. (2001) add to this, arguing that the design management should also incorporate reductions of, e.g., process times and rework.

MODULAR DESIGN IN CONSTRUCTION

Compared to regular construction, modular construction strategies provide not only investors but also developers and builders with increased standardization (Peltokorpi et al. 2018). Not only does this enable specific sites (O'Connor et al. 2015), but it also provides opportunities for extended off-site productions providing various prefabricated modules (Song et al. 2005). Wind turbine projects in particular rely on these strategies.

From a design perspective Pashaei and Olhager (2019) revealed the impact from design to supply chains and operations, and Salvador et al. (2002) reveal that this interdependence should be managed. McHugh et al. (2019) show how lean methods and BIM designs can improve the productivity for modular projects. While Innella et al. (2019) instead suggested applying lean construction methods to modular, others applied alternative methods, such as location based scheduling (Lerche et al. 2019; Lerche et al. 2019), takt (Lerche et al. 2022) or last planner (Lerche et al. 2020). Besides the obvious opportunities from repetition, like positively impacting the learning curves for technicians (Thomas et al. 1986) it also allows reaping the fruits of repetition and standardized processes, creating construction flow (Lehtovaara et al. 2020). Design constructability seeks to achieve similar benefits (Fischer and Tatum 1997), and having a constructable program is identified to require less resources (Kog et al. 1999). It is evident that neither regular, modular construction, or the constructability discipline have considered work sampling as a method for evaluating the impact on labour productivity from the design specifications.

HOW IS PRODUCTIVITY MEASURED IN CONSTRUCTION

Productivity is the ratio between output and input volume, whether this is quantified in value, time units, or the relationship between planned and completed tasks. Two of the dominant ways for predicting productivity within the lean construction community include Percent-Plan-Complete (PPC) (Ballard 1999; Gonzalez et al. 2008; Liu et al. 2011) from the Last Planner System (Ballard 2000; Ballard and Tommelein 2016; Lerche et al. 2020). Here, the productivity measures are the ratio between planned and completed tasks (Gonzalez et al. 2008; Lindhard and Wandahl 2011), which is indifferent when applied in modular construction (Lerche 2020; Lerche et al. 2020; McHugh et al. 2019) or any other type of construction (Ballard and Tommelein 2016; Ebbs et al. 2018; Olivieri et al. 2019; Power and Taylor 2019). This method was not pursued further in this case study, as neither of the contractors relied on LPS. The other dominate way is measuring direct work (DW) through work sampling (Josephson and Björkman 2013; Neve et al. 2020; Neve et al. 2020; Thomas 1981). In addition to these, some use motion to identify labour productivity (Barnes 1968), while others again use alternative technologies to identify the productivity (Golparvar-Fard et al. 2011; Kim and Cho 2021).

THE WORK SAMPLING METHOD

Work sampling (WS) is a technique first introduced in 1927 by the British industrial engineer Leonard Tippett in which work can be observed and the amount of time spent on various tasks can be determined (Barnes 1968). In the construction industry, the method was introduced in the 1960s, where H. R. Thomas (Thomas 1991) conducted one of the first WS studies. Currently, WS is being used by some larger construction companies to benchmark their projects so that improvements can be made and quantified. Some contractors have productivity departments or process facilitation departments that complete these studies (Gouett et al. 2011). This could also be done through various type of tracking (Teizer et al. 2020) or motion detectors (Ahn et al. 2019).The WS method categorized the amount of conducted work time into various categories, identifying not only what is perceived to be value-adding work for the customer but also what is considered none-value-adding work, which in other terms could be categorized as waste

(Koskela 2000; Ohno 1988) or reasons for delays (Lerche et al. 2022; Sanni-Anibire et al. 2020). All WS studies apply a DW category. However, when it comes to the none-value-adding work category, the picture is not as clear. Some studies categorize all none-DW time as none-value adding, while other studies have a more detailed view of None-Value-Adding Work, including a number of subcategories. Generally speaking, None-Value-Adding Work time in WS can be divided into Indirect Work (IW) and Waste Work (WW), resulting in Work Sampling having three categories of time: DW, IW, and WW. Thomas (1981) and Josephson and Björkman (2013) indicate a weak or no causal relationship between DW and Productivity. This is mainly due to the fact that WS does not consider the output, i.e., how much or how fast work is done. In contrast, a recent review by Neve et al. (2020) does, however, show that many studies have identified a statistically significant correlation and causal relationship between DW and productivity. This study takes the same standpoint – that work sampling can provide an insight into team and project productivity. The literature search also made it evident that work sampling has not been utilized previously to understand the impact of technical design choices.

METHOD

The research project was conducted as a case study (Yin 1994), sampling data from project execution in a modular construction setting. As the opportunity arose, the study was inspired by Brown and Eisenhardt (1997), comparing two different actors in order for the study to provide a more rich knowledge of how their decisions during the project design affected the execution productivity. The case selection follows Voss et al. (2002). Still, to ensure internal validity and reliability, the research mixed the data sampling methods not limited to work sampling, but also using field observations, progress data, and interviews with the actors on both operational and managerial levels. Seven interviews were conducted, along with a process workshop before execution with both companies. The case conditions are outlined in Table 1, allowing individual and combined evaluation of the companies (Gibbert et al. 2008). The external validity was established through discussion in relation to the literature and practically showing the results to the company management actors to gain their view brought forward as well.

BASIC CASE INFORMATION

The case investigated is a cable termination scope of a more significant modular construction site. The contract is awarded based on bids, with a contract sum around 2-3 million EUR each. Both contracts are well-known tier 1 contractors with at least 13 years of experience within the field. But with two different approaches to the management of such a contract, the case was chosen to compare technical and organizational details. Table 1 shows the number of locations each contractor handles, their contractual forms, and their technical solutions for fulfilling their contract.

Table 1. Case conditions.

Category	Contractor A	Contractor B
Number of assembly locations	110	55
Contract form	Lumpsum	Lumpsum
Management	Contracted	Permanent staff
Workforce	Independent contractors	Independent contractors
Progress data capturing	Not in place, established for this project	Daily progress system in place
Cable	Ethylene propylene rubber (EPR)	Cross-linked polyethylene (XLPE)
Cable shielding	Required	Not required
Cable Hang off system	Prototype	Standard
Conductor assembly method. Special requirement.	Water blockage needs removal.	No particular actions are required.

The working methods for preparing, stripping, and terminating the cables are similar between the contractors; their risk and method statements have similar descriptions around tools, equipment, and cable handling.

CASE DATA AND ANALYSIS

The data collection combines three data sources. The first two data sources are the primary data of 1) observations (longitudinal studies) and 2) work sampling, with the third data source consisting of secondary data 3) progress reporting from quarter 2 of 2021 to quarter 1 of 2022. —The paper looks at in-depth work sampling studies of two similar locations—the chosen locations only had the differences outlined in Figure 1 for cabling and its equipment. The routing paths and the environment are identical. The studied teams had completed a minimum of 5 locations each prior to the work sampling; Contractor A had chosen two jointers, a fiber technician, and a cable mate, where Contractor B used one jointer, a fiber technician, and a cable mate. The work sampling method followed similar categories as Lerche et al. (2022); Neve et al. (2020); Wandahl et al. (2021), ensuring that working on a specific part of the cable or its equipment was also coded. This study considers work sampling as a method that can provide insights to productivity, and progress reporting could be regarded as related to this method. As the hourly progress reports offer insights into the contractors' hour consumption, which a customer is paying for, these are considered value related. The limitation with the progress reporting compared to work sampling would be accuracy, which was intended gained through work sampling.

Figure 1. Work process steps. (Step 4 was only required for Contractor A’s cable solution, Step 6 included the conductor assembly)

The data analysis is used to illustrate differences between the contractors and the impact of their choices in Table 1. The analytical tools for this are descriptive statistics and percentage calculations. To ensure reliability between the two contractors, we isolated locations with 2-cable ends, which resulted in 90 locations for Contractor A and 40 locations for Contractor B. The additional numbers of locations for Contractor A could be perceived as an advantage from a learning perspective (Thomas et al. 1986) which is seen in Lerche et al. (2019); Lerche et al. (2020).

RESULTS

The results are presented in the following order: first, the work sample study shows the relations between non-value-adding work (WW) and value-adding work (DW) activities. Second, combining both progress data and work sample data to present, 1) location productivity measure, 2) performance comparison: durations of the assembly processes, including specified times for cable preparations, stripping, cable hang-off system, shielding, and conductor assembly (see Table 1) comparing team registrations and work sampling.

PRODUCTIVITY MEASURE WITH WORK SAMPLING STUDY ON LOCATION

Table 3 shows how the two contractors perform on a given location, showing the distribution between the value-adding, non-value-adding, and necessary work performed.

Table 3. Work sampling two identical locations.

Categories	Contractor A	Contractor B
Non-value-adding activities (WW)	118 hrs. (37%)	45 hrs. (28%)
Necessary activities (IW)	114 hrs. (38%)	74 hrs. (47%)
Value-adding activities (DW)	76 hrs. (25%)	39 hrs. (25%)
Number of work shifts	9.3	4.8
Total duration	308 hrs.	158 hrs.

From a productivity perspective, Contractor A and Contractor B have a similar percentage of value adding activities, but Contractor A is almost spending twice the number of hours from a duration perspective. During the work sampling analysis, it became apparent that teams of Contractor A were less prepared for the tasks at hand; there were multiple start-stops for various reasons, like relocating tool parts or waiting for the working space to be free, despite having a management walkthrough of the expected process flow before commencing work. In relation to this, Contractor B had prior to the execution spent time asking the teams to illustrate the sequence of tasks through post-it notes. After a few completed locations, this was followed up by asking the teams for sequence adjustments or sharing of learning across teams.

PERFORMANCE COMPARED

Table 4 presents the full project data view in hours for all the process steps shown earlier in Figure 1, their progress registered duration, and the hours from work sampling as a comparison. The right column shows the difference between the two contractors. Cable preparation was not segregated in the progress data as cable shielding was not included in Contractors B's design, and this is marked. The data monitoring from Contractor B gave them an advantage compared to A, as they (B) constantly reminded their teams of their involvement, questioning progress, and using quality pictures with timestamps as hidden evaluation of the team's performance. Contractor A relied on the customer data interpretations, relying on trust in the teams and their performance reporting without showing greater interest in the progress or durations.

Table 4. Comparison of average process durations, minor delays included. (hrs.)

Process	Registration form	Contractor A	Contractor B	Difference
1. Cable preparation	Progress	Included in routing and termination		
	Work sampling	28:57	42:11	13:14
2. Cable stripping	Progress	26:53	14:45	12:08
	Work sampling	17:04	12:25	4:39
3. Hang off system assembly	Progress	38:36	8:01	30:35
	Work sampling	28:29	6:48	21:41
4. Cable shielding*	Progress	20:16	Not applicable	20:16
	Work sampling	14:00		14:00
5. Cable routing	Progress	82:15	70:41	11:34
	Work sampling	74:34	43:13	31:21
6. Cable termination	Progress	116:20	75:31	40:49
	Work sampling	83:09	38:09	45:00
7. Conductor assembly*	Progress	**	Not applicable	-
	Work sampling	8:10		8:10
7. Finish up	Progress	56:30	9:35	45:55
	Work sampling	53:45	16:17	37:28
Total	Progress	341	177	163
	Work sampling	308	158	150

* Only applicable for Contractor A

**Was reported as part of the termination

The biggest differences are found in the following steps: Step 3- hang-offs systems (30:35 hrs), Step 6 cable termination (40:49hrs), Step 7 finish up (45:55hrs.).

DISCUSSION

To ensure the validity of the results, the results did not rely on the progress data alone, as the understanding came through combining these results with work sampling of randomly selected locations. The differences also allowed the practitioners to question their own team's progress. The difference between progress and work sampling showed an unintended result, raising questions to how supplier and customer relations are handled from a progress reporting perspective. Further research would be required to understand why there is a gap between the two, and whether it intentional or not. The trust and commitment between actors is addressed in LPS, Hämäläinen et al. (2014) for one argues how leadership is also required for performance.

Implications from design

The literature made it evident that construction design has not previously been evaluated through work sampling. The results show that reducing project cost by looking for options which do not require additional on-site assembly or processing, as step 6 for Contractor A shows. This supports that modular construction strategies (McHugh et al. 2019; Peltokorpi et al. 2018) and pre-fabrication can lead to duration reductions (Kog et al. 1999). But as the repetition and standardization should allow construction flow (Lehtovaara et al. 2020), it is peculiar how Contractor A does not deliver massive time reductions. As both contractors have a large number of identical assemblies, the results of Contractor A questions the knowledge of learning curves (Thomas et al. 1986), as these should have been expected to perform better than Contractor B. If not for any other reason, but just through more repetition. It was not possible to isolate the exact reason for this, but the management and the design are seen as key drivers which could be supported by Lerche et al. (2019); Lerche et al. (2020) as they show how increased focus from the management supports the learning curve and its development.

IMPLICATIONS TO INDUSTRY

The results show how the choices during the design phase can relate to durations during the project execution, encouraging one to consider that one solution is to be evaluated at this stage alone, which supports the statements made from a quality perspective by Koskela et al. (2019) and value design perspective by Ballard et al. (2001). But it also raises the question of whether the focus is on the right things with defined productivity measures, as the results show that teams can be productive and have long durations simultaneously. This supports the arguments from Thomas (1981) and Josephson and Björkman (2013), which shows that productivity can have a weak link to output, resulting in 25% value-adding with a duration difference of 94 %, which emphasizes the necessity of focusing on technical solutions and their assembly complexity early in the project development phase.

LIMITATIONS TO THE STUDY

The focus was on understanding the difference between the already chosen technical solutions and how these affected the productivity, meaning that the progress reports from the teams had a focus on hours spent in total within each process steps. As the focus was on overall process times, the waiting times were not further specified during the selfreporting, as seen in Lerche et al. (2022); Lerche et al. (2022). The work sampling studies revealed a broader view on the delays that affected the productivity other than the start-stops it caused. A proposal for future research would be to follow the technical solutions from the design phase to the instalment and later through the service life. In particular, understanding if some end-of-life considerations were made in relation to one technical solution over another.

CONCLUSION

The study showed how the design choices affect productivity, partially if the value-adding activities and necessary work related to these activities are affected. While it showed how the design choices significantly affects the durations of the task, the results also show how it is possible to measure the impact of design choices directly with productivity measures, such as work sampling. The results are seen as way to inspire new questions within both the academic and practical domain, and where else can we use work sampling to measure productivity. Has the method been exploited, or could an expected time per assembly be evaluated through this method, not accepting status quo? Further research would be required to understand other areas of interest from design to execution.

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