THE WASTES OF PRODUCTION IN CONSTRUCTION – A TFV BASED TAXONOMY

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ABSTRACT

A paper by the authors presented at IGLC 21 in 2013 concluded that the classical list of seven wastes presented by Ohno is context specific (related to mass production) and that there is a need for the creation of a list specific for construction. The present paper presents a draft of such a list. The draft list is constructed in compliance with the Transformation – Flow – Value theory of production. Three main categories of waste are established: Material waste, time loss and value loss. The first is related to the transformation perspective, the second to the flow perspective and the third to the value perspective.

Making do, buffering and task diminishment are not included as such in the proposed taxonomy. The paper therefore discusses how these phenomena relate to the categories of waste in the proposed taxonomy.

A taxonomy of waste must be based on an explicit definition of the term waste. The two terms value and waste are tightly interconnected. Although value and waste are among the most central and used terms in the "lean" literature, no commonly accepted definitions of the two terms exist. The following definitions are proposed:

- Value is a wanted output
- Waste is the use of more than needed, or an unwanted output

Value is related to wanted things (coming out of production), whereas waste can be related both to activities (inside production) and to unwanted things (coming out of production).

KEYWORDS

Waste, value, value loss, making do, task diminishment, buffering.

INTRODUCTION

Koskela, Bølviken and Rooke (2013) analyze the classical list of seven wastes presented by Ohno (1988) and find that it is contextual specific related to mass production and that there is a need for the creation of a list specific for construction. The present paper follows up on this and presents a draft of such a list. The Transformation – Flow – Value (TFV) theory of production presented by Koskela (2000) represents a generic theory of production, but is also commonly seen as the

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main theoretical foundation of Lean Construction. In the search of a list (taxonomy) of wastes in construction, we have therefore taken the TVF theory as our point of departure.

Koskela, Bølviken and Rooke (2013) include the design phase in the analysis of waste in construction. In the present paper we do not include design, thereby limiting the proposed taxonomy to *production* in construction.

A taxonomy of waste must be based on an explicit definition of the term *waste*. The two terms *value* and *waste* are tightly interconnected. Our work with waste has revealed that although *value* and *waste* are among the most central and used terms in the "lean" literature, no commonly accepted definitions of the two terms exists. We therefore start by proposing definitions of the two terms. Thereafter we present the TFV based taxonomy of waste. Finally we discuss the taxonomy's relation to Ohno's classical list of waste, and to making do, task diminishment and buffering.

DEFINITIONS OF VALUE AND WASTE

Some authors offer explicit definitions of value and waste, some only implicit definitions and some no definition at all. Many authors are of course more or less in line in their use of the terms, but there are also examples of contradicting use. We will in the present paper not go through all the different uses of the two terms in literature[1], but only give one example of contradicting use of the value term and one of the use of the waste term.

Value is in one way or the other about functionality, utility and benefits, about the products ability to satisfy needs and desires. In most cases there will be a disadvantage related to getting access to the product (f. ex. resources to be used or a price to be paid). Should we then, when we consider the value of the product, take into account or not take into account the cost side related to getting access to the product? Taking the cost side into account can be called the net view, not taking the cost side into account the gross view. In the net view value is seen as benefit minus cost (value=benefit-cost) or benefit divided by cost (value=benefit/cost). An example of the net view can be Drevland and Svalestuen (2013). For a criticism of the benefit/cost view on value, see Rooke and Rooke (2012). Koskela (2000) sees value as the fulfilling of customer requirements and is an example of the gross view. The present paper is in compliance with the gross view on value.

Turning to waste, we can use Womack and Jones (2003) as an example of what we can call a one-dimensional view on waste and Koskela (2004b) as an example of a two-dimensional view. Womack and Jones see the relationship between value and waste as an either-or, waste is all that has no value. The one-dimensional view on waste tends to establish a circular argument: If waste is all that has no value, value could also be seen as all that is not waste. Koskela (2004b) criticizes the one-dimensional view and argues that value and waste exist in "different, even if intersecting dimensions. A product with a wonderful value may be produced in a most wasteful process. On the other hand, a product with a clearly deficient value may be produced in a most waste-free process" (p.29).

[1] Drevland and Svalestuen (2013) give a review of the use of the value term in literature.

Modern production takes place under commercial conditions in a monetary (and capitalistic) economy. This means that both value and waste will usually have monetary representations, value as price and waste as unneeded costs. The costs of waste can be both direct (the costs of wasted production resources) and indirect (f. ex. low return on investment due to low turn-over which again is due to high levels of inventory and low throughput). When discussing value and waste within the framework of production theory we seek to avoid the use of monetary terms and instead address directly the generic phenomena taking place in the production process. This is because monetising abstracts away the production relevant details of the activity.

When working out the definitions of value and waste presented below, we have been aiming at definitions that 1) are as condensed as possible, 2) respect the intuitive qualities of the terms, 3) avoid the use of monetary terms, 4) are not circular and 5) are in line with what we above have called a gross view on value and a two-dimensional view on the relationship between value and waste. The proposed definitions are as follows:

- Value is a wanted output
- Waste is the use of more than needed, or an unwanted output

As the wording reveals, value is related to things (coming out of production), whereas waste can be related both to activities (inside production) and to unwanted things (coming out of production). In the following value and waste are discussed in some further detail.

VALUE IS A WANTED OUTPUT

Our topic is production and production theory. In production, value is another word for the purpose of the production process. Value is about the usefulness of the product, about functionality, utility and benefit. Something wanted is wanted by somebody. Value is therefore always value for somebody. We can therefore talk about value for any actor in the process, f. ex. value for the supplier, for the producer or for the client. If an actor is to remain contributing to the process, the process must deliver value for the actor in question, there must "be something in it" for him/her. A stable and equitable process must there produce value for all involved.

In the "lean" tradition value is usually seen as value for the customer / client. The reason for this is that the "lean" tradition advocates a holistic view where the entire process is to be understood and improved and sub-optimization should be avoided. The intended use of the product by the customer is the final goal of the production process. This makes value for the customer the dominant value perspective in the "lean" tradition. Within this tradition we can therefore specify the definition of value as an output of production wanted by the customer.

WASTE IS THE USE OF MORE THAN NEEDED OR AN UNWANTED OUTPUT

The proposed definition of waste indicates that there are two principally different types of waste:

1. The use of more resources than needed
2. Unwanted outputs

The first type is related to the process inside production. This part of our proposed definition of waste is in line with Ohno (1988), who sees waste as what is "not needed at all in doing the work" (p. 58). As we will describe later, this type of waste is found in the transformation and flow perspective on production. Wanted outputs of production are value. However, there can also be unwanted outputs of production. These outputs can be seen as negative value, as waste. Being a negative value, this type of waste is found in the value perspective on production.

What we need for the production of the product (with value) we call production resources. Koskela (2004b) points out that "terms such as (...) waste and value are not independent, self-contained concepts – rather they are embedded in different conceptualizations of production, which provide their meaning" (p.28). Different taxonomies of production resources or different conceptualizations of production will therefore result in different taxonomies (lists) of wastes. Different types of production will use different resources or use the resources in different ways. Taxonomies of waste can therefore be different also for different types of production. Our case is construction, a type of project production (Bølviken, 2012).

THE TFV THEORY OF PRODUCTION AND WASTE

Koskela (2000) sees production as transformation, flow and value creation. Production is a purposeful process and the value perspective represents the purpose of the process. Transformation and flow represents two ways of seeing this purposeful process. In the transformation perspective production is seen as the transformation of raw materials and parts into products through the use of machinery, energy and labour. In the transformation perspective waste is the use of more of these production resources than needed.

The flow perspective is about flow in time and space. Flow in space is always also flow in time, but flow in time is not always flow in space. In the flow perspective time is therefore the fundamental production resource. According to this, waste is seen as time loss, the use of more time than needed.

While the transformation and flow perspective focuses internally on the production process, the value perspective focuses on the external output of the process (Koskela, 2000, p.74). The output is primarily a product with the potential to be used by the customer according to the customer's needs and requirements. However, there can and will also be secondary outputs from production in the form of unwanted by-products as harmful emissions and injuries. In the value perspective waste is value loss, a situation where the product is not used as intended and "part of value (is) not provided even if potentially possible" (Koskela, 2000, p. 77), or where there is output of by-products with negative value.

THE TRANSFORMATION PERSPECTIVE: WASTE = MATERIAL LOSS

In the transformation perspective production is seen as the transformation of raw materials and parts into products through the use of machinery, energy and labour. In the transformation perspective waste is the use of more of these production resources than needed. In the transformation perspective we can identify the following types of waste:

1. Material waste
2. Non-optimal use of material (Unnecessary amount used in the product)
3. Non-optimal use of machinery, energy or labour (Unnecessary amount used in the production process)

Material waste is material that is not included in the final product. Material waste is an absolute type of waste. Whatever material consumed in the production process and not included in the final product is waste, without regard to the reason for this. Non-optimal use of production resources is a relative type of waste. The reason for this is that what can be seen as necessary and unnecessary will always have to be based on our current level of knowledge and technology. What is considered necessary at one point in time, can very well be considered unnecessary at a later point.

None of the wastes in the transformation perspective are specific for construction. All though they are a major concern of Shingo's, they are not covered explicitly by the classical list of wastes. We can suggest two possible explanations to this. The first is that Ohno's point of reference is the manufacturing of cars and that because car manufacturing is basically an assembly process, material waste is a more limited concern than in other forms of production. The second explanation can be that although it is not said explicitly, the entire reasoning of both Ohno and Shingo is focused on flow and not on the transformation perspective. Material waste is not part of the conceptualisation of waste in the flow perspective. Regarding both explanations we should bear in mind the practical nature of the Toyota Production System within its economic / industrial context. The most expensive inputs into this type of manufacturing process are labour and plant. They both boil down to time, that is how long time it takes to make a particular product (how much salary is to be paid and how much investment has to made in the plant pe. produced unit).[1]

THE FLOW PERSPECTIVE: WASTE = TIME LOSS

In the flow perspective time is introduced as an attribute and production resource. In this perspective waste is the use of more time than needed.

Shingo (2005 and other books by Shingo) identifies two different flows in production. The first he calls the process. This is how the product flows through the production process. We will in the following call this the product flow. The second flow identified by Shingo he calls the flow of operations. This is the flow in which the work is carried out by the workers. We will in the following call this the workflow. There can be waste both in the product flow and in the workflow.

[1] For Ohnos's explanation of the economic/industrial context that led to the Toyota Production System, see (Ohno 1988 pp. xiii – xiv and 1 – 3).

In the flow perspective we propose the following taxonomy of waste in construction:

In the work flow

1. Unnecessary movement (of people)
2. Unnecessary work
3. Inefficient work
4. Waiting

In the product flow

5. Space not being worked in
6. Materials not being processed
7. Unnecessary transportation (of material)

In the following we will comment on the proposed taxonomy in the following two ways: First we will go through the proposed list and comment on each of the wastes. Secondly we will go through Ohno's classical list and comment on each of the wastes in his list and how they relate to the construction specific list presented here.

1. *Unnecessary movement (of people)*: This waste we find also in Ohno's list. However the main focus in manufacturing and in construction is somewhat different. Dating back to Taylorism, movement is in manufacturing often seen as "micro" movement, as movement of arms and feet within the work station. In construction, the main focus is "macro" movement, the movement of workers within the construction site.
2. *Unnecessary work*: This is the waste of doing things that need not be done. In Ohno's list this is part of the waste of processing, re. our comment on this below.
3. *Inefficient work*: This is the waste of doing (necessary things) in an inefficient way. In Ohno's list this is part of the waste of processing, re. our comment on this below.
4. *Waiting*: This waste is identical to the one we find in Ohno's list.
5. *Space not being worked in*: This is a waste specific to construction. In construction work flows through the product, while in manufacturing the product flows through production. With reference to Ohno space not being worked in can in construction be seen as an inventory of unutilised space.
6. *Materials not being processed*: This is the waste of inventory of materials stored on site.
7. *Unnecessary transportation (of material)*: One of the peculiarities of construction is that the product is rooted to the ground. This means that the place of production is also the final location of the product. For this reason transportation to the construction site can hardly be seen as waste. Unnecessary transport is on the other hand waste.

Now we turn to Ohno's classical list of seven wastes (Ohno, 1988, pp.19-20, re. also Shingo, 2005, pp. 191-194) and how they relate to the taxonomy presented here.

1. *Overproduction:* Overproduction is about the output of production. Overproduction can be interpreted both as producing earlier and more than needed. In the TFV context, this is part of the value perspective. In the proposed taxonomy overproduction is part of a waste we call *Lack of intended use* under the value perspective. This is therefore described in the section on the value perspective below. In Koskela, Bølviken and Rooke (2013, p. 7) it is argued that overproduction is not a dominant waste in construction.

2. *Time on hand / Waiting ("Delay" in Shingo, 2005):* Waiting refers to workers waiting for work to be done. In the proposed taxonomy we find waiting by workers as a waste in the work flow.

3. *Transportation:* In Ohno's taxonomy transport can be understood both as transportation of material to the place of production and as transportation of the intermediate product from work station to work station. The classical list simply says "transportation", but on page 58 Ohno qualifies this to be "transportation to a place other than the destination". In construction the product is rooted to the ground, making the location of final production identical to the product's final location.

4. *Processing:* As pointed out by Shingo (2005, p. 191) waste in processing can be related to the processing speed, to the processing method and to the need for the processing. Shingo's point is that instead of just increasing speed, we should be asking why we make a given product and use a given method. To do something in an inefficient way and to do something that is unnecessary as such, are two very different situations. They are therefore seen as two different wastes in the proposed taxonomy.

5. *Inventory:* Inventory can be interpreted both as inventory of materials, as intermediate products waiting to be further processed and as inventory of complete products (se overproduction). In our proposed taxonomy inventory is represented by space not being worked in and materials not being processed.

6. *Movement ("Wasted motions" in Shingo, 2005):* Movement is the movement of the worker and is a waste we also find in the proposed taxonomy. However the main focus can be somewhat different in manufacturing and in construction, re. the comment on "micro" and "macro" movement above.

7. *Making defective products:* In the TFV context, lack of quality and defective products is best analyzed as part of the value perspective. This waste is therefore discussed in the section below.

Of these seven classical wastes, five are part of the flow perspective (# 2 – 6) and two of the value perspective (# 1 and 7). None are part of the transformation perspective.

THE VALUE PERSPECTIVE: WASTE = VALUE LOSS

In the value perspective the focus is on the external output of the process. In this perspective waste is value loss, a situation where the output of production is not as wanted. The reason for this can be that the product does not meet the requirements of the client, could have met them in an even better way or is not used as intended (for whatever reason). All these reasons are related to the product coming out of production. But the unwanted outcome needs not only be related to the (main) product, it can also be related to unwanted by-products of the production process, as harmful emissions, injuries and work related sickness. When analyzing value, Rooke et al. (2010) draw a distinction between outputs and outcomes (p. 17). Twisting this distinction, we can say that in the value perspective waste is a situation where the outputs of production are not outcomes.

In the value perspective we have identified the following types of waste:

Related to the main product

1. Lack of quality (incl. defective product)
2. Lack of intended use

Related to by-products

3. Harmful emissions
4. Injuries and work related sickness

Lack of quality means that the product is not as fit for purpose as it should or could have been.[1] The two wastes on Ohno's list that are part of the value perspective are overproduction and the making of defective products. In our proposed taxonomy overproduction is part of the waste we call lack of intended use, while making defective products is part of lack of quality.

MAKING DO, BUFFERING AND TASK DIMINISHMENT

Making do (Koskela, 2004a) refers to executing a task although all preconditions (Koskela, 1999) are not present.[2] Lacking preconditions are often brought about through organizational provisions over which local decision makers have little or no control. They are therefore faced with a choice between making do and a complete

[1] In the literature we can find different ways of understanding the term quality. One is to see quality as compliance with specifications, see e.g. Patton (2013) who also refers to several authors sharing this view (p. 33). It has however been argued that this is a too narrow perspective. The specification may not be complete, it may not be correct and it may not reflect what the customer wants or needs. Should we really regard a product that is not working as being of good quality simply because it complies with (wrong or incomplete) specifications? And should not quality instead be seen as compliance with needs? The European standard on quality management systems (ISO 9000:2005) tries to solve this dilemma by defining quality as the "degree to which a set of inherent characteristics fulfils requirements" (3.1.1). Requirement is defined as a "need or expectation that is stated, generally implied or obligatory" (3.1.2).

[2] Koskela (2004a) gives the following precise definition of making do: "Making-do as a waste refers to a situation where a task is started without all its standard inputs, or the execution of a task is continued although the availability of at least one standard input has ceased." (p. 5)

project standstill, a situation that makes making do a both rational and understandable option. However, from the perspective of the production system as a whole, making do can be counterproductive and increase the negative impacts instead of reducing them. It can result in root causes not being addressed and thereby increase instead of decrease negative consequences. Referring to Ohno's list of seven wastes, Koskela (2004a) sees making do as a separate eighth type of waste, typical for construction. Koskela, Bølviken and Rooke (2013) present making do as a likely lead waste in construction.

In the taxonomy of waste presented in the present paper, making do is not one of the categories. How should we then regard making do? Here we see the following alternatives:

1. Making do refers to the execution of tasks. Tasks are part of the work flow perspective on production. We can therefore simply see making do as *a variant of the waste of inefficient work*, as a situation where work is carried out in an inefficient way due to lacking preconditions

2. Making do can be seen as *a strategy* to reduce the negative impact of lacking preconditions on the production process as a whole. Instead of what often appears as a dramatic choice, to stop production and create wastes as waiting and materials not being processed, one chooses to do whatever is possible. The paradox with making do as a strategy is however that it tends to turn out counterproductive. It can be rational from the local perspective but irrational from the global perspective of the production system. Instead of reducing the negative consequences, it can end up increasing them by hiding waste, hindering root cause analyzes and through this end up triggering a chain of wastes.

3. Several types of waste can obviously be present in a making do situation. Making do can therefore be seen as *a complex waste*, as a situation where more than one of the wastes in the taxonomy are present and linked together.

Buffering is a strategy where one type of waste is used to reduce others. When buffering, specific types of waste are deliberatively introduced into the production system in order to establish a satisfactory level of flow and thereby reduce the total amount of waste in the system. A production system with continuous flow and no buffers can be seen as the ultimate lean goal, but only as an ideal. There are buffers in all real life production systems, and will always be, the point is to reduce these to the minimum necessary to maintain a level flow. However, similar to what we described regarding making do, the paradox is that buffering can hide variability and reasons for variability and can thereby result in root causes not being addressed and high levels of waste. A central element in many "lean" improvement strategies is therefore to reduce buffers to a minimum so as to allow breakdowns, which reveal inefficiencies in the system.

Task diminishment (Patton, 2013) refers to not executing a task to comply with specification or not executing it the way it should be done. These diminished tasks are undiscovered, or if discovered, remain uncorrected. Task diminishment is a value loss situation where what should have been delivered from production is not delivered.

With regards to the taxonomy presented in the present paper, task diminishment is obviously lack of quality. It can however be argued that task diminishment could also be seen as a separate type of waste in the work flow, namely *the waste of not doing what should have been done.*

CONCLUSIONS

The presented taxonomy of waste in production in construction is summarized in Table 1.

Beneath the concept of waste lie three fundamental features.[1] First, waste is a practical tool, an intellectual construct designed to make our understanding of the world practically effective. It is not primarily about understanding of the world but about acting in it. Second, waste is comparative in the sense that it requires a vision of how the world could or ought to work, against which it can be compared. Third, waste functions by eliminating resistance to achieving the vision. It is hard to disagree that waste is wasteful and should be avoided.

Table 1: Taxonomy of the wastes of production in construction

	Transformation	*Flow*	*Value*
Production resource	Materials, machinery, energy and labour	Time	
Type of waste	Material loss	Time loss	Value loss
Wastes	1. Material waste 2. Non-optimal use of material 3. Non-optimal use of machinery, energy or labour	*In the work flow* 1. Unnecessary movement (of people) 2. Unnecessary work 3. Inefficient work 4. Waiting *In the product flow* 5. Space not being worked in 6. Materials not being processed 7. Unnecessary transportation (of material)	*Main product* 1. Lack of quality 2. Lack of intended use *By-product* 3. Harmful emissions 4. Injuries and work related sickness

A "construction related list of wastes (…) should be conceptually compatible with construction, empirically justified (i.e. focusing on the most significant wastes) and persuasive and motivating for action." (Koskela, Bølviken and Rooke, 2013, p. 11) The presented list is as we see it compatible with construction and with the TFV theory of production. The most important question is however if the list will turn out useful in the improvement of construction processes by helping us find and reduce waste. Does it focus on the most significant wastes, and does it have the intuitive

[1] This section is based on (Alexander 2009, pp. 1026 – 1027). Although Alexander is reasoning about the term *efficiency* and not about *waste*, we find her reasoning equally valid for waste.

qualities that can make it persuasive and motivating for action? This remains to be seen. A next step should therefore be to test the list in empirical studies.

The present paper has examined waste in *production* through the use of the TFV theory. In (Koskela, Bølviken and Rooke 2013) we argue that in construction, design is "intrinsically present in production" (p. 9) and that we can expect tight connections between waste in design and waste in production. Koskela (2000) sees the TFV theory as equally valid for design and production. Another next step in our attempt to understand waste in construction should therefore be to examine whether the TFV theory can also be a fruitful framework for the understanding of waste in design and the relationship between waste in design and waste in production.

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