FURTHER WORK ON MEASURING WORKFLOW IN CONSTRUCTION SITE PRODUCTION

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ABSTRACT

This paper focuses on the operationalisation of workflow. It builds on and expands work conducted in relation to a research project on this topic. The OEE (Overall Equipment Efficiency) concept from the manufacturing industry is discussed and applied to the context of building production. From this discussion, ideas are derived for how to measure the workflow. A premise for the discussion was to include smoothness and quality as well as throughput in the operationalisation of workflow, and to give priority to continuous improvement.

The solution suggested as a preliminary conclusion in this paper is based on a workplace survey related to downtime losses, speed losses and defect losses. The intention was to identify time losses in the production according to its different causes, such as the seven flows, "making-do" and rework. The conclusion of the discussion is that unlike the focus of the underlying research project, our operationalisation of workflow should not be based on productivity or throughput; rather, it should focus on work intensity. Work intensity is assumed to be approximately constant, but even with constant work intensity, things are not necessarily done as they should be done, and the tasks are not necessarily sound. The potential for improvement therefore lies in implementing the clarifications built into the Last Planner System. Data from the workplace survey provides the basis both for calculating workflow, and for discussing improvement work at the construction site with reference to concrete examples.

The present study contributes towards creating a better understanding of the nature of workflow, and of how it can be measured.

KEYWORDS

Construction, workflow, OEE, quality, intensity, throughput, productivity, earned-value method

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 – 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 improvement work.

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Historically, many attempts have been made to measure construction sector productivity. However, what these attempts have in common is that the measuring instruments tend to be either too complex, or impractical in other ways. In this paper we focus on a method for measuring workflow based on smoothness and the attributes of quality and throughput/intensity/productivity. The work is part of an on-going research project and builds on a series of works previously presented in IGLC (Bølviken and Kalsaas 2011, Kalsaas and Bølviken 2010, Kalsaas 2010, 2011).

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, the present paper also introduces some new ideas. OEE (Overall Equipment Efficiency) is used as a basis for the discussion of different ideas for how to measure workflow in building site production.

Kim and Ballard (2000: 8) build on the Lean Construction Institute's (1999) understanding of workflow, as the "movement of information and materials through a network of production units, each of which processes them before releasing to those downstream". This kind of definition can be associated with process flow as described in Shingo's works (see, e.g., Shingo 1988). The present paper is founded on a different understanding. This understanding, discussed in Kalsaas and Bølviken (2010), and Kalsaas (2011), is based on Shingo's idea of distinguishing between operation and process. Furthermore, workflow 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: 2). 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. We return to this point below, in the discussion of smoothness.

The paper is organised as follows: First, the OEE concept is presented, followed by a discussion of OEE as it applies to building production. Further focus is then given to the operationalisation of workflow. A building site survey plays an important role here. Challenges associated with data reliability and term validity are discussed before, finally, a conclusion is offered.

OEE AND BUILDING SITE PRODUCTION

OEE CONCEPT

Nakajima (1988) introduced OEE as a method for measuring the productivity of industrial production. It was part of the Total Productive Maintenance (TPM) framework, and its suggested use was to evaluate TPM progress. It was also proposed as an aid to achieving zero loss production. OEE identifies efficiency loss caused by activities that absorb resources without contributing to value creation (Jeong and Phillips 2001). According to Bamber et al. (2003) this makes it a good tool and a sound basis for continuous improvement work. Nakajima (1988) argues that TPM represents an approach to maintenance work which focuses on continuous improvement aimed at maximising production and achieving the best possible and most efficient use of equipment. Jeong and Phillips (2001) describe TPM as a work incentive, and as a preventative maintenance system that involves all divisions and functions of an organisation in the effort to maximise equipment efficiency. According to Cua et al. (2001), the concept of TPM is a critical supplement to lean production, manifest in its influence on the production process through its impact on equipment availability, production rhythm, and production quality.

When Nakajima (1988) identified and classified what he regarded as the most important causes of equipment efficiency losses, he took as his starting point three dimensions of efficiency, namely availability (A), performance (P) and quality (Q). He described the following as the six big losses": 1) equipment failure; 2) setup and adjustment; 3) idling and minor stoppages; 4) reduced speed; 5) defects in the production process; 6) reduced yield.

Of the six big efficiency losses, 1) equipment failure, and 2) setup and adjustment, were regarded as time lost on account of the equipment being unavailable for production. The efficiency losses due to 3) idling and minor stoppages, and 4) reduced speed, were identified as disruption of pace that result in reduced production performance efficiency. The last two efficiency losses, 5) defects in the production process, and 6) reduced yield, were regarded as losses caused by quality defects in the production process. Bamber et al. (2003) explain that the six big efficiency losses are measured in the shape of OEE, and that the measured OEE is a function of the three efficiency dimensions. Nakajima (1988) defines OEE thus: $OEE = A_{eff.} \times P_{eff.} \times Q_{eff.}$

Muchiri and Pintelon (2008) studied how the development of the practical application of the OEE tool. They found that its application varies between different industries, and that different companies have adapted the original OEE concept to the specific needs of their organisation. The measuring method now includes production losses that were not part of Nakajima's (1988) original OEE parameters. Other differences in terms of what losses are now included have also emerged. These differences make it difficult to use OEE as a benchmarking tool when two or more companies are involved. However, it has retained its value when it comes to its most important function, namely as a tool in continuous improvement work. This use of the OEE concept and method is also its most interesting aspect with regard to the topic of this article.

MANUFACTURING OEE CONCEPT AND BUILDING SITE PRODUCTION

Figure 1 illustrates the components which are part of OEE calculations, and the connections between these components. "Equipment" is too narrowly defined for our approach, which seeks to measure workflow in building site production. Our focus is on the production system. Likewise, "Loading time" is of limited use, since it is tied to Equipment. One possibility is to replace loading time with "Available working time", which would allow us to define "Operating time" as the available working time minus total production Downtime/Waiting. Next, we can define "Net operation time" as Operating time minus time loss due to "reduced speed", and "Value creating time" can be defined as net operation time minus time loss caused by defects. This is illustrated in Figure 2.

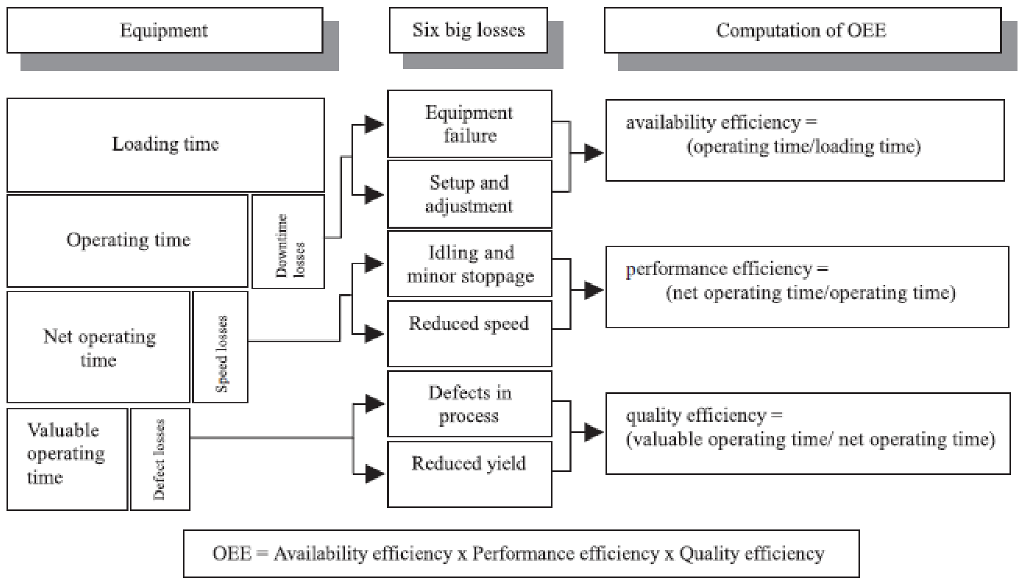

Figure 1: Illustration of the OEE method related to equipment, the six big losses, and computation (Nakajima 1988, Jeong and Phillips 2001)

Available working time			
Operation time			Downtime losses
Net operation time		Speed losses	
Value creating time	Defect losses		

Figure 2: Illustration of the OEE method applied to construction work

Available working time is the number of working hours multiplied by the number of employees minus lunch breaks and other agreed breaks. Table 1 identifies the potential empirical contents of the loss concepts.

Table 1: Time losses related to OEE in construction

Downtime losses	Waiting for crane, materials, etc.
Speed losses	Extra rigging up and down and associated preparations. Clearing to allow access to workplace, etc.
Defect losses	The work quality. Time consumed by reworking

We have earlier discussed how to operationalise workflow, arguing that its operationalisation must include the dimensions of smoothness and throughput/productivity (Kalsaas and Bølviken 2010), since good flow is of little value unless accompanied by good throughput. The idea of integrating the dimension of quality into the operationalisation of workflow emerged in student work connected to this project (Ellingsen and Fredriksen 2011). This idea fits into our discussion on how to integrate the OEE method into our goal of operationalising construction sector workflow, and leaves us with three workflow dimensions: its smoothness, its intensity, and its quality. Rather than develop an OEE suitable for benchmarking purposes, our ambition from this point onwards is to operationalise a workflow concept whose primary purpose is to function as a tool for continuous improvement work.

IDEAS OF HOW TO CLOSE IN ON AN OPERATIONALISATION OF WORKFLOW

Workflow Smoothness

The degree of workflow smoothness in construction work can be understood in a straightforward manner. How much waiting, how many delays, and how much general downtime and losses due to rework slowed down the process? Relatively few disruptions of this type is an indication that the work is running smoothly. Such smoothness can be expected to correlate with an intuitive experience that the workflow is good.

In Kalsaas (2011) the figures for workflow and smoothness are based on a detailed data sampling method, where work-related activities performed during the working day are categorised into the following aggregated notions: direct work (transformation); indirect work (rigging etc.); coordination and safety; rework and unutilised time; and personal time. This categorisation is used as a basis for the discussion on how to calculate workflow.

The present paper pursues a different path, however. It is based on the workmen's own daily assessments of workflow related to the seven flows, i.e., the necessary preconditions for work tasks to be categorised as sound (Koskela 1999; Bertelsen et al. 2006, 2007). In this approach, the workmen are asked whether the tasks they faced during the day were delayed in terms of a series of reasons related to the seven flows (Table 2). They are also given a supplementary question tied to making do (Koskela 2004) and rework. For each question where they confirm that there has been time loss, they are asked to assess how much time was lost.

Table 2: Possible reasons for delay/downtime during a working day

Preceding activity was not finished in due time
Preceding activity failed to meet the quality standard, which includes it not being completely finished (done-done)
The work area was inaccessible due to other work
The work area had to be cleaned up before it was accessible
Lack of drawings, or defective or missing information in the drawings
Other information missing or unclear
Materials with errors, or shortage of materials
Shortage of equipment, or inappropriate equipment
Other cause for delay/downtime in your work

The question tied to making do is as follows: Have you engaged in work today that was not part of the plan when you began work this morning? For rework the question is: Have you spent time today on correcting your own mistakes or mistakes made by others? The idea behind the making do question is that unplanned or unforeseen activities generate a relatively large amount of indirect work related to rigging, transferal, discussion of solutions, studying of drawings, etc.

Unpublished empirical material suggests that carpenters are particularly prone to end up performing unplanned tasks, and that these tasks are necessary in order to achieve flow in the handover between the different trades[2].

In addition to the questions where the respondents give concrete assessments of time losses, they are asked to evaluate the following statement: "Today my work was characterised by good workflow." They tick one of the following answers: strongly agree; agree; neither agree nor disagree (neutral); disagree; strongly disagree. The purpose is to gather a basis for calibrating time losses in relation to the intuitively and subjectively perceived flow.

Quality is included in the workflow concept because rework obviously constitutes waste in a Lean context. Or, more precisely, the defective work that necessitates the reworking constitutes the actual waste. Furthermore, quality is related to value. This is not least the case when hidden construction errors are not rectified or identified before handover to the client.

Quality can be understood as "conformance to established requirements" (Burati et al. 1992, Ledbetter 1994). Non-conformance includes deviation from the requirements that result in rework, as well as products or results that do not meet all of the specified requirements, but are sufficiently satisfactory not to require rework.

Formoso[3] proposes that a stronger emphasis on the aspect of quality should be introduced to the methods of Last Planner and Lean Construction. The main idea is to link quality to the weekly work plans, checking not only whether the planned task has been performed (as in the PCC), but also whether the work has been completely finished ("done-done"), and whether it satisfies the other quality criteria.

Workflow Intensity

Our reason for introducing a measure for intensity is that conceptually, it is possible for the workflow to be good even if the throughput or productivity is relatively weak. Helgesen and Helleland (master's thesis in progress, 2012) are studying whether the earned value method (EVM) is useful here. This method is already in use in the case company, and we want to maximise our use of readily available data. Furthermore, existing alternative methods – such as PPC and the piecework system already in use in the case company (Bølviken and Kalsaas 2011) – also have major flaws.

The EVM uses an integrated cost-schedule concept as a separate means of control, and in this context, cost is easily distorted. For example, it is possible to keep within the limits of a cost budget while at the same failing to produce at the rate needed to

[2] Based on our own dialogue with carpenters in construction companies where carpentry work and concrete work were part of the in-house tasks. A different perspective was presented by a representative of a Portuguese construction company at EGLC 11 (Guimaraes, Portugal) in 2010. This company outsources all of the work to different subcontractors – an approach which makes it more difficult to cover tasks which are located in the interface between different trades. Typically, such tasks can be classified as indirect work, which constitutes 7-41 % of all work in four studied cases taken from Norway (Kalsaas 2011).

[3] Based on ideas presented by Carlos Formoso in a workshop arranged by the Working Group for Understanding Waste in Construction (UWC): 16-17th February 2012, University of Salford (http://prosjekt.uia.no/uwc/). Publication of the ideas and underpinning research is pending.

meet the project schedule. According to Kim and Ballard (2000), the EVM is currently the best available tool for controlling projects when risk related to cost and schedule are partially or wholly vested in a single entity.

Kim and Ballard (2000) are critical of the method in their article "Is the earned value method an enemy of work flow?", however. The vulnerability of the EVM, they claim, is rooted in its framework, "i.e., its assumption that the productivity of each type of work activity is independent of the performance of other work activities, even when they are in a predecessor-successor network" (page 2). Some of this critique stems from the weakness of the work package concept (Elmore and Sullivan 1986), which is based on the presumption that costs can be calculated for each separate element in a work package without taking into account its other elements. Kim and Ballard explain why, in their view, the effects of dependence and variation should be considered, although according to the EVM the variance of each cost account is independent of the others. They demonstrate that the bad performance by trade "B" may not originate in trade B, but in trade "A". Tommelein (1998) addresses the effect of dependence and variation in downstream direction, and Alarcon and Ashley (1999) demonstrate the impact of uncertainty on schedule and cost.

Kim and Ballard (op cit.) point out that the problem with the EVM and other cost control methods is that they fail to include the concept of flow, and thus also flow control; as well as their failure to include the concept of value generation. In doing so, they refer to Ballard and Howell's (1997) argument that workflow can be improved significantly by making quality assignments which shield production from workflow uncertainty.

Combining smoothness, quality and intensity

Data from the workplace survey, partially shown in Table 1, can give us a basis for designing an OEE-inspired structure for time losses, and for losses related to rework (correcting errors). And since we already know the available working time, we can easily calculate the net operating time (Figure 2) as a percentage of the total hours of work. Correspondingly, we can also calculate the value creating time if we disregard net operation time calculated on the basis of reduced speed, which is the more problematic element in this approach.

In earlier works (Kalsaas and Bølviken 2010, Bølviken and Kalsaas 2011) we have focused on showing that smoothness is not by itself a sufficient basis for a workable operationalisation of workflow. We have insisted that we need to include a measure for throughput or productivity, since flow can be slow or fast. The ways a river flows can be used as a metaphor here. At this point, however, throughput emerges as a misconceptualisation, because indirectly, the idea seems to be based on an assumption that the work that constitutes a workflow consists primarily of direct transformation work, plus perhaps the elements identified by Shingo (op cit.). This is not so, however. Kalsaas (2011) shows that direct work constitutes only 38-59 % of the total work, and that a large proportion of working hours is spent performing various forms of indirect work, and so on. Only a small proportion of this time use can be identified as visible waste, such as rework and unutilized time. The point here is that all of these activities are part of a workflow understood as operation.

Furthermore, it seems to be the case that in practice (at least at Norwegian building sites), workmen usually work reasonably hard and steady, but not necessarily in a smart way and with the right tasks. Hence it may be that one or more of the prerequisites for sound work are not met, thus hampering the throughput/productivity. If this—based on unsystematic empirical observations—is indeed the case, the Lean slogan “do not work harder, but smarter” makes good sense.

This also opens up the possibility of understanding workflow intensity as different from throughput; or from productivity, for that matter. In our conceptualisation, it is the intensity of the work that is important. This is the energy we want to harness in a way that benefits productivity. For practical purposes, we can simplify intensity as constituting an approximately constant factor; and if so, we can increase throughput by minimising downtime and defective production through continuous improvement—achieved, among other things, through systematic analysis of root causes. Our developed work place survey does not include any measure for this. Such improvements should nevertheless be detectable by means of an earned value method – despite all the shortcomings of the method identified above – and also in connection with the subcontractors’ profit. Hence we are back at the conclusion that the result of workflow is a measure of productivity. In other words, the same as in a productivity measurement, but with the important difference that we are actively seeking to influence the processes which take place between input and output. In productivity approaches, these processes are hidden in a “black box”. Compared to the starting point of using the tree dimensions, this preliminary result of the conceptualisation and operationalisation of workflow has thus taken a somewhat unexpected direction.

Ad hoc or periodic surveys conducted, for example, over a full work-week and repeated a few times in the course of the construction project’s duration can yield valuable data for discussing—in an inclusive setting—systematic improvements related to uncovered problems and their causes. In other words, provide a good basis for continuous improvement work. In addition, we can establish a connection between the findings from the workplace survey and the workmen’s intuitive perception of workflow. Data from the workplace survey also enables us to calculate the OEE for construction work (Figure 2 and Table 1). This is not an ultimate goal, however, since our primary focus is to create a tool for continuous improvement.

RELIABILITY AND VALIDITY

The validity of the concepts in the workplace survey is tied to well-established terms within the Last Planner System and Koskela’s well-known notion of “making do”. We consider “making do”, with its mixed basis, to be of weaker validity, and will be making it the subject of critical focus in further work in this area. The validity of the earned value method was addressed in the above. The weakness of the workplace survey is that, unlike the method for detailed sampling of data based on Kalsaas (2011), it does not focus directly on the different work activities. In some cases, workplace surveys should therefore be supplemented with detailed registration of activities to ensure as concrete an approach as possible in the improvement work. The prerequisite that work intensity can be assumed to be approximately constant needs to be challenged in the future efforts to operationalise workflow.

The workplace survey has been tested to some degree in connection with several master’s theses (in progress: Helgesen and Helleland 2012, Grønvold and Frydenberg 2012, Ellingsen and Fredriksen 2012). The experiences so far have established that survey participants need not only clear instructions, but also motivating explanations.

Thus the production of reliable data depends on an active improvement and learning environment. It cannot be taken for granted that every individual is always consciously aware of all the obstacles they encounter, and the connection of these obstacles to their time use, when “things have always been this way”. Some of the answers in the test material are from respondents who gave negative answers to all questions tied to the existence of time losses, while at the same time disagreeing with the statement that the workflow was good. Helgesen and Helleland (2012) use a method of detailed sampling of data based on Kalsaas (2011) as part of their approach in their Master’s thesis. This is expected to improve the reliability of the data.

CONCLUSION

The discussion in this paper steered us towards the conclusion that we should test out a workflow concept for construction that is inspired by an OEE for construction based on operationalising the seven flows, “making-do”, and the impact of rework on the time use among the workmen at a building site. In itself, the OEE measure is of limited importance. It is the contents of the time losses, and the discussion of its causes, that are important in a workplace strategy for continuous improvement.

The discussion in this paper offers a clarification of the relationship between intensity and throughput/productivity. In our operationalisation of workflow, we aim to capture intensity, and we argue that work intensity is an approximately constant entity. We wish to contribute to a development where this energy is increasingly spent on working smarter, with sound activities. When this is, hopefully, gradually achieved, we will be able to measure changed throughput by means of an adapted earned-value method.

Achieving good data reliability on the basis of the underlying workplace survey has proved to be a challenging exercise, and emphasis on training and motivation of the respondents seems to be a critical factor for success.

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