ON THE DISCOURSE OF MEASURING WORK FLOW EFFICIENCY IN CONSTRUCTION. A DETAILED WORK SAMPLING METHOD

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ABSTRACT

The purpose of this paper is to test out a detailed work sampling method in the operationalisation of workflow – as part of the discourse about workflow and waste. The paper is part of a wider, ongoing research project on flow in construction work, which has resulted in the identification of several alternative strategies for measuring workflow. The conceptualisation of workflow is based on the premise that it must integrate the two dimensions of uniformity (smoothness) and intensity (productivity). The method builds on an operationalisation of the factors involved in workflow which has its basis in Shingo's well-know distinction between operation and process. Furthermore, the conceptualisation draws on the social methodology of critical realism in order to distinguish between different causes for good or bad flow. It also includes an understanding of waste as visible and observable, and as hidden in transformation work (direct work) and indirect work; and of what initiatives can be taken to reduce visible and hidden waste. An inductive approach is applied to operationalise operations in construction, and to the question of how this data based on work can be used to calculate workflow. The verification of the explored instrument or measurement model draws on data from different construction sites. Theoretically, the paper contributes to the Lean literature by conceptualising workflow and waste within a social scientific framework. Practically, it contributes by establishing detailed benchmark figures on the basis of different construction projects.

KEY WORDS

Workflow, waste, operationalisation, work sampling, measurement.

INTRODUCTION

This paper is part of an ongoing research project where the aim is to establish a method for measuring workflow in construction. In Kalsaas and Bølviken (2010) we sought to develop a conceptual description of flow that would enable its operationalisation – thus making is measurable – while retaining the concept's intuitive qualities. The flow concept is understood in terms of two dimensions: throughput volume, and throughput uniformity. By uniformity is meant the degree of throughput volume stability per time unit. In short, the argument is that if we imagine a production process which delivers a completely stable, but minimal product volume per time unit, it makes little sense to describe this as a process that has a "good flow". Conversely, it makes no more sense to describe a production process which delivers large volumes, but by fits and starts, as having a "good flow". "Good flow", then, is

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characterised by a combination of high production volumes and uniform production volumes per measured time unit (*ibid.*).

Bølviken and Kalsaas (2011) discuss different measurement strategies connected to the operationalisation of the flow concept related to construction. A distinction is made between two approaches, described as 1) self-assessment; and 2) third-party observation. In relation to the self-assessment measurement strategy, the actors' perception of three factors is briefly discussed, namely 1) work stoppage (extent and causes); 2) degree of work flow; and 3) distribution between flow, making do, and stoppage. In relation to the third-party observation measurement strategy, seven possible approaches are addressed: 1) PPC; 2) Actual time use compared to estimate; 3) Perfect person-to-person handover of work; 4) Perfect handover of work between trades; 5) Detailed breakdown of activities and studies of individual time use (work sampling); 6) Piece-work earnings; and 7) Turnover per person per time unit. This paper is based on the testing out of the fifth category, detailed work sampling. The purpose of the paper is to contribute to the discourse on workflow and waste. Whereas most of the existing Lean literature in this area takes quite a broad approach, treating the flow concept intuitively, my intention here is to sustain the discourse by narrowing the focus.

In the first part of the paper I use a theoretically informed approach to identify the workflow concept. This is followed by an inductive experimental approach to operations (Shingo 1988) in construction.

EXPLORATION OF WORKFLOW FOUNDED ON DETAILED WORK SAMPLING

Koskela (1999) identified the seven preconditions for successful undertaking of tasks in construction, namely information, materials and components, labour, equipment and tools, space, connecting tasks, and external conditions. These are central aspects of the constraint or hindrance analysis built into the lookahead planning process in the Last Planner System (Ballard 2000). The lookahead planning process constitutes a central element in the procedures to achieve workflow control in Ballard's conceptualisation of causing work to move between production units in a desired sequence and rate.

Bertelsen (2006; 2007) has conceptualised and illustrated the seven preconditions for successful workflow as "the seven flows", which forms the inspiration for our conceptualisation, as illustrated in Figure 1. But unlike Bertelsen, we see external conditions as the context of the flow rather than a particular type of flow. Bertelsen argues that the primary flow is constituted by the previous, current, and next tasks. However, based on Shingo's (1988) understanding, Bertelsen seems to be describing a process – in other words, product flow. What we endeavour to address in our work is 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 more indirect work. However, reworking, waiting, and so on, are also among the activities described as operations in construction, cf. Figure 1. Shingo defines both process flow and operational flow as consisting of processing (direct work), waiting/delay, movement/transport, and inspection. This is probably an appropriate subdivision for manufacturing, which is the main focus area for Shingo. In construction, though, we find these categories too narrow, as the workmen perform a wide selection of tasks within the building and construction industry that do not fit into Shingo's taxonomy.

However, Bertelsen enables us to see the other types of flow (materials/components, people, information, flow of available space, equipment and tools) as necessary ingredients of the workflow. Hence, an internal relationship can be perceived to exist between workflow and each of the other flows (Sayer 1992); and vice versa. There is, in other words, a reciprocal dependence. We have sought to illustrate this in Figure 1, which has two levels for causes which can influence workflow. At the first level we find the primary causes: material and component flow, information flow (design work, client decisions), flow of people, flow of tools and equipment, and flow of space; whereas the second level is labelled contingency, based on Sayer's (*ibid.*) exposition of critical realism. These are factors which can influence, although not necessarily, workflow and the other five types of flow in an internal relationship to workflow.

In our conceptualisation, it always exist a workflow, good or poor (Kalsaas and Bølviken 2010), but it can be influenced. Direct influence can be exerted by training the workmen, and by developing and introducing more innovative working methods. Furthermore, the design work obviously has a major impact on the build-ability, and thus on the workflow, and the productivity, for that matter. Likewise, predictability in the supply of labour, and materials, components, and equipment of the right quality help ensure a good workflow, and can be influenced through project and supply chain management, and by more general management through the introduction of instruments such as the last planner system (LPS). Moreover, innovation related to materials and equipment, as well as pay systems and so on, can also influence the workflow. Some external factors (contextual conditions) are givens that cannot easily be modified, such as when the location of a construction project is an urban site with a lack of available space and surrounded by heavy traffic, but technological management can identify and implement alleviating measures, such as adapting the logistics to the context; as illustrated in principle in Figure 1.

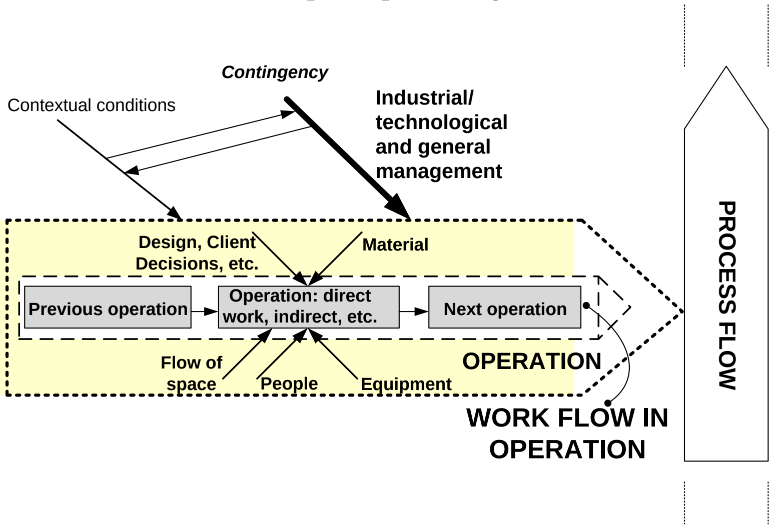

Figure 1: Operational workflow in site production influenced by other flows, contingency, and contextual factors

In terms of waste, we conceptualise it as follows. In order to perform the different tasks and the connection between them, we introduce the categories of direct and indirect work, as well as visible waste. “Visible” waste refers to the fact that we must also expect there to be “hidden” waste, representing a potential for increasing the efficiency and flow of the direct work, and above all the preliminary work of preparing the site for the different tasks to be performed. Different measures on the management and technology sides are possible ways of potentially increasing the workflow and to drive out visible and hidden waste.

APPROACHING MEASUREMENT BY DETAILED WORK SAMPLING

Our approach in this part of the paper is induction, but within the framework of the conceptualisation shown in Figure 1. We begin with a detailed registration of tasks and time use in construction that can be related to operations in construction. This is followed by a discussion of how these detailed operations can be used to measure flow. We envisage that these operation activities can be divided into the categories of direct work, indirect work, counterproductive work, and unutilised time, as well as necessary personal time. Direct work is the type of work that we associate with value-creation work (transformation); the aim is for all of the operations conducted during work hours to constitute or generate this type of work. Indirect work covers activities that are necessary for the direct work to be performed; also known as necessary non-value creating work in the Lean literature (see, for example, Rother & Shook 1999). Counterproductive work and unutilised time cover correction of mistakes and time use that is obviously wasteful, such as some forms of waiting, and excessively long lunch breaks. Short breaks of 5-10 minutes distributed across the working hours are not considered wasteful; on the contrary, by improving the social atmosphere and job contentment, they can help improve overall productivity (Covey 1989). The variables chosen for registration of construction site activities are described in Table 1 below.

Table 1: Conceived production work operation activities in construction

DIRECT WORK ACTIVITIES (Primary transformation activities)
Direct work; Crane operation etc. as part of direct work; Collecting materials within a radius of 12 metres; Inspections and control[2]
INDIRECT WORK ACTIVITIES
Rigging (up and down); Clearing to allow access to workplace; Cleaning up after work; General tidying-up work; Receiving materials and procedures related to this; Unpacking materials; Collecting materials using a trolley or similar; Collecting materials beyond a radius of 12 metres; Carrying waste to skip/container; Transferring between places of work; Moving and fetching tools; Moving to/from saw with mitre gauge, and similar; Moving excess materials; Crane operation etc. as part of indirect work
COORDINATION and SAFETY
Securing work, outside; Planning meetings; HSE meetings and similar; Construction site coordination
COUNTERPRODUCTIVE WORK ACTIVITIES and UNUTILISED TIME
Correcting mistakes; Correcting mistakes made by a different team/trade; Waiting/downtime; Unutilised time
PERSONAL TIME
Coffee and meal breaks; Essential/necessary personal time

[2] Conceived as necessary to guarantee and document the contracted and regulated quality. We depart from Shingo at this point: Shingo does not include inspection as part of processing.

The next big question is how to combine these activities so as to measure the workflow in a way that captures both uniformity and efficiency in relation to the performance of the activities. Let us begin with uniformity.

A large proportion of direct work over time is the aim for any work process we assume, and an important factor in a good workflow. In terms of counterproductive work activities and unutilised time, such activities have their own workflow, but for these categories, we define the workflow as negative. It means, however, that if such work has a good workflow, the negative contribution is smaller than in the opposite case. The indirect work is more or less necessary in order to allow the direct work to be done, and it is thus reasonable to consider it as making a positive contribution to the workflow. But should indirect work be given the same weight as direct work? It is possible to reduce the relative volume of most types of indirect work through good management. For example, rigging up and down and moving between work places can be reduced if one successfully manages to curtail or do away with “making do” solutions. Hence, indirect work can often be reduced by driving out hidden waste by improving the way supply chains are organised, etc. Thus, it seems fair that indirect work is given less weight than direct work in the calculation of workflow. On the other hand, improvements can often be made to the direct work too. Nonetheless, we have chosen to attribute different weight to the two categories since direct work is the primary goal, and since the scope for efficiency savings is expected to be greater for the category of indirect work.

However, some subcategories of non-direct work are of a different character compared to the rest of the work categories listed in Table 1, namely “Securing work, outside”, “Planning meetings”, “HSE meetings and similar”, and “Construction site coordination”, which we have denoted Security and coordination. It is not obvious that it is desirable to reduce these activities – based for example on the acknowledgement that there may be a need to put increased emphasis on safety efforts, thus potentially improving both efficiency and workflow through improved workplace safety and environment. On the other hand, it is conceivable that the amount of time dedicated to safeguarding the premises and work processes can reach proportions one might classify as verging on the counterproductive. Therefore, a concrete evaluation should be made at each construction site as to whether the safety work has reached proportions which classify for workflow reduction, or whether it should be given the full positive weight. For example, the scope for improving the workflow by increasing the emphasis on production process safety work can be expected to be greater in a third world country than in Scandinavia. Likewise, better coordination of the construction activities may require that workmen spend more time participating in meetings or engaging in dialogue, both with their own trade and across different trades; but the amount of time dedicated to such meetings and dialogues can also potentially be drawn out to the extent that it reaches absurd proportions. Personal time is of interest because it allows us to identify how, in sum, the working hours are spent. However, we can see no strong arguments for including the activities contained in this category in the measurement of the uniformity or smoothness of the workflow, but might be taken into account as part of the basis for efficiency correction.

One way of including efficiency in the measurement of workflow is to compare the number of hours for the different workflow components with the total workflow hours. The figure for total workflow hours represents the resource hours invested in the workflow. This approach has its parallel in productivity measurements based on the relationship between output and resource input. However, a fundamental difference is that our approach does not apply the transformation model; instead, we open up the 'black box' and examine the site production process in detail.

EMPIRICAL ANALYSIS

In order to verify this alternative approach to measuring workflow, data was gathered from four different construction projects.

1. Concrete work. Extension of a shopping centre. System formwork and making of large-scale load-bearing constructions. Crews consisting of 5-6 persons; the boss participates fully in the on-site work (Gundersrud et al. 2010[3]).
2. Carpenter work. Construction of a new school in a city centre. Indoor work with crews consisting of some 10 persons plus the boss. The boss devotes most of his time to office work (Forsberg 2010).
3. Carpenter work. Construction of detached housing in a suburban area. Crews consisting of 2-3 persons erect one house after another; no boss (Grepperud & Hinlo 2011).
4. Carpenter work. Rehabilitation of a school on the outskirts of a city centre. The measurements were conducted during the initial phase of the project (Hermann 2011).

All of the data was collected by means of registering activities over the course of full workdays according to the categories listed in Table 2[4] through observations of the workmen's activities every 5 minutes. Thus it amounts to a kind of high-resolution frequency method where the activity registered every 5 minutes is generalised as lasting for 5 minutes. On each of the projects, 1 or 2 students followed 1 or 2 workmen each.

Table 2: Utilisation of working time (%) for four construction projects

	Direct work (DW)	Indirect work (IW)	Coordination and safety (C&S)	Counter-productive work and unutilised time (VW)	Personal time (PT)
Project 1	42	17	15	10	14
Project 2	59	7	11	6	17
Project 3	54	23	4	8	11
Project 4	38	41	6	6	8

A significant difference in the measured projects can be seen between the rehabilitation project (Project 4) and the other three, whose proportion of indirect work is considerably higher. This is also reflected in less direct work as well as partly in the rest of the categories. A plausible explanation is that coordinating the work is more challenging on rehabilitation projects than on new construction projects. There is reason to believe that activities which involve considerable reciprocal

[3] Heidi Haugebo collected the data in June 2010; Gundersrud et al. based their project report on this data.

[4] Some adjustments have been made to the registration form as a result of experience gathered along the way.

interdependencies occur in an early phase of the former kind of project (Kalsaas and Sacks 2011). Furthermore, the data was collected during the initial phases of this project. Project 2 has a relatively low score for indirect work. This can be attributed to the fact that people were employed especially to tidy up and to bring the building materials to the places where they were needed. Their efforts benefitted all trades. The time use of these employees is not included in the data. Project 3 has a relatively low score for time spent on coordination and safety. The fact that the project concerns the building of detached private housing is a likely explanation, since such projects are more straightforward than those involving larger and more complex buildings, thus requiring relative less coordination work and effort. A considerably larger proportion of time, relatively speaking, is spent on coordination and safety on Projects 1 and 2 compared to the other projects. For Project 1, which is a concrete construction project, this may be ascribed to the differences between the trades involved, as there may be more safety issues involved in tasks connected to the type of concrete-related work involved. For Project 2, the boss is engaged more or less full time in office work due to a relatively large team requiring a considerable amount of coordination. Furthermore, the division of labour between the foreman and the boss seemed to be somewhat unclear on this project. These are factors of uncertainty which may contribute to the high figures for time spent on coordination and safety (Figure 1).

CALCULATED WORKFLOW

Based on the line of argument above, the following formula for calculating workflow was tested.

Work Flow=100%(DW+ β∗IW+ α*C&S)/TW; where DW=direct work, IW=indirect work, TW=total work, C&S=Coordination and Safety work

β = efficiency coefficient indirect work ($0<\beta<1.0$),

α = efficiency coefficient coordination and safety work ($0< \alpha <1.0$) og

(DW+IW) = (TW-VW).

Table 3 shows the calculated workflow for the four projects, where $\beta = 0.5$ and $\alpha = 0.9$.

Table 3: Calculated workflow from four construction projects

	Project 1	Project 2	Project 3	Project 4
Workflow %	65	73	69	64

Not unexpectedly, Project 2 achieves a high score due to a small proportion of indirect work, whereas Project 4 (rehabilitation) has a score for calculated workflow that is only marginally poorer than the score for Project 1. If we reduce the weighting of indirect work (β) the score for workflow is lower for Project 4, as it has a relatively high proportion of indirect work. Furthermore, the calculation exemplifies that there are good reasons for making indirect work count less than direct work. Without weighting, Project 4 would have achieved the best score for workflow – which seems unreasonable, given that it has the lowest proportion of direct work. Moreover, it is worth noticing that unless the time-use for the different activities is related to total time use (TW), comparing data from the different construction projects makes no sense.

A central challenge when trying to achieve good flow in construction projects is to make sure that the work involving two or more trades and players is handed over with the right quality in place, and with the agreed degree of completion. In this test, only activities concerning the same trade were registered for all of the construction projects. However, a good score for flow in the above equation depends on smooth and efficient handover of jobs between trades. In the opposite case, the proportion of visible waste will increase.

Workflow as calculated in Table 3 represents and indicator given as a percentage figure; thus, it does not conform completely with the aim of using instruments that measure the phenomenon in question as directly as possible. In order to be able to make comparisons across projects (which is not, however, a primary goal) we need to relate the measuring results to one another. Whether this instrument preserves the intuitive aspect can be debated, and it probably depends on becoming accustomed to using it in practice, thus to build up a sense of what it means in relation to different experiences.

The partial results shown in Table 2 can also be regarded as a way of indicating flow, and they are more intuitive than the overall indicator where the different results have been weighted together. But, as already argued, they lack correction for efficiency. However, the measurements which form the basis for Table 2 can serve as a useful tool for discussing efforts to improve the work (Figure 1) while construction projects are in progress – a use to which they were actually put in some of the projects the data was taken from. It will often prove difficult to measure improvements of the same type of work, but when the work is repeated through the building of several very similar houses, or stories in a high-rise block, this may be possible; see e.g. the Finnish measurements addressed in Kalsaas (2010).

The categories of "Counter-productive work and unutilised time" are identified as visible waste (VW) in our work. To drive out visible and hidden waste can be done in our conceptualisation on the basis of studying and discussing each of the factors contributing to indirect work (Table 1) before implementing measures in cooperation with the workmen designed to improve the work processes. The next measurements can be expected to show a larger proportion of direct work at the expense of indirect work and visible waste, and thus an improved workflow.

VALIDITY

With regard to validity, the main question is whether what we measure are the factors we set out to measure, namely the two dimensions of throughput volume and throughput uniformity. The validity of using work sampling as a measure of throughput is debatable. A large proportion of direct work can be claimed to indicate that given the chosen level of industrialisation and tools, the work is relatively speaking well organised in terms of the conditions for workflow (Figure 1); but it is only when we divide this by the total time use, which also includes visible waste, that a somewhat clearer measurement of efficiency emerges. Efficiency is then output in the shape of direct work and proportions of indirect work, coordination and safety divided by the resource input, which in the tested formula is the total time. It is also debatable to what extent the formula reflects throughput uniformity. It can be argued that a large share of direct work indicates flow uniformity, but this is not necessarily the case, since we have not included any measures of dispersion. Finding verification for the weighting factors, β and α, is also challenging.

DATA RELIABILITY

The reliability of the data must be seen in the light of the fact that we are dealing with conditions that are very far from a laboratory setting's opportunities to control the conditions and keep some variably stable while changing others. The data from the different construction projects was collected through registration of the activities of different workmen over a period of time. Sometimes the workmen are from different crews. This means that measurements have been made of different types of work on developing projects. On the other hand, the data that is used was aggregated on the basis of different crews and trades involved in the same project in order to increase its quality. An element of uncertainty is furthermore contained in interpreting the choices made in relation to allocating activities according to the different categories of the forms that were used. However, there was close cooperation between the students who collected the data and their supervisor at the University of Agder during the preparation and about how to use of the forms, and they showed a great ability and motivation to communicate with the workmen whose activities they sought to register. The data was also presented to the companies involved after completion of the registration. Feedback from such meetings has contributed to further development and refinement of the categories used for the registration of data.

CONCLUSIONS

In this paper workflow is conceptualised as operations in construction, on the basis of Shingo's differentiation between operation and process. In addition, a realist perspective is applied, distinguishing between internal and contingent relations between measures in relation to workflow. The internal relations are necessary in order for there to be a workflow, and workflow is necessary for the other flows (materials, tools, information, people, and available work spaces).

Within the framework of the conceptualisation of operational workflow, this paper describes the testing, using an inductive approach, of a possible method of measurement: detailed work sampling. Validity challenges arise when we seek to calculate flow based on our set of data according to the tested method. The usefulness of this approach is a matter for the anticipated discourse to decide. The method is still being developed, and there is potential for improvement within its defined parameters. There are also other possible approaches – which are not tested here, but included in the research project this paper is an integrated part of.

The method is verified with data from four different construction projects. Observations and time measurements were made of a detailed set of construction activities based on the realisation that workflow must necessarily be a result of activity. Using these measurements as a starting point, an inductive approach was taken in order to develop an experimental calculation method which rested on a division of construction activities into the categories of direct work, indirect work, safety and coordination activities, visible waste (Counter-productive work and unutilised time), and personal time. Of all these categories, the proportion of direct work makes the most important contribution to a positive workflow. We propose, and have partly verified, that indirect work as well as safety and coordination activities should be given less weight than direct work in the calculation of overall workflow. The efficiency dimension is maintained in the calculations by using the total amount of time within the measured time spans in nearly the same way as when calculating productivity. This relativisation of the measured activities is also necessary in order to make it possible to compare workflow across different projects.

Workflow is tied to the concept of waste in construction, and we argue that the instruments can be applied in continuous improvement work within construction projects to drive out visible and invisible waste by involving the actors and conducting repeated measurements. Organising the measurement of similar tasks can often be difficult, however. One disadvantage of this method of measurement is that it is labour intensive. Consequently, it may be best suited to research purposes in order to establish baseline figures.

Theoretically, the paper contributes to the Lean literature by conceptualising workflow within a social scientific framework, and by establishing detailed benchmark figures on the basis of different construction projects.

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