WHICH ARE THE WASTES OF CONSTRUCTION?

Lauri Koskela[1], Trond Bølviken[2] and John Rooke[3]

ABSTRACT

In the Toyota Production System, the seven wastes presented by Ohno have provided understanding on the foundations of production management and guidance for action for more than half a century. This list has been widely used also when the Toyota Production System and its derivatives, like lean production, have been adapted and diffused into other industries, such as construction. However, the seven wastes originate from a mass production context and do not cover, for example, the design stage of a productive endeavour, as it is commonly found in construction.

The purpose of this paper is to contribute to the understanding of waste in construction as well as to explore the potential of creating a list of wastes particularly for this type of production. Such a list would be instrumental in creating awareness on the major waste types occurring in construction, as well as mobilizing action towards stemming, reducing and eliminating them. The discussion is structured by analyzing the sufficiency of the classical seven wastes from a construction viewpoint and by exploring alternative wastes in cases where the classical list is not found adequate. It is anticipated that this preparatory discussion will propel the next stage of research towards producing a list of wastes specifically for construction.

KEYWORDS

Waste, seven wastes, construction management. design management.

INTRODUCTION

In the Toyota Production System, the seven wastes presented by Ohno have provided understanding on the foundations of production management and guidance for action for more than half a century. This list has been widely used also when the Toyota Production System and its derivatives, like lean production, have been adapted and diffused into other industries, such as construction. However, the seven wastes originate from a mass production context and do not cover, for example, the design stage of a productive endeavour, as it is commonly found in construction.

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[1] Professor, School of the Built Environment, University of Salford, Crescent, Salford, l.j.koskela@salford.ac.uk.

[2] Director, Strategy and Improvement, Veidekke Entreprenør AS, P.O. Box 506 Skøyen, N-0214 Oslo, trond.bolviken@veidekke.no

[3] Research Fellow, School of the Built Environment, University of Salford, Crescent, Salford, jalfro@eml.cc.

The paper is structured as follows. The following three sections discuss the classical list of seven wastes; its origin, content and influences. Then, this list of seven wastes is evaluated regarding its compatibility with and sufficiency for construction. Next, alternative construction specific wastes explored and discussed. The paper ends with conclusions.

THE SEVEN WASTES AS PRESENTED BY OHNO AND SHINGO

The seven wastes were identified by Taiichi Ohno in his 1978 book *Toyota Seisan Hōshiki*, under the heading "complete analysis of waste" (Ohno 1988:18). These included: overproduction; time on hand; transportation; processing itself; stock on hand; movement; and making defective products (listed in that order). Ohno argues that the elimination of these seven wastes will reduce the cost of production, thus increasing profit. Ohno sees overproduction as a "primary" waste driving other wastes in a "vicious circle of waste generating waste" (Ohno 1988: 55). The elimination of overproduction is therefore central to in his waste reduction strategy. "We must make only the quantity needed" (Ohno 1988:20). This, in turn, releases workers to perform more profitable activities. It follows that time on hand also has a special position in the taxonomy: the time spent by workers waiting for something to do will initially increase as overproduction is eliminated. This will make those resources visible and available for redeployment.

A deeper understanding of the anatomy of waste requires reference to another architect of the Toyota Production System, Shigeo Shingo. Shingo (1985:5) distinguishes between processes and operations: "A process is a continuous flow by which raw materials are converted into finished goods. […] An operation, by contrast, is any action performed by man, machine, or equipment on raw materials, intermediate, or finished products." He further analyses manufacturing processes as having four phases: processing; storage; transportation; and inspection. Each phase has a corresponding operation.

Applying this analysis to the seven wastes, it can be seen that they can be separated initially between operational and process waste. Waiting and movement are wastes of people or machines which are idle or moving unnecessarily, these are operational wastes. The other five wastes are process wastes, four of which can be understood in terms of Shingo's four phases (Table 1). The fifth process waste is overproduction which relates to the outcome of the production process as a whole. As noted above, overproduction has a special place in Ohno's analysis.

As can be seen from Table 1, there is a direct one to one mapping of three wastes onto process phases (processing, storage/inventory and transportation). The fourth waste, making defective products (more commonly referred to in construction as rework) relates to both inspection and processing, as (a) it represents wasted processing time and (b) without it, inspection would be unnecessary.

There is also symmetry between the two operational wastes and two of the process wastes. The first constitutes pauses in the flow, expressed as waiting in the case of people and machines (operational) and as inventory/storage in the case of materials (process). The second is the occurrence of non-value-adding flows, expressed as movement and transportation.

Table 1: Comparison of process phases with types of waste.

Process phase (Shingo)	*Type of waste (Ohno)*
Processing	Processing
Storage	Stock on hand (inventory)
Transportation	Transportation
Inspection/processing	Making defective products

EXAMPLES ON THE ADOPTION OF THE SEVEN WASTES TAXONOMY BEYOND MANUFACTURING

The seven wastes taxonomy has been adopted beyond manufacturing, resulting in some adaptation but also conceptual puzzles. Focusing on health care, Bush (2007) includes both staff and patient (customer) waiting under 'time on hand'. However, 'movement' retains its status as a purely operational waste, while unnecessary movement of patients is included under transport. He identifies, inter alia:

- Overproduction: fragmented and/or parallel care;
- Time on hand (waiting): this is taken to refer to either staff or patients waiting, though the two are actually quite different in the original taxonomy, due to the fact that in a service industry like healthcare, the customer is actually processed by the system;
- Transportation: of files, supplies, equipment or patients;
- Processing: duplication or inefficient handling of information;
- Stock on hand (inventory): unnecessary implements, expensive clinical supplies;
- Movement: supplies or information not available to hand, requiring doctors and nurses to leave the patient;
- Making defective products: hospital acquired infection.

Bicheno and Holweg (2009) are more radical, giving a generic list for service industries, which omits the key category of overproduction, presumably on the grounds that a service is consumed as soon as it is produced, making overproduction apparently impossible. In addition, 'waiting' and 'movement' are both now taken to refer to the customer experience, meaning that operational wastes are effectively hidden in this version.

Abilla (2010) applies Ohno's original categories to waste in a billing system, finding forms of waste that correspond to each of them. However, overproduction would seem to have a smaller role than in the original classification. As in other service taxonomies, customer experience is included, but this time under defects:

- Transportation: unnecessary or inefficient movement of information;
- Inventory: information awaiting processing;
- Motion: editing, checking or making enquiries;
- Waiting: waiting for information;

- Overprocessing: checking, reprocessing, repeated enquiries, new procedure codes;
- Overproduction: multiple invoices, duplicate files, chasing minor debts;
- Defects: complaints, corrupted or miscoded data, recording and transcription errors, unauthorised procedures.

Several candidates have been suggested for an 8th waste. Macomber & Howell (2004) identify several, which can broadly categorised as: failure to use people's talents, skills and capabilities; information waste; behavioural waste; and wasting good ideas.

Within IGLC, two major innovations have been introduced. Koskela (2004) suggests that 'making do', the practice of compensating for incomplete upstream operations through improvisation, is of particular concern as an important waste in construction. Macomber & Howell (2004) argue that failure to speak and failure to listen are 'the two great wastes of construction'. This brief account of attempts to contextualize and expand the original list of seven wastes suggests, at least, that there are different understandings on several types of waste (in the list of seven wastes). Thus, either the concept and different types of waste have been poorly defined or general understanding of the concept is defective.

CHAINS OF WASTE

The processual character of the classical waste notion deserves to be expanded. A process is a chain of events. When we examine waste in a process we can therefore expect also to find chains of waste. By this we mean chains of causes and effects where one waste leads to another. In these cases, the main damage of one specific waste on the system need not be the waste itself, but the entire chain of wastes it creates. Ohno refers to such a chain as a “vicious circle of waste generating waste” and distinguishes between what he calls “primary and secondary wastes” (p. 55).

Instead of Ohno’s “primary” we propose the terms *core and lead waste*. A *core waste* is a phenomenon that is both a waste itself and is at the same time the cause of other wastes. A *lead waste* is a dominant core waste, that is a core waste with substantial negative impact on the production system. With this terminology a waste can either be caused by a core waste or by one or more other phenomena that are not themselves wastes (other root causes).

EVALUATION OF THE SEVEN WASTES FROM THE VIEWPOINT OF CONSTRUCTION

Can we hold the seven wastes as a universally valid set of wastes, or perhaps a set valid for car manufacturing [4], and thus not representative for wastes in other production contexts? We investigate this by considering these wastes against the peculiarities of construction (Koskela 2000): One-of-a-kind production, site production and temporary organization. One-of-a-kind production implies two significant characteristics. First, the question is about producing for a specific need,

[4] Or maybe even more specifically, the assembly of cars. Williams et al (1992) point out that “the final process of weld, paint and final assembly (…) usually account for not much more than 15 per cent of the labour in a car.” (p. 330)

for a specific customer (client). Secondly, one-of-a-kind production contains a design stage as an intrinsic part of the productive endeavour. Regarding these four characteristics, the following comments can be presented:

- **Specific customer.** The idea of overproduction as the most important waste is conceptually and experientially not consistent with one-of-a-kind production. Construction is usually a produce-to-order process. This is in contrast with the situation in mass production, where it can be necessary or tempting to produce before there is a customer order[5]. From experience, we know that construction projects get completed more often after the due date than before it. If there is the possibility of completing before the planned due date, it may be possible to take the facility into use earlier. All in all, the claim of overproduction as the most important waste of construction cannot be justified.

- **Design stage.**Although the seven wastes can largely be interpreted as applying also to design, there may be aspects in design that are not covered. Thus, for example, the failure to achieve the best possible solution in design, certainly a waste for the customer, is not pinpointed.

- **Site production.** In manufacturing we find three types of transportation: The transportation of resources to the location of production, internal transportation of the incomplete / intermediate product in production and transportation of the complete product to the customer. The first type of transportation occurs also in construction, the two last not. In site production, it is the teams and equipment that move around the product. Thus, intermediate (or complete) products do not move at all, whereas workers will by necessity move around the site. However, in our estimation, these differences can be taken care of by a suitable slight redefinition of the waste of movement.

- **Temporary organization.** This characteristic may lead to think about the vagaries of communication and requests and promises between parties previously unknown to each other. The language/action perspective has been used to analyze such a setting in construction (Azambuja & al. 2006). However, there we may be dealing, not with wastes as such, but primarily with the causes of waste.

Thus, our initial examination reveals that the characteristic of one-of-a-kind production raises questions about the lead waste in construction, as well as about the inclusion of the design stage into the scheme of wastes. These two issues are considered next.

WHAT IS THE LEAD WASTE OF CONSTRUCTION?

If we cannot accept overproduction as the lead waste in construction, what should it then be? For examining the question, we need to go deeper into the role of

[5] In some cases, this situation exists also in construction, namely when a company acts simultaneously in the roles of the developer and the contractor and builds, say, housing for demand estimated to emerge in the future.

overproduction as the lead waste. Beyond the arguments presented by Ohno, there are important additional arguments for the primacy of this type of waste. The elimination of overproduction ideally requires that the production cycle is compressed to be the same or shorter than the ordering cycle of the customer so that the pull principle can be used. This, in turn, requires the elimination of all slack, in the form of inventories, from the production cycle time. As shown in Factory Physics (Hopp & Spearman 1996), this requires variability (in the sense of inflow and process time variability) to be reduced, as inventories are needed for absorbing variability. Major means for this are redesign of the production system and continuous improvement throughout it.

It is now possible to better discern the nature of overproduction as the lead waste. The elimination of overproduction requires a systemic change in the production system, whereas other wastes can probably be tackled through more point wise measures (regarding systemic and point change, see (Koskela & al. 2003)).

Now, what would the waste in construction that would play a similar role than overproduction in mass manufacturing? It is argued that the characteristics of construction lead to an erosion of the idea of a task at its both ends: making do and task diminishment.

Making-do (Koskela 2004) refers to starting a task before all preconditions are ready. This is done for keeping the utilization of capacity high but also for the sake of schedule compliance. In turn, task diminishment refers to not executing a task to comply with specification (Patton 2013). The drivers towards task diminishment are varied and complex, but include schedule compliance and minimization of work time and cost of a task. From the viewpoint of quality management, task diminishment translates into informally accepted non-compliance.

The prevalence of both making-do and task diminishment in construction has been confirmed in recent empirical research (Formoso & al 2011, Patton 2013, Emmitt & al. 2013). Now, especially making-do serves the same purpose of absorbing variability as inventories. Thus, similarly to overproduction, making-do requires systemic changes to be eliminated. And similarly to overproduction, making-do and task diminishment cause further wastes. Thus making-do/task diminishment is proposed as the lead waste of construction.

An example of making-do starting a chain of wastes can be the following: In a turn key project a designer is lacking information from the client or from another designer in order to be able to finalise a design. This is causing some irrational sequences in the designer's work. On the other hand the construction site is waiting for the design. The designer therefore makes some assumptions, finalises the design and informs the construction site. On site the work is done according to the design. After the work is completed, it turns out that the solution will not work properly. A new design has to be carried out and the work has to be redone. The cost of the rework results in an economic dispute both between the client and the contractor and between the designer and the contractor. In this example we can observe the following: Although the waste of making-do by the designer seemed an innocent shortcut when carried out, it is a core waste causing substantial waste in the production process. In the example we also see that the "waste of making defective products" (Ohno, p. 20) is actually the end of a chain of wastes with its lead or origin in design.

SHOULD WE INCLUDE THE DESIGN STAGE IN OUR ANALYSES OF WASTE IN CONSTRUCTION?

Construction is project based production, which is a form of production where a temporary and one-of-a-kind organization produces a one-of-a-kind product. On the one hand the design process can be seen as a separate process taking place before production, determining what is to be produced. On the other hand, when we refer to “a construction project”, we refer to the entire scope of the project, both design and production. In construction there is a 1:1 relationship between design and production where one design is used to produce one product, while in (mass) manufacturing the relationship is 1:∞, one design can be used to produce any number of products. In construction the one-of-a-kind nature of both the process and the product establishes a tangled relationship between design and production where we can se design as intrinsically present in production. In product design and manufacturing the design is completed before production. Not so in construction, where design is done partially before and partially in parallel with production. The part of design done in parallel with production creates a need to coordinate the time scheduling of design and production (Bølviken, et al, 2010).

Ohno’s topic is the Toyota Production System, that is a system for the manufacturing of cars. With this point of reference his analyses of waste (and of improvement) is focused on the production / assembly process, and not on the design process or on the relationship between design and production. We, on the other hand, are focusing on construction, where design as intrinsically present in production.

The physical goal of the design and production process is a product with value for the customer. This value is realized when the product is used (consumed) as intended. We can therefore see the design-production-use process as a chain where the value is *created as a potential* in design, is *embodied* in production and is *realized* in the intended use by the client. Our starting point is waste in production. But to what degree will it be fruitful to maintain an isolated perspective on waste in production, and to what degree will it be fruitful instead to have a waste perspective on design and production, production and use or the entire design-production-use process?

Value is always value for somebody. What is value for one party, need not be value for an other. This can also be the case for waste. What is waste for one party, needs not be waste for an other. There will usually be different parties involved in the design, production and use phase. If we are to extend our focus from waste in production to waste in the entire design-production-use process, we can expect to be “forced” to be more precise also on the waste for whom? question.

Koskela (2000) uses the term *waste* in relation to the flow perspective, as waste (for the producer) in production. In the value perspective the term *value loss* is used. Value loss occurs when “part of value (is) not provided even if potentially possible” (p.77). Value loss is waste for the customer.[6] Problems in design causing waste and value loss are in Koskela (2000) analyzed as direct and root causes (f. ex. on p. 153).

[6] One example of value loss in agriculture: Between 30 and 50 % of all the produced food in the world is never eaten (Institution of Mechanical Engineers, 2013). This means that from a global perspective, measures reducing value loss (at the use end of the process) has a much bigger potential regarding the reduction of starvation and pollution from agriculture than the reduction of waste in the food production process itself. Looking at construction one can argue that due to the

Turning to design, we can start by observing that the design establishes both goals and preconditions for production. The goals are set by deciding what is to be produced, what we earlier called the creation of potential value. On the other hand design is also one of the seven preconditions of production (Koskela 1999). Design is both a production process (producing information) (Reinertsen 1997, referring to Patterson 1993) and a creative process (creating potential value). We can therefore expect both waste (from the flow perspective on production) and value loss (from the customers value perspective) to be relevant to design. But we can also, on the other hand, expect issues where reasoning relevant to production of physical products (production) is not relevant to the production of information (design), and where reasoning related to value loss (in the use phase) need not be relevant to potential value loss (in design). We can also expect issues where there is conflict between the waste perspective on design as production and the value loss perspective on design as creation of potential value. Reinertsen (1997) gives one example of such a conflict: In production variability is considered as a source of waste and the goal is to make things right the first time. Not so in design where variability can be the source of potential value and "eliminating variability in design processes can easily lead to a process with no value-added" (p. 16). Referring to Simon (1981) Reinertsen explains design tasks to be inherently expandable. Because there always can be a better solution than the one we have at hand, design can go on for ever and has to be ended either by a decision or by time running out. In contrast to this (physical) production is ended through physical completion.

There can be three types of interdependencies between tasks; pooled, sequential and reciprocal interdependencies (Thompson 1967)[7]. In production we hardly have reciprocal interdependencies[8], and if we have, we usually try to transform them into sequential interdependencies. Not so in design. In design, there are many reciprocal interdependencies, and often they cannot be transformed into sequential. This makes coordination by dialog and mutual adjustment common and important in design (Bølviken et al, 2010). Above we described chains of waste as chains of causes and effects where one waste leads to another. There is hardly any doubt that there can be such chains of waste between reciprocal interdependent design tasks. However, compared to sequential chains of waste in production, we can expect such reciprocal chains of waste in design to be harder to identify, understand and eliminate due to the fact that every task in such a chain is both caused by other wastes and is at the same time causing the wastes that are causing itself. Design costs in construction usually represent a minor amount of the total costs (typically 10 – 15 %). Regarding the design process, this can of course be an argument for focusing on the creation of potential value alone, and not on waste within the process. It is on the other hand obvious that design is one of the important sources of both waste in production and value loss in use. If we find that some of these reasons are themselves wastes (that is

produce-to-order process in most of construction, the construction industry produces very few products that are never used. On the other hand, if we look at the utilisation of constructed space, the hours during a day or days during a year when a specific space is actually used, is often very small.

[7] Thompson's topic is the interdependencies between organizations, but his terminology has shown useful also for the analyses of other types of interdependencies.

[8] A reciprocal interdependency is a circle where each part of the system becomes input for the others.

they are core wastes), this will be an important argument for including the design phase in our main analyses of waste in construction.

However, the time required by design is usually a considerably larger part of the total duration of the project than in the case of cost. A cogent example of the fertility of looking at time wastes in engineering design is given by the concept of latency (Chachere & al. 2009). One type of it is response latency, the lag time from a participant asking a question to receiving an answer that is good enough to enable further work. Chachere & al. claim that through Integrated Concurrent Engineering, enabled through several aligned features, it will be possible to reduce response latency from weeks to minutes. This will speed up the process in a significant way. They assert that in so doing, a just-in-time system for knowledge work is set up. Traditional practices provide time buffers between designers, and this slows down the process. All in all, there are several arguments for addressing the wastes of design.

CONCLUSIONS

Arguably, the discussions presented show that the classical list of seven wastes indeed is context specific and that for the context of construction, the crucial wastes have to be identified and defined starting from the characteristics of this type of production. This insight will be important in the task of adopting lean to any context different from car manufacturing. Indeed, there seems to be a significant need to conceptually clarify the concept of waste from the viewpoint of the context.

In setting out for the preparation of a construction related list of wastes, three major requirements accentuate. The 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. This paper has initially examined the first requirement and in so doing, also to some extent the second. In our work towards a better understanding of waste in construction and the possible creation of a construction specific list of wastes, the two other requirements mentioned will be addressed next. Hopefully this work might also lead us towards explicit definitions of waste and value.

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