

THE FLOW OF WORK IN CONSTRUCTION: A CONCEPTUAL DISCUSSION

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ABSTRACT

The purpose: To review the term “flow” in production conceptually. The paper is a step towards fulfilling an ambition to find a way of measuring flow (of work) in construction in a manner that does not destroy the intuitive quality of the term, and of measuring flow as directly as possible.

Research method: Theoretical and empirical exploration.

Research findings: Flow is a construct widely used in different disciplines. It has a strong intuitive appeal in terms of meaning and experience, but it is not easily defined in relation to the operational level of production. The lean construction community seems to take a casual attitude to the concept of flow even though much hinges on it in this area of knowledge. In order to develop a more precise concept of flow in construction, and one that is geared towards measurability, we suggest building on Shingo’s distinction between process and operation, and that, for example, a clear distinction be made between conditions for flow and the flow as such.

Main contribution: The relevance of the paper is that it will help unpack the concept of flow as it applies to the construction industry.

KEY WORDS

Lean Construction, Production theory, Flow, Measurement

INTRODUCTION

Innovation and improvement work informed by lean construction thinking is taking hold in the construction industry in Scandinavia. Veidekke is one of the major construction companies in this context. For some time, the company has been developing and implementing its expanded version of Last Planner (LP) (Ballard 2000), which includes the workers as the last planners. According to Veidekke, the aim of its LP-informed planning method is to stimulate the *flow* of its production by 1) achieving the right sequencing of work, 2) making the different levels of the project organisation (head of project, foreman, squad leader) responsible for the production planning in different time windows, 3) removing hindrances to production, and 4) involving all staff on all levels in the production planning (Veidekke 2008).

The company sees flow as the goal they want to achieve, and the four points as strategies through which the goal can be achieved. According to information from the company, the aim is intuitively understood and well embedded in the organisation, but when it comes to implementation, a more precise definition of what flow actually is and how it can be measured is called for. In Veidekke’s approach to flow in construction, flow is seen as a positive attribute in a variable that can take on different values.

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A research project financially supported by the Norwegian Research Council has been established to develop conceptual and empirical knowledge with the purpose of understanding and measuring flow in project-based production³. Part of that effort is also to address and to provide a basis for considering under which conditions the four points above contribute to the flow. The research proposal pointed out the current lack of an accepted method for measuring flow in project-based production, and the research question of this paper *explores the meaning of flow in construction*. The paper is a step towards fulfilling an ambition to find a way of measuring flow (of work) in construction in a manner that does not destroy the intuitive quality of the term, and of measuring flow as directly as possible, or via appropriate performance indicators – one or more. The methodology applied in the paper is theoretical and empirical exploration.

Below we first consider the “flow” term in general and as it applies to construction, before we consider how flow is measured in manufacturing and different manners in which production is classified. This is followed by an exploration of Shingo’s concept of flow in manufacturing, which is transferred to construction. Finally, we approach ideas for further operationalisation and the associated challenges.

FLOW IN GENERAL AND IN LEAN CONSTRUCTION

The concept of *flow* as used in relation to production was originally borrowed from physics. This claim should need little or no substantiation. The next question is how flow is defined in the context of production in general, and in lean production in particular. A proposition in this paper is that flow is first and foremost used intuitively in the production literature, as a metaphor. The widespread use of the term of *flow* in production and logistics seems a good reason to invest effort in unpacking an appropriate concrete meaning of the term as it relates to the thinking surrounding construction industry production and daily operations.

Let us pay physics a short visit before we return to flow in production. In the fluid dynamics of physics a distinction is made between laminar and turbulent flow, and the term velocity indicates that the flow has a direction. The liquid flow can be hindered or controlled by artificial means, such as dams used in hydropower projects to store water for later usage or reservoirs used for the supply of water to urban areas. In (inventory) reservoirs the flow takes on a value close to zero, and when turbulence occurs in streams, what we are dealing with is backward flow, which we might compare to rework in construction, during which the flow might be conceived as taking on a negative value. Moreover, liquids flow with some friction, which can be compared to downtime in construction. Downtime can be caused by such factors as shortage of materials and long walking distances, to take but a couple of examples.

Flow is widely referred to in production, logistics and supply chain management. For instance, it is common to divide supply chains into flow of material, information and capital/money transactions. Pipeline (materials in the pipeline – particularly upstream) and channel (distribution channel) are other notions from logistics associated with flow, such as is Porter’s (1985) value chain and value system concept, illustrated as a flow of value and chain of primary and supportive activities. Traffic engineering is another field which borrows the term, as exemplified by traffic flow, congestion, etc. Furthermore, flow and circulation of capital are well known concepts in the language of economics.

³ This is one of two main goals.

In social science research exists on *flow* associated with knowledge and related to efficiency and innovation (Quinn 2005). In this research flow is a mental state in humans that is linked to phases of high performance. Csikszentmihalyi (1975, 38) notes that “*perhaps the clearest sign of flow is the merging of action and awareness*”. Quinn (ibid.) develops four statements that describing the merging of awareness and action: 1) I could sense how to perform this activity well, 2) I could tell how to respond to things that came up, 3) I could sense why the decision I made were correct, and 4) I knew what to do as each circumstance occurred. This is not the notion of flow we are looking for, but there is some overlap, such as when we ask a worker whether there has been “a good flow to his work today”. We know from research that such a question makes sense in a Norwegian context, and the answer might be: “*Today it was awful. I did not have access to the ceiling where I was supposed to be working. I actually did not know what to do*”, or “*today it was really good, it was better than it usually is*” (Kalsaas 2010). Such responses can be conceived as based on a subjective feeling and a mental state rather than on instrumental rationality underpinned by measurement. People use mental models to perceive and filter reality.

Koskela’s TFV-model from 2000 is well known in the Lean Construction community. “T” is short for transformation, “F” for flow, and “V” for value, and the model is referred to as a production theory for LC. In this case flow captures what is happening between transformation or production processes. Koskela lists six principles to achieve flow: (1) reduce the share of non-value creating activities (waste), (2) reduce the lead time, (3) reduce variation, (4) simplify by reducing the number of steps, parts, components and relationships (linkages), (5) increase flexibility, and (6) increase the transparency. The first point is the normative basis for the theory, the second is derived from queue theory (Hopp and Spearman 2007), and points 4-6 are heuristic principles with a weaker theoretical basis. Lead time is understood by Koskela as processing time, time for inspection, waiting, and time for movement, and waste is associated to the seven wastes in the lean literature, namely overproduction, defects, unnecessary inventory, inappropriate processing, excessive transportation, waiting, and unnecessary motion. Koskela argues that time is the natural unit for measuring flow, and that it is a better alternative than measuring costs and quality, as reduction in lead time is likely to also reduce costs and improve quality. However, Koskela makes no further attempt to unpack the notion of flow.

According to *Oxford Advanced Learner’s Dictionary* (1995), “to flow” means to “*move freely and continuously* (verb)”, and “flow” is “*the flowing movement / continuous stream of something* (noun)”. Using this definition of flow, it makes sense to ask *whether* the production has flow, *whether* the flow is *good*, etc. This is the way the term has been used in many Lean Construction based discussions on “How to improve work flow”. Used this way, the flow term is not necessarily very precise, but it has some important intuitive qualities that have made it popular among both practitioners and academics.

Womack & Jones (1996, 10) apply the term *flow* in their lean thinking principles, for example in the principle that value should be made to *flow* without interruption. The other principles are: specify value by specific product, identify the value stream for each product, let the customer pull value from the producer, and pursue perfection. Ohno (1978) uses the term in two different ways. When referring to establishing a *production flow* (p. 10), he uses the term in the same way as Shingo (1988); that is, as the chain of events (sequence) in which the production process is arranged. When discussing *continuous flow* on the other hand, he obviously sees flow as movement,

and *continuous flow* as a way to reduce waste (p. 33). Liker (2004) and Womack and Jones (2007) also use *continuous flow* in the same way.

A broader literature search on the term of *flow* related to construction returns few hits beyond the already visited literature. On the other hand, there are huge resources on productivity in construction, a topic which is not studied at this stage in the flow research project.

Before we proceed any further with our focus on the conceptualization of flow based on Shingo’s (1988) dual dimensions of process and operation, the next section deals with flow in manufacturing, including a classification of different types of production. We shall later draw upon the points made here.

FLOW IN MANUFACTURING

The term of manufacturing is most commonly applied to industrial production in which raw materials are transformed through the use of tools, machines and labour into finished goods on a large scale, e.g. car manufacturing. Industrial production can be classified according to different market interaction strategies (Browne et al. 1996): (1) make-to-stock, (2) assemble-to-order, 3) make-to-order and (4) engineer-to-order. We can associate manufacturing/repetitive production to make-to-stock and assemble-to-order, while engineer-to-order and partly make-to-order is likely to be organized as project-based production, one-of-a-kind or non-repetitive production. All of the categories above are associated to discrete production, which is different from continuous production as found in the process industry. This is why we do not find “continuous” an appropriate adjective to associate to flow in construction. Production based on engineering-to-order may be mixed with make-to-order, as typically found in construction, shipbuilding, and offshore oil- and gas installations and supply chains related to these.

Our literature review (discussed above) does not reveal any clear understanding of flow in the manufacturing literature expanding on Shingo (ibid.), but the following measurable terms (Table 1) can be identified (see for example Kalsaas and Jakobsen 2009).

The theory of constraint (Goldratt 1984) is furthermore relevant for considerations of flow in manufacturing, where a main point is to protect the bottleneck (the constraint) that is limiting the physical output from production. In construction a crane might be identified as the constraint.

Table 1: Key Performance Indicators (KPIs) related to flow in manufacturing

KPIs	Comments
Throughput time	The time it takes materials to flow through a plant from raw material stock via transformation to finished goods stock. Compressed throughput time indicates high score on flow and vice versa.
Customer order cycle	The time from dispatch of customer order/ call off to delivery. Throughput time is a sub element.
Inventory turnover ⁴	Cost of goods sold / Average inventory. A low rate indicates too much WiP and other inventory. Low level of inventory reduces the throughput time.
Value-adding time / throughput time	Associated to value stream analysis (VSA) ⁵ , which is in the toolbox of lean production.

⁴ Different KPIs are utilized with the aim of measuring the inventory level and capital tie-up.

KPIs	Comments
Set-up time / changeover time	The time it takes to change tools. Short changeover time paves the way for small-batch production and thus for less WiP and compressed throughput time/lead time. Capability to short-change over time indicates good conditions for high score on flow.
Overall Equipment Effectiveness (OEE)	OEE (%) is a performance indicator addressing machines availability/up-time, performance in term of relative output and quality of production: High OEE score indicates good conditions for high score on flow, but may also lead to sub optimisation applied on operations.
Defects (parts per million)	Low defect rate is a condition for flow.

A CLOSER LOOK AT *PROCESS* AND *OPERATION* ACCORDING TO SHINGO

Shingo (1988, 232, 305 and 308) uses *flow* in the sense *a chain of events*, and he sees the distinction between *process* and *operation* as one of his main contributions to production theory and as fundamental for the understanding of production. He explains *process* and *operation* through a two-dimensional figure with the processes flowing vertically (parallel to the y axis) and the operations flowing horizontally (parallel to the x axis). *Processes* (the y axis) are the chains of events during which raw materials are converted into products (p. 305). *Processes* are object flows, flows of goods (p.78). *Operations* (the x axis) are the chains of events during which workers and machines work on items (p. 305). *Operations* refer to “a human temporal and spatial flow that consistently centres around the worker” (p.5), and are subject flows, flows of people (p. 78). Both *processes* and *operations* consist of four phenomena, however, which are partly different in terms of content: Processing, inspection, transport, and delay (pp. 79–80). When working to improve production, *processes* should have priority over *operations* (pp. 310–311).

Let us now take a closer look at the relationship between the *process* and the *operations*. This can be seen as a zooming in on the intersections between *processes* and *operations* in Shingo’s two-dimensional figure. Shingo builds on Gilbreth and Gilbreth (1922) when he conceptualises both *processes* and *operations* as made up from four phenomena or components (processing, inspection, transport, and delay) – and denotes the four phenomena making up the *processes* as identical to the four that make up the *operations*. But are they identical with respect to content? The *processing* and *inspection* carried out as part of the *operation* are obviously the same as the *processing* and *inspection* carried out as part of the *process*, namely the *processing* and *inspection* of the item being produced. *Transport* and *delay* are, on the other hand, not identical. As part of the *process* flow *transport* is the transportation of the object from one workstation to the next, and *delay* is the delay of the object between or within workstations. As part of the *operation* flow *transport* is the

⁵ In value stream analysis (Rother and Shook 1999) customers’ takt time is the amount of time, related to working hours, the customers demand for a specific product, which is the trigger in VSAs and applied for calculation of movement of inventory. The aim is to align transformation processes to produce with the same takt as the market. Toyota calls the method “big picture mapping”. Value is added when work is done to an object. Inventory, movement and inspection are conceived as non-value adding.

movement of the worker between workstations, and *delay* is the delay of the worker between workstations. In total we therefore have the following six components:

Common components in both flows:

- Processing (of the object by the worker)
- Inspection (of the object by the worker)
- Transport / movement (of the object by the worker or machines)

Component only in the *process* flow:

- Delay (of the product)

Component only in the *operation* flow:

- Transport / movement (of the worker between work stations)
- Delay (of the worker between work stations)

The second aspect to be examined is the sequence (chain of events) in which these six components occur. During *processing*, *inspection* and *transport of the object*, the *process* and the *operation* are actually identical in Shingo's conceptualisation. Then they part company: The object might be *delayed* before the next step in the *process*, while the worker is *transported* and *delayed* to (moves to and waits for) the next *operation*.

In the above process and operations are analyzed as two different flows. Bertelsen (2003, 57) and Rooke, Koskela, Bertelsen and Henrich (2007) emphasize the difference between process and operations more as a question of perspective and focus, as different ways of "looking at" the factory / project: Seeing production as a process focuses on the product (what happens to materials and information) and the creation of value, whereas seeing production as operations focuses on what people and machines do. Moreover, Goldratt's (1997, 88-89) distinction between "the throughput world" and "the cost world" can be related to Shingo's distinction between process and operations, where Shingo's statement that process should take priority over operation relates to "the throughput world", whereas a unilateral focus on single operations without taking into account the horizontal value chain can be associated to "the cost world". Goldratt conceives the two as different management philosophies, which differ from and are more comprehensive than different ways of regarding production.

CONCEPTUALIZATION OF *PROCESS* AND *OPERATION* IN CONSTRUCTION

Using Shingo's concept of flow, it makes no sense to ask *whether* production has flow: the question is *how* it flows. This is necessarily the case since delay, among other things, is included in flow.

Shingo's main point is understood as being that maximising output from operations implies sub-optimisation, and operations should be coordinated to maximise overall throughput / throughput time, the flow of objects. This is central in lean thinking and represents a philosophy that differs from for example the Western thinking underpinning methods addressing the economic order quantity (Wilson 1934) on the operations level.

Shingo's frame of reference is manufacturing as characterized by repetitive, standardized and large-volume production, e.g. car manufacturing. Car manufacturing and construction are two different types of production. They therefore have some characteristics in common and some characteristics that differentiate them from each other (Sandretto 1985; Ballard and Howell 1998; Koskela 2000; Bølviken 2006). Is, then, the distinction between *process* and *operation* equally relevant for construction

as it is for car manufacturing?⁶ And if so, should process have priority over operation in the same way as in manufacturing?

The immobility and the size of the construction product are obviously important characteristics differentiating construction from car manufacturing. Because the construction product is fixed to the ground, the production has to be moved to the location of the product (the site), instead of the product being moved to the location of the production (the factory). Because of the size of the construction product, work has to move through the product, instead of the product being moved through workstations. Car manufacturing is most often conceptualized as operations being carried out in sequence (the product being processed at one work station at a time, such as in assembly); see for example Thompson (2003). Due to the size of the product, construction is mainly carried out in parallel (multiple operations being carried out at the same time). For this reason, different parts of the construction product will at any given moment during production be at different stages of completion. In manufacturing the worker works in one and the same factory. When the operation on one product is completed, he either starts working on the next product or waits (delay). This is not the case in construction. When a construction worker has completed one operation, he starts on a new operation within the project, waits, or leaves the project and moves on to a new project. Another difference is that construction also involves reciprocal interdependence (Thompson 2003) in addition to the sequential interdependence dominating car manufacturing. This increases the complexity of production, with the different actors imposing contingency on each other.

When applying Shingo's terms to construction, the *process* can be conceived of as the progress of the project, while the work undertaken by the different trades constitutes the *operations*. A construction project is seen as a process of aggregated sub-processes; however, not primarily comprising sequential but also reciprocal interdependencies. Operations in constructions can be split into more or less aggregated work-packages, each of which has its own internal flow that includes processing, inspection, transport/movement and delay. Each work-package is in turn handed over to a different trade or profession, or handled further within the same trade. But when work-packages are aggregated, with all the sub-flows involved, each package or task becomes a process in Shingo's concept, influencing the progress of the whole project. When a work-package is delivered it is delivered with delay, in due time or too early. Before being delivered the work is likely to be inspected, and there is a transport aspect, which is the movement of workers, tools and material to proceed with new work-packages.

Shingo does not explicitly include "supportive work" in his two-dimensional term of flow but it can be conceived to be part of operation. In construction, supportive work makes up a significant proportion of the total, and should be included in line with the other flow elements in the operation.

Process in Shingo's terminology is what we can identify as "progress" in construction, while the operators' movements in relation to the object of construction to add to its gradual transformation can be identified as operations or work flow. And still following Shingo's arguments, the workflow should be coordinated such that the throughput time is minimized as much as possible (within the given resources). Methods for measuring and calculating progress are well established (e.g. Gantt,

⁶ Bertelsen (2003, 56 - 59) explains the differences between processes and operations and therefore obviously sees the differentiation as relevant to construction. However, he does not explain how or why.

Critical Path, Perth, and Line of Balance), whereas standard methods for measuring the flow of construction work (flow of operations) need to be developed. Such instruments must register the appropriate level and type of details to uncover waste and improve flow and productivity.

The question was raised in the above as to whether process should have priority over operation in the same way as is the case in manufacturing. There is insufficient room here for an extensive discussion, but we assume that even Toyota needs to make trade-offs from time to time between operation costs and process in questions related to batch sizes; or at least this is the case upstream in Toyota-related value chains. In lean construction trade-offs certainly have to be made between the operations of the different trades, and collaboration is a central aspect in this context.

CIRCLING IN ON A DEFINITION OF FLOW

Flow is a construct that is widely used in different disciplines and that has a strong intuitive appeal in terms of meaning and experience, but it is not a term that is easily defined, and it is not easy to draw up a clear-cut demarcation line between flow per se and its causes and conditions, attributes to how it flows, and consequences of the flow.

Koskela's definition of *flow* (see above) can be seen as addressing the macro level, in that it defines some conditions articulated in principles of how to create flow without actually defining flow itself. Reduction of lead-time and variation derived from queue theory may, however, be an exception.

Womack and Jones also address the macro level with their principle that one should seek to "make value *flow* without interruption". They add *value* to the understanding of flow, such as in the value stream analysis method, which is discussed briefly later. According to this, being busy with rework does not add positively to flow even if the rework is perceived by workers as flowing well. However, good flow on rework gives a better overall flow than the opposite. In a way, Shingo operates on the micro level with his arguments related to processes and operation, where flow is interpreted as a chain of events including processing, inspection, movement and delay.

According to *Oxford Advanced Learner's Dictionary* (ibid.) "to flow" is to "*move freely and continuously*". Scholars like Ohno (ibid.), Liker (ibid.), and Womack and Jones (2007) apply the expression to flow "without interruption", which is related to "continuously" in terms of meaning.

Flow can be associated with the following, then: a chain of events (sequence), continuous movement, moving freely, and adding value. A chain of events is a descriptive and neutral association that fits in with the characterisation of construction as discrete production (see later discussion). To think about flow without including movement makes no sense, but free and continuous/free of interruption adds a flavour of goal or value judgment to the notion. "Free of interruption" fits better, however, with discrete production than "continuous" due to the nature of the objects in question.

Moreover, in line with lean thinking it makes sense to include the value concept in an understanding of flow in production. Replacing the challenging concept of value with use and exchange value might be an option. For Adam Smith and Karl Marx value was tied to the human labour invested in a product. In modern economic theory this has of course been substituted by utility or usefulness, but usefulness is also a problematic or relative concept, because we have to consider for whom or for what something is useful. There is a restless interplay of sorts between value, utility and

price, where utility and price are definable and measurable but virtually tautological entities, whereas it is very difficult indeed to define "value".

Value statements like "free of" and "moving freely" are not compatible with the development of a term that can be used as a measurable variable or indicator. Shingo's work conforms more readily to this purpose, and derived from Shingo we can approach a conceptualisation of flow as made up of the qualitatively different aspects of processing (direct work – transformation), inspection, movement/transport (workers and objects), and delay (waiting time). All of these elements can be objects of improvement in change informed by lean construction. The flow might be poor or excellent depending on organisation, management, skills, etc., but there is always a production flow. To achieve excellent flow we need to create conditions that allow the physical flow to move with a minimum of interruptions.

CONCLUDING

A review of the existing literature seems to show that the lean literature has an unclear and imprecise approach to the concept of flow, which the tradition hinges on to such a great extent. It may seem as though the flow concept is primarily used as a metaphor among lean construction scholars. An exception to this is Shingo's contribution, but there is no evidence that this two-dimensional flow concept (process and operation) is the one that is used by central lean construction contributors.

With a view to future operationalisation this paper circles in on a preliminary concept of flow that contains the following properties:

- Flow is seen as a chain of events
- Seeking to build and expand on Shingo's flow concept with the dimensions of process and operation, which include processing, inspection, delay, transport/movement and supportive work
- The question is not *whether* production flows, but rather *how* it flows
- Inclusion of added value or added use value
- Rework results in flow with a negative value
- Construction work is discrete production and interruptions represent an attribute to be considered rather than an assumption that there is uninterrupted continuous flow
- A distinction must be made between conditions for flow and the flow as such
- Both sequential and reciprocal dependencies in building production must be taken into account

The ambition in terms of further research is to find a way of measuring flow (of work) in construction in a manner that does not destroy the intuitive quality of the term, and of measuring flow as directly as possible, or via appropriate performance indicators – one or more.

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