MEASURING WASTE AND WORKFLOW IN CONSTRUCTION

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ABSTRACT

Applied to continuous improvement work in a construction site setting, a way to operationalize workflow measurement in the construction industry is proposed in this paper. Our conceptualisation uses the metaphor of a river. This river flows with a certain smoothness, intensity and quality (more or less turbulently). The water represents the man-hours available to the employer – which are divided between productive work (direct work, indirect work, planning and HSE work); and waste (e.g. rework, waiting and other forms of downtime). We distinguish between observable and hidden waste. Hidden waste is tied to the potential improvement of methods used in transformation work and indirect work. Our conceptualisation draws on the OEE (Original Equipment Efficiency) concept from manufacturing.

For practical reasons, work intensity is assumed constant. Thus the work pressure is even, but the tasks are not necessarily productive. Observable waste, except rework, relates to the smoothness of the river; rework relates to its quality.

Flow was measured through observations and self-reporting. All workmen involved in a construction project over time, e.g. for one week, fill in a form estimating their time use, including the daily time loss and its causes. The principle is to detect "making-do" and other sources of waste or downtime. Suspecting that a time ratio cannot produce enthusiasm whereas time reduction can, low values for wasted time are to be interpreted as good flow. Sufficient data validity depends on staff training and motivation.

A period of measurement culminates in a joint meeting with the workmen. This is where continuous improvement comes in. Results are discussed, efficiency improvement measures identified, and action plans prepared. Later, e.g. another two months into the project period, new measurements are made, and the figures are followed up with reflections about further improvements.

KEYWORDS

Workflow, waste, measurement, continuous improvement

INTRODUCTION

Two different construction projects can produce an acceptable profit for the contractor even if one is for a good price but with badly run operations, and the other is for a bad price but is well run (Kalsaas 2012) – for instance if the latter is managed according to the principles of the Last Planner System (Ballard 2000; Kalsaas and Sacks 2011). This shows the central importance of developing tools for measuring how construction projects are run, in order to establish a basis for making

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improvements while the project is in progress. In this paper we focus on a method for measuring workflow based on smoothness and the attributes of quality and intensity of work. The work is part of an on-going research project and builds on a series of works previously presented in IGLC contexts (Bølviken and Kalsaas 2011; Kalsaas and Bølviken 2010; Kalsaas 2010, 2011, 2012). Bølviken and Kalsaas (2011) focussed on how to understand and measure workflow, listing a series of alternative approaches to its quantification. Building on this and the other previous works, Kalsaas (2012) introduced some new ideas, using OEE (Overall Equipment Efficiency) as a basis for the discussion of how to measure workflow in building site production. In the Last Planner System (Ballard 2000), flow is understood as reliable handoffs of work between trades, or expressed as the "movement of information and materials through a network of production units, each of which processes them before releasing to those downstream" (Kim and Ballard 2000: 8). Shingo (1988) distinguishes between operation flow and process flow. Process flow is the flow of materials, which corresponds to Ballard's and Kim and Ballard's definition of flow.

The present paper is founded on a different understanding. This understanding of workflow, discussed in Kalsaas and Bølviken (2010), and Kalsaas (2011, 2012), is tied to Shingo's "operational flow": "that is, the flow of work operations performed by the workmen, such as different forms of direct work (transformation), and tasks which constitute indirect work. However, reworking, waiting, and so on, are also among the activities described as operations in construction (…)" (Kalsaas 2011, 2012). Shingo defines both process flow and operational flow as consisting of processing (direct work), waiting/delay, movement/transport, and inspection. This subdivision is probably appropriate for manufacturing, which is Shingo's main focus area. However, in the construction context we find these categories to be too narrow, as the workmen in the building and construction industry perform a wide selection of tasks that cannot be fitted into Shingo's taxonomy (Kalsaas 2011). In this paper, we develop the ideas presented in Kalsaas (2012) further. We clarify the concepts, and present some new empirical material in order to demonstrate the method. The premise is added that flow cannot be understood without an understanding of waste, and vice versa.

Shingo (1988) argues that the process takes precedence over operations in manufacturing. In other words, it is not the operation of each work station that needs to be optimized, but the flow of material. This can also be identified as a central thesis of the Japanese ideas underpinning lean production in manufacturing. In our study we break with this thesis, and argue that operation/workflow represents a more promising approach for construction which also addresses flow within trades and disciplines. If we succeed in the efforts to reduce downtime, identify smarter ways of working, etc., the work process will be more predictable, and the process flow also improved. However, measuring process flow can also be a supplement to workflow, and to identify why there are delays in handoffs of work. To some extend overall process flow is already being measured in construction by the Earned Value method.

Drawing on deductive as well as inductive methods, a theoretically oriented approach is applied to the results of a case study in this paper. The data was collected through direct observation and questionnaires. One of the objectives of collecting data through observation was to enable benchmarking of the results gleaned from the questionnaires. The emphasis of the paper is on analysing the observation data.

CONCEPTUALIZATION OF WORKFLOW AND WASTE

The OEE method uses available working time – i.e. what remains of the work hours when agreed breaks are subtracted – as the starting point. Operation time is the available working time when downtime losses are subtracted; net operation time is the operation time after subtraction of speed losses; and value creating time is set as net operation time minus defect losses. Thus, value-creating time is determined by available working time minus downtime, speed and defect losses. The OEE method is linked to continuous improvement, TPM (Total Productive Maintenance), and lean production within manufacturing (Nakajima 1988; Bamber et al. 2003; Jeong and Phillips 2001; Cua et al. 2001). The value concept is addressed below.

Kalsaas (2012) relates OEE to construction and argues that waiting time for crane etc. can be defined as downtime losses; extra rigging (up and down) and associated preparations, clearing to allow access to workplace, etc. can be defined as speed losses; and time use associated with rework can be defined as defect losses.

In the further conceptualization work, we use as our basis all of the work performed within working hours from clocking in to clocking out, minus regulated breaks, as defined in the OEE concept. We can use the metaphor of a river (Figure 1). All of the work flows downstream. It starts with the clocking in every morning, and ends with the clocking out every evening (for day work). The flow of workflow can be divided into different categories. Shingo (1988) defines both process flow and operational flow as consisting of processing, waiting/delay, movement/transport, and inspection.

Construction work is often far more diverse than assembly line or machining work. Furthermore, the objective of this work differs somewhat from the focus defined by Shingo. We therefore categorize this work in a way that differs somewhat from Shingo's definitions, and go into much greater detail. Construction work is thus divided into the following main categories:

- "direct work" (transformation and documentation/inspection);
- "indirect work" (physical preparation)
- "planning, coordination and HSE" (conceptual adaptation and safety)
- "observable waste" (waiting, rework, etc.)

With regard to Shingo, his "processing" category is the same as our direct work. We include his "inspection" category in our definition of direct work since we are also concerned with value. Inspection and the documentation associated with it we claim is part of the value generation, and in some trades constitute an absolutely necessary part of the construction product, for example in terms of the documentation of "as built", material commissioning and quality control documentation. Shingo's "movement/transport" category is included in indirect work.

We have chosen to describe Shingo's "waiting/delay" as "waste" although this is a normative description, which is something we generally seek to avoid. Our waste concept also includes other categories of activities and downtime, as explained below.

The waste categories are hampering elements in relation to workflow; furthermore, our research interest is tied to waste in construction, and waste and workflow are inextricably connected in on-site production. We have chosen to include rework as a category of waste, although the actual waste is the faulty work (for whatever reason) originally performed, not the correction of these mistakes in the shape of rework. Moreover, we include “compensational work” in the waste category. Compensational work is particularly relevant in relation to steelwork, when prefabricated parts and components do not fit. The installers may have to widen an opening in a steel sheet or concrete wall, compensate for great inaccuracies in the steel foundation for machinery, or they may have to move a pipe-support welded to the wrong spot.

All categories are broken down into a detailed set of activities, especially with regard to direct and indirect work. Such detailing of indirect work, especially if there is much of it, can be particularly relevant with regard to lean-oriented improvement work. Also, reducing the extent of waste is, naturally, a main focus of any such improvement work. We have earlier discussed how to operationalize workflow, arguing that its operationalization must include the dimensions of smoothness and throughput/productivity (Kalsaas and Bølviken 2011; Salthaug and Sørensen 2010), since good flow is of little value unless accompanied by good throughput. The idea of integrating a “quality” dimension into the operationalization of workflow emerged in student work connected to this project (Ellingsen and Fredriksen 2011). This idea is consistent with our discussion above on how to integrate ideas from the OEE method into our goal of operationalizing construction workflow. The extent of rework needed in construction reflects the quality of construction site production as such; in the river metaphor, such rework can be associated to turbulence.

The dimensions of smoothness and quality have been retained, but throughput/productivity has in the meantime become the revised category of ‘work intensity’ (Kalsaas 2012). The background for this revision was insights derived from empirical studies on time-use during working hours (op.cit). The fact is that work throughput may constitute only some 50 % of the direct transformation work, but this does not necessarily mean that those performing the work are not working hard. The point is to work with the right tasks, work smarter. This includes adapting conditions in such a way that the proportion of direct work increases by making activities sound, as done in the Last Planner System. Hence work intensity is best related to a river’s water velocity. One approach might have been to look at work throughput minus visible waste as a measure of this dimension, but this would have been tantamount to approaching a measure of workflow as such.

For practical purposes, we assume that work intensity remains constant over a measuring period, for example of one week’s duration. We know, however, that motivation varies between workplaces according to factors such as management and local culture (e.g. Schein 2006), but we have no reason to assume that there is significant short-term fluctuation in motivation, although anyone can have an off day. The improvement achieved by eliminating or reducing some waste components, e.g. waiting for information and rework, can lead to increased motivation and work satisfaction. Conversely, unsystematic empirical knowledge suggests for example that rework can harm work motivation.[2]

[2] In one example from southern Norway, a new shop was being built. When the client decided to make radical changes to the layout, extensive floor areas had already been tiled. All of the tiles had to be removed in order to redo the cables and plumbing, before new tiles were laid. An observer from the contractor relates that “the workers’ motivation sank like a stone” when they were asked to do the work all over again.

One of the goals of this work is to retain the concept's intuitive character (Kalsaas and Bølviken 2010). Questions like "has there been a good flow to today's work?" seem to make sense, especially in terms of whether the work could be conducted without bother such as waiting (beyond an expected minimum) or lack of necessary information etc., confer Table 1.

Based on the above, we define workflow as follows: *Workflow in construction site production is all types of work conducted within available working hours – except obstructions such as downtime, rework and other forms of waste subtracted. Smoothness is expressed through the absence of downtime; quality through the absence of rework; and work intensity is assumed constant for measuring periods of approximately one week's duration.*

Workflow can be calculated thus: "*100% (Man hours at employer's disposal – Wasted time) / Man hours at employer's disposal"*. The most important point in the measuring method is to direct the focus towards continuous improvement; for purposes of analysis, however, measuring can be a useful tool.

Furthermore, waste in construction site production is understood as work and work-related activities which do not add value to the construction under erection in the shape of transformation value, necessary preparations (indirect work, coordination, etc.) for value generation, or documentation of technical quality with regard to the owner's specifications and government regulations. Thus, our value concept primarily focuses on value in terms of the companies/builders who do the work, not on customer value, although the concepts are not mutually independent. Value for those who do the work is seen as good use of manpower and equipment and adjustment of the work in ways that maximize efficient use of resources, including minimal waste of working hours. However not by intensify the work but by removing hindrances as delays and waiting, which we assume to be irritating for the operators.

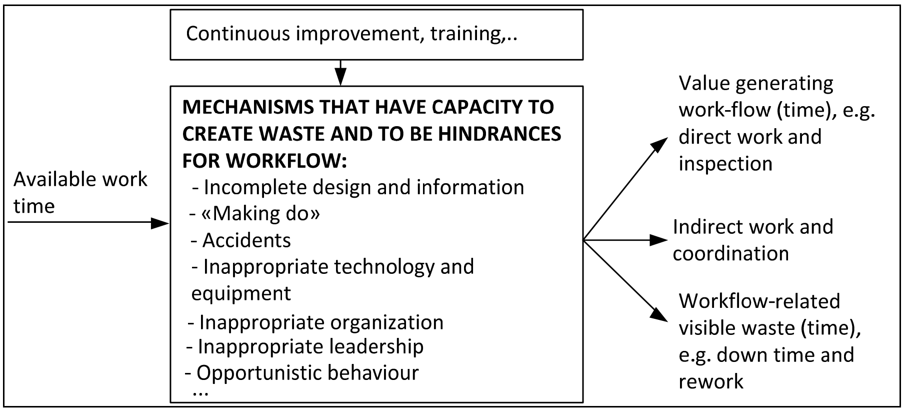

Figure 1. A conceptual model for understanding workflow and waste[3]

Figure 1 seeks to illustrate our conceptual understanding of waste and flow. This figure emphasizes the causes for waste generation with a direct impact on the workflow. The improvement work seeks to manipulate and influence the mechanisms capable of producing waste.

[3] Inspired by discussions in the UWC group "Understanding waste in construction" (Frankfurt, March 4-5, 2013), attended by Rafael Sacks, Carlos Formoso, Daniela Dietz Viana, Patrick Dupin, Lauri Koskela, Sigmund Aslesen, Trond Bølviken and the author of this paper.

The method of measurement explained below is based on the case study method (Yin 2009), and its purpose is not statistical, but to aid analytical generalization; it is part of a continuous improvement process where measurements are used to identify short term and longer term improvement measures – measures which are then followed up with concrete implementation in order to bring about improvements in the ongoing project. The measurement data exemplify waste and flow in the conditions of the given context. This approach must not be confused with the Taylorist tradition of surveying the work process in order to achieve work intensification[4].

MEASURING WORKFLOW IN CONSTRUCTION

Operationalization of the measuring method/instrument should take into account the trades involved. The measured example is taken from mechanical work: the building of steel constructions which are part of offshore drilling systems where the floating unit is a ship or a platform. The engineering and construction tasks include drilling decks with heavy drilling equipment distributed across several stories, as well as mud modules and derricks. Such systems involve extensive pipe systems for pressure regulation, drainage and hydraulics. The pipe systems are prefabricated in the company's workshop before installation. This kind of production system is subject to major changes during the production phase, often generated by the client via engineering (Kalsaas 2013). The collaboration across trades that is required in order to ensure access to the different module locations represents a considerable challenge.

The measurements reported here were conducted within pipe installation over two one-week periods six weeks apart. Two students observed two operators continuously throughout the working hours every day during the measured periods. Thus the measurements cover two periods of 10 days' work, i.e. a total of 20 days' work. The data was collected through registration of observed activity every 5 minutes throughout the day. The activity at each point was generalized to apply for a full 5 minutes. The categories used in the observation approach largely emerge from Figures 2-3 (Koland and Lande 2013).

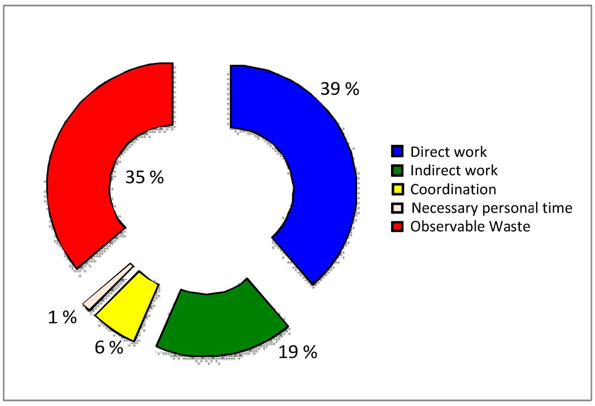

Figure 2. Combined results for two one-week measurement periods four weeks apart

[4] We have not succeeded in finding references to such works in academic sources.

Since there were only small differences between the measured periods, only the aggregated results from both periods are presented here. Figure 2 shows the activities during available work hours distributed between the main categories. This is followed by detailed results for the categories of indirect work and waste.

The aggregate results in Figure 2 show that more than one in every three hours of performed work is registered as observable waste. Figure 3 distributes the waste according to categories. We see that work-related downtime constitutes nearly 45 % of the total, and rework 30 %.

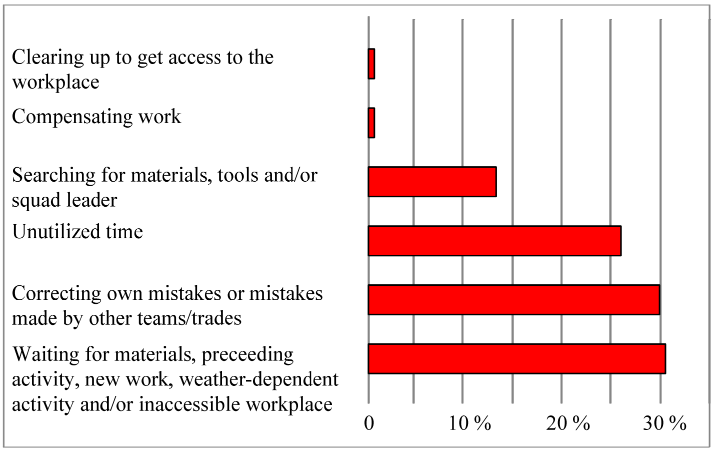

Figure 3. Distribution of waste categories

Direct work is constituted by 72 % “Direct transformation work” and 27 % “Inspection and control”, whereas “Crane operations etc.” constitutes 1 %. 44 % of the time used for indirect work was spent “transferring between places of work”; 25 % of it was spent “collecting materials/tools from a distance of more than 5 m”. This indicates a potential for improving the way the work is organized in addition to minimizing observable waste.

As part of the measurement regime, a two-part data collection from all of the members of the measured team was conducted. In the first part, the participants were invited to make suggestions for improvements, and a range of measures were suggested. Contrary to the intentions of this method (cf. Figure 1), however, no systematic improvement measures were implemented on the basis of these suggestions. We underestimated the effort needed to achieve this in the reported example.

In the second part of the data collection based on self-reporting, the workers of the team were asked whether they had experienced delays tied to concrete questions about the soundness of activities, and “making do” and other factors. If the answer was positive, the respondents were asked to estimate the lost time. The results, to be published in more detail at a later date, show relatively good correlation with the data collected through direct observation.

Table 1 below shows relatively good correspondence between directly observed waste and waste reported by those who were observed, particularly for the first period of measurement. The team as a whole seemed to under-report wasted time during the first period, but we cannot know for certain: it may be that the work of those who were not observed involved less waste. The discrepancy between observed and self-reported waste is somewhat larger for the second measurement period. The striking fact is that those who were observed report more wasted time than suggested by the observations. We had expected the opposite to be the case, as one cannot expect people to report unutilized time – of which there is a good deal – as waste. We also need to keep in mind that the figures for self-reported waste are based on each worker's estimate of his time-use; the figures resulting from the observations are therefore significant more accurate.

Table 1. Comparison of self-reported and observed waste

Measuring method/Group	Measurement no. 1	Measurement no. 2
Waste reported by those who were observed, four pipe operators in 10 days (sum)	42 %	38 %
Directly observed waste, four pipe operators in 10 days (sum)	40 %	32 %
Self-reported waste for the whole team (12 operators) (sum)	25 %	30 %

RELIABILITY AND VALIDITY

Reliability is a question of to what extent the collected data is influenced by the method of collection. The data was collected by fifth-year master's degree students. They were given proper training in the method, and maintained close communication both with supervisors and the observed. It is not always possible to understand what is going on during observing without asking those who are being observed.

In terms of the self-assessment forms, we can expect weaker reliability, but good correspondence between registered (observed) and self-reported waste indicates strong reliability. A meeting for everyone participating in the survey was arranged before and after each registration period. In addition, the students were there to assist the respondents while they filled in the self-report forms. The respondents were given time off to fill in the forms during working hours.

Validity is a question of whether the developed concepts for workflow and waste are helpful with regard to describing the phenomena and processes they are meant to capture. We do not claim that the concepts are applicable to all work conducted during a construction process; only to the actual construction-site production. Measuring waste in construction site production gives us limited insight into the mechanisms that generate waste. Large resources being spent on rework could for example be a result of initial production being based on the wrong drawings. Whether this was generated by internal non-conformance or by the owner's wishes is difficult to tell without close communication with the foreman, and perhaps also the operations manager. Rework caused by change order is in reality value generation, not waste for the producing companies in question.

The regime of conducting measurements during two separate periods has its inbuilt weaknesses. These are due to the fact that the setting is by no means a laboratory situation. Thus the measuring is subject to variations in contingent and contextual conditions. The limitations are tied to the interpretation of the measuring results in terms of whether improvements can be detected compared to the previous measuring period. In order to improve the validity of comparing different periods, the survey form used for subsequent periods could be expanded to include questions on whether or not the operator perceives an improvement in workflow after the commencement of improvement work. Such a survey would cover a period that extends beyond the period of direct observation (measurement).

The measuring of unutilized time may contain a weakness related to the precondition of invariable work intensity. For example, it may be the case that an extra effort is made to try to finish a task by the end of the day, resulting in task completion may be 30 minutes early; in which case the natural thing to do may be to relax until it is time to clock out and go home for the evening. The same mechanism may occur when the operators prolong their lunch break after working hard. Extra cold or bad weather may have similar effects on the need to take additional breaks. If the communication is good enough between the observers and the observed, such weaknesses in the measuring instrument can, however, be compensated for.

In our theoretical perspective, the developed method is analytical generalizable for project organized construction; the empirical findings, however, are not.

CONCLUSION

Workflow in construction site production is understood as all types of work conducted during available working hours minus obstructions in the shape of downtime, rework and other forms of waste. Smoothness tends to be expressed through the absence of downtime; quality through the absence of rework; and work intensity is assumed constant for a measuring period of approximately one week's duration. Furthermore, waste in construction site production is understood as work and work-related activities which do not add value to the construction under erection in the shape of processed value, necessary preparations for value generation, or documentation of technical quality with regard to the owner's specifications or government regulations.

The helpfulness of the method of distributing the measuring workflow and waste between two separate periods linked by an intervening period of systematic improvement work has not yet been fully tested in practice. However, the trial attempts so far seem promising, especially because the self-reporting method appears to produce sufficiently reliable results on its own. In order for this to be the case, however, motivated staff and a positive attitude towards improvement are necessary – as indeed seemed to be the situation in the case company. The actual method/instrument of measurement is primarily suitable for improvement work, not for measuring absolute differences between two points in time, since the contextual framework is subject to variations. Further development of this method should focus on better capturing the causes of obstructions to workflow and the associated waste.

ACKNOWLEDGMENTS

This paper is part of the research project “Involverende planlegging” (“Inclusive planning”), which is partially financed by the Norwegian Research Council. The research project owner is Veidekke Entreprenør. Veidekke Entreprenør AS is a Norwegian subsidiary of Veidekke ASA, a major Scandinavian construction and real-estate development company.

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