Denzer, M., Muenzl, N., Sonnabend, F.A. and Haghsheno, S., 2015. Analysis of definitions and quantification of waste in construction. In: *Proc. 23rd Ann. Conf. of the Int'l. Group for Lean Construction*. Perth, Australia, July 29-31, pp. 723-732, available at www.iglc.net

ANALYSIS OF DEFINITIONS AND QUANTIFICATION OF WASTE IN CONSTRUCTION

Michael Denzer[1], Nils Muenzl[2], Felix A. Sonnabend[3], Shervin Haghsheno[4]

ABSTRACT

Waste avoidance is an essential idea of the Lean philosophy, as this approach significantly contributes to maximize value from the customer's perspective. Waste occurs in diverse forms, depending on the types of industry and of working processes. Elimination or reduction of waste to a certain extent requires the ability to identify waste and to make it transparent to the parties, involved in the working process.

Based on a comprehensive literature review, existing fundamental and independently developed definitions of waste in Lean Management in general as well as in Lean Construction are presented and compared to each other. A systematic overview of waste definitions is developed. Within this context three specific characteristics are assigned to particular definitions. Furthermore, case studies and empirical studies from literature are presented, which focus on the identification and quantification of waste of time in the value chain of construction processes. Arguments, showing that different waste of time studies are not comparable, are brought forward.

KEYWORDS

Waste; lean construction; definition of waste; waste of work-time; theory

INTRODUCTION

Starting from the automobile industry, a new management approach evolved in the last century. Particularly Toyota had been involved in creating this new approach, which was called Lean Production in the following. The major objective of this approach is the maximization of product value for the customer. To achieve this goal, Ohno (2009) stated that waste should be eliminated in the production system. Womack and Jones (2013) picked up the idea of Lean Production and adapted it to a general management approach, called Lean Management. The principles and ideas of Lean Production and Lean Management were transferred to the construction industry. The term "Lean Construction" is used in this context. Here the focus is on value maximization for the customer and on the elimination of waste as well.

[1] Research Fellow, Karlsruhe Institute of Technology, Germany, +49 721 608 45476, michael.denzer@kit.edu
[2] Research Fellow, Karlsruhe Institute of Technology, Germany, +49 721 608 44124, nils.muenzl@kit.edu
[3] B.Sc. Student, Karlsruhe Institute of Technology, Germany, +49 721 608 43650, felix-sonnabend@msn.com
[4] Professor, Karlsruhe Institute of Technology, Germany, +49 721 608 42646, shervin.haghsheno@kit.edu

Since there are various definitions of waste in literature, the question arises, how waste is understood by different authors. Waste in production is usually associated with non-value adding activities. Nevertheless, definitions differ, not only between industrial production (production under controllable conditions) and the construction industry (on-site production), but also within each industry. In this paper three specific and defining characteristics of waste will be introduced to examine several definitions:1) Object of contemplation; 2) Effort and 3)Value perspective

Comparing the definitions, waste – especially in the construction industry – is associated with an extra effort of time. Most empirical studies, which are conducted, aim on measuring waste of work-time in construction. Thus, the paper analyzes and presents work-time studies.

DEFINITIONS OF WASTE IN LITERATURE

RESEARCH METHOD

Based on a review of English and German literature, in total thirteen significant definitions of waste are analyzed – six definitions deriving from the industrial production and seven definitions deriving from the construction industry. This analysis focuses only on fundamental and independent definitions of waste. Thus, the main criteria for the selection of significant definitions are that more than one specific kind of waste is defined by the authors, e.g. corruption (Stifi, Gehbauer and Gentes, 2014).

In the following the definitions of waste within literature are presented and compared to each other (see Table 1). The definitions are analyzed with respect to the above mentioned characteristics. All aspects covert in specific studies are assigned with "x" (e.g. effort by Ohno, 1988). As some researches do not give a broad explanation on the characteristics, some other aspects of their definitions cannot be precisely assigned. Where applicable, an "o" is used (e.g. object by Polat, et al., 2004).

CHARACTERISTICS OF WASTE IN PRODUCTION

In literature waste in production is usually associated with an object of contemplation that does not provide any value and requires some kind of effort. Hence, there are three defining attributes that are characteristic for waste in production and construction.

Object of contemplation

The object of contemplation defines, what is related to waste. In general there are two approaches. Focusing on the processes, which is passed by product, in the first approach waste is related to activities. In the second approach waste is related to the product and therefore focuses on the outcome of production processes.

Effort

Regarding specifications made concerning the efforts linked with waste, there are two groups of definitions. Some definitions give accurate specifications, others only give a vague description of efforts they associate with waste.

Value perspective

Considering the entire production process, another essential feature of waste is linked with value loss. Basically there are two different approaches dealing with value in literature. On the one hand, researches describe value for the client. The client defines the value of a product in compliance with its ability to satisfy his needs and requirements. According to Bølviken, et al. (2014) value for the customer can be defined from the gross view and from the net view. Unlike the net view on value, the gross view does not consider the costs linked with the product. On the other hand, some authors describe value for the producing company. Here value is the efficient use of resources to reduce production costs.

FINDINGS

Using examples, four definitions of waste are analyzed in the following. Therefore, two definitions (the oldest and newest in the analyzed time period) from industrial production and two from the construction industry are chosen.

"In production waste refers to everything that only raises the costs, without adding any value [...]" (Ohno, 2009, pp. 91-92)

Ohno (2009) does not limit the object of contemplation. But he notes that his definition relates specifically to production. Ohno relates waste to *additional expense of costs*. Furthermore, he states that costs are incurred by *surplus stocks of workers, machine/equipment and products*. For Ohno (2009) value added is the transformation of product in its shape or function.

"[...] Muda refers to waste of unnecessary activities. This type of waste is characterized by using time, money and resources, while not adding any value to the customer." (Pieńkowski, 2014, p. 3)

Pieńkowski (2014) connects waste with *activities*, which are not necessary. Thus, an activity that adds no value is not waste, as long as it is necessary to perform a value adding activity. Further, an activity has to consume *resources* to be waste. In this case, the consumption of *money* and *time* is mentioned. Pieńkowski (2014) attributes explicitly the *customer* to his definition of waste. According to this definition the costumer decides, which activities will be classified as value added.

"Non-value adding activity (also called waste): Activity that takes time, resources or space but does not add value." (Koskela, 1992, p. 17)

As in other definitions, Koskela relates waste with *activities*. Effort is defined according to definitions in industrial production. A characteristic of waste is the effort of *resources*. Furthermore, two dimensions are introduced, which play an important role in construction projects: *time* and *space*. Koskela considers a missing value added as a major characteristic of waste. Only activities which transform material and information according to customer requirement extract maximum value.

"Waste is the use of more than needed, or an unwanted output." (Bølviken, et al., 2014, p. 813)

The definition of waste by Bølviken, et al. (2014) is based on the TFV-Model (see Koskela, 1992) of production and relates waste to unnecessary *activities* as well as to

the *product*. In Bølviken, et al. (2014) the use of more than needed is the characteristic related to waste. This is about the use of resources during production. It is distinguished between the transformation aspect (involved resources: *equipment, energy and work*) and the flow aspect (involved resource: *time*). Thus, waste has the characteristic to consume more resources – equipment, energy, work und time – than necessary. Bølviken, et al. (2014) define value as the output requested by the *costumer*. The product value depends on the usability and functionality. It is pointed out that the definition is developed from the *gross perspective* and that the product costs are excluded.

Table 1: Definitions of waste

		object		**effort**									**value**		
Authors	year (first edition)	activity	product	energy	machine /equipment	material	money/cost	performance/labor	resources	rules	space	time	Client gross	Client net	company/product
industrial production															
Ohno	1988		x		x	x	x	x					o		
Womack and Jones	1996	x							x					x	
Gorécki and Pautsch	2010	x			x			x			x			x	
Zollondz	2013	x					x		x				o		
Wagner and Lindner	2013	x							x					x	
Pieńkowski	2014	x					x		x			x	x		
construction industry															
Koskela	1992	x							x		x	x		o	
Formoso, Isatto and Hirota	1999	x			x	x	x	x					x		
Howell	1999		x									x	x		
Alwi, et al.	2002	x					x		x		x	x			x
Polat, et al.	2004		o						x	x			x		
Kalsaas, Formoso and Tzortzopoulos	2013	x							x			x			x
Bølviken, et al.	2014	x	x	x	x	x		x				x	x		

DISCUSSION OF THE RESULTS

Table 1 shows that waste is primarily associated with activities. Especially in industrial production all definitions of waste, except Ohno's, link waste to activities. Looking at the construction industry differing approaches can be found. Particularly the definition of waste by Bølviken, et al. (2014) is outstanding. Exclusively this definition of waste is built on the TFV-model of production. Hence, it is possible to distinguish between a transformation, flow and value perspective of waste.

Comparing the efforts that waste is associated with in the different industries, one finding is that the extra effort of time is stressed in the construction industry.

A general finding of the literature analysis is the different interpretation of waste: In particular this applies to the meaning of the term "resources". Some definitions only link resources to raw materials, whereas others also link resources with space, time etc.

EMPIRICAL STUDIES ABOUT WASTE OF WORK-TIME

RESEARCH METHOD

In the past several empirical studies were conducted, trying to quantify the amount of waste of work-time in construction. Since construction work is highly labour intensive, time is an important resource in construction.

Referring to the TFV-Model, Bølviken, et al. (2014) states that from the flow perspective waste is directly linked to time loss. Therefore, data collected in these studies are expected to provide a better understanding of possible improvements in flow activities in construction.

Starting with an analysis of IGLC papers and their references, the review of literature dealing with waste of work-time is extended to the main journals and conferences on construction management. After analyzing seven significant studies on waste of work-time, the research is stopped since there is sufficient data to show that the results of the studies vary too much to compare them to each other. Subsequently reasons for the noncomparability are discussed.

As there are several different categorizations of work activities, this paper aims to unitise the different studies. According to the categorization by Womack and Jones (2013), the basis for this homogeneous categorization of work activities is as follows:

- Value adding activities
- Non-value adding activities, but required (Muda 1)
- Non-value adding activities, not required (Muda 2)

Value adding activities are all activities that transform material towards the requirements of customer. Therefore, all non-value adding activities are defined as activities, which do not transform material towards the customer's requirements. The non-value adding activities are further differentiated in Muda 1 and Muda 2. There are non-value adding activities that are necessary (Muda 1), because they enable a following value adding activity. Muda 1 is necessary, because the following value adding activity could otherwise not be executed according the current state of technology. And there are non-value adding activities that are not necessary and can be prevented (Muda 2) (Womack and Jones, 2013).

Besides the empirical studies in waste of work-time in construction, there are also attempts to quantify waste of work-time in product design and material waste in construction. Measurements of waste of work-time in product design are often executed within a survey. The results of these surveys show that the respondents estimate the amount of waste representing about 30 % of the complete working capacity (Graebsch, Lindemann and Weiß, 2007). Here it has to be noted that these surveys do not surely focus on the product design phase in construction, but embrace a lot of different branches.

DIFFERENCES BETWEEN THE STUDIES

Table 2 summarizes the characteristics of each study. Besides the use of different categorizations of work activities, the studies also use different measurement methods. Furthermore, they measure waste of work-time in different countries and in different trades.

A lot of studies do not distinguish between trades, but give an overview of the measured waste of work-time. Other studies combine trades and thus the comparison of findings is impossible.

There are differences in applied methods of measurement. All analyzed studies use the observation method. The main difference between the methods is the extent of the measurement. Diekmann and Krewedl (2004) for example, record every activity change of workers, whereas Kalsaas, Formoso and Tzortzopoulos (2013) and Kalsaas, Walsh and Alves (2010) record activities in five minute intervals. Some studies do not provide detailed information on their methods.

Diekmann and Krewedl (2004) as well as Ramaswamy, et al. (2009) already use the homogeneous categorization of work activities. Differing categorizations can be seen between Josephson and Saukkoriipi (2005), Kalsaas, et al. (2014), Kalsaas, Formoso and Tzortzopoulos (2013) as well as Kalsaas, Walsh and Alves (2010). The defined "direct work" can be classified as value adding activity. The category "indirect work" can be linked to Muda 1, as it is necessary to enable further value adding activities. Moreover, the categories "material handling", "work planning", "planning, coordination and HSE (Health & Safety)", "coordination", "handling of materials", "cleaning up", "unloading and unpacking" and "rigging" can all be related to Muda 1. The remaining categories, which are not linked to any of the homogenous categorizations yet, are considered to be Muda 2. These are: "reworking", "unutilised time", "waiting and interruptions", "other", "necessary personal time", "observable waste" and "inspections".

DISCUSSION OF THE RESULTS

Figure 1 shows that the results of the different studies (waste of work-time) vary a lot. In the following possible reasons for these variances are discussed.

In general, the assumption can be made that a wide range of constraints exist in a study (e.g. equipment, technology, climate etc.). Only if one constraint is variable, the influence of this aspect on waste of work-time can be analyzed precisely. However the outcomes of studies are not comparable, if several constraints of the respective studies differ.

Hence, the analyzed studies in this paper are not comparable, because of the following two reasons: The underlying data of the studies is insufficient and the constraints differ significantly.

The studies are executed in different countries, by different observers. Furthermore, the studies are conducted in different projects with different trades. Thus, the hypothesis of this paper is that there are three decisive constraints. If these constraints are kept constant, it might be possible to compare certain construction processes and thus reveal room for improvement.

Table 2: Summary of empirical studies concerning waste of work-time in construction

	Study	Year	Country	Trade	Method of Measurement	Work categorization
A	**Diekmann and Krewedl**	2004	USA	structural steel erection	three cases, hand data collection, video data collection (every activity change recorded), 2 days	value adding, Muda 1, Muda 2
B	**Diekmann and Krewedl**	2004	USA	pipe spool installation	2 cases, hand data collection, video data collection (every activity change recorded), 2 days	value adding, Muda 1, Muda 2
C	**Josephson and Saukkoriipi**	2005	Sweden	different trades	observation	direct work, indirect work, material handling, work planning, reworking, unutilised time, waiting & interruptions, other
D	**Ramaswamy, et al.**	2009	India	different trades	6 cases, random work sampling, video analysis, 5-7 days	value adding, Muda 1, Muda 2
E	**Kalsaas, Walsh and Alves**	2010	Norway	electricians, plumbers, carpenters	observation (every 5 minutes), 11 days	direct work, personal time, coffee and lunch breaks, handling of material, cleaning up, reworking, rigging, unloading and unpacking, inspection
F	**Kalsaas, Formoso and Tzortzopoulos**	2013	Norway	pipe installation	observation (every 5 minutes), 2 weeks	direct work, indirect work, coordination, necessary personal time, observable waste
G	**Kalsaas, et al.**	2014	Norway	plumber, electrical, concrete, iron, carpenter, bricklayer	six cases, observation	direct work, observable waste, planning coordination and HSE, indirect work, logistics, indirect work, other, necessary personal time

Constraint 1: Observer and method of measurement

Comparing the findings of the studies, it should be considered that observers might interpret the work-related activities differently. Graebsch, Lindemann and Weiß (2007) found out in a survey that respondents with experience in lean management tend to estimate the portion of Muda 2 higher than those without. This can lead to a distortion of the results. Furthermore, different time intervals are used to register the changes in activities. Kalsaas, Walsh and Alves (2010) claim that the shorter the time intervals the better activities can be distinguished and the more waste emerges. This could be one of the reasons, why the amount of Muda 2 differs in the studies. Diekmann and Krewedl (2004) recorded every single change of activity, whereas Kalsaas, Formoso and Tzortzopoulos (2013) and Kalsaas, Walsh and Alves (2010). recorded the activities in five minute intervals.

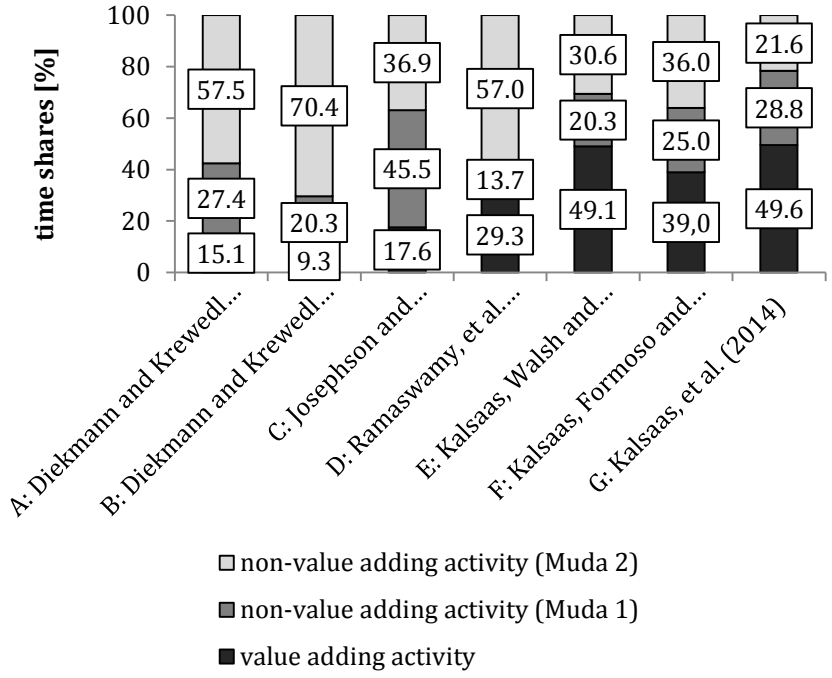

Figure 1: Overview of time measurement studies

Constraint 1: Observer and method of measurement

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Constraint 2: Characteristics of the projects and trades involved

Diekmann and Krewedl (2004) determined that the characteristics of a project have a big impact on the subdivision of the work-time. First of all, their study shows that light-gauge steel construction consists of less Muda 1 than heavy-gauge steel construction. Heavy-gauge steel constructions require the workers to pay extra attention on safely positioning elements into their final position. Thus they require more time than necessary non-value adding activities (Muda 1) than in light-weight steel construction projects.

There are also differences in the subdivision of work-time use between trades. Diekmann and Krewedl (2004) reveals that the pipe layers' or plumbers' work contains significantly more Muda 2 than the steel workers' work. The study of Kalsaas, et al. (2014) supports these findings. In the study it is found out that plumbers only use 31.5 % of their work-time with value adding activities, which is by far the lowest measured data value.

Constraint 3: Country

The country-specific ambient conditions could have an influence on measured waste of work-time. First of all, the developmental stage of the particular country might have an impact on the amount of waste of work-time. Especially the level of present infrastructure determines the possibilities to build lean (e.g. poor road systems affect supply).

Another country specific influence might be politics, providing the legal framework. The minimum wage for example affects the amount of construction workers a contractor can employ. On the one hand, the employment of more workers than necessary can speed up the construction process, but on the other hand, it can lead to mutual interferences and thus resulting in a higher amount of measured waste of work-time.

Furthermore, the climatic location of the country might be a reason for variances in the measured waste of work-time. Construction workers working in tropical climate for example, are expected to require additional breaks.

CONCLUSIONS

The research on the definitions of waste in literature shows that in both areas, industrial production and construction industry, primarily assign waste to activities. Nonetheless, these definitions reveal differences in the determination of value loss and in the effort connected to waste. Addressing the effort waste is associated with, time loss is emphasized in construction. Regarding value, the examined definitions differentiate between value for the customer and value for the company. However, most researches have an emphasis on the customer's perspective.

Since the definitions of waste in construction focus on time loss a lot of empirical studies in construction focus on waste of work-time. Due to differing work categorizations used in these studies and the different conditions of the projects, they are hardly comparable. In this paper the different work categorizations were unitised. Based on this it is found out that the measured data varies intensely. The amount of Muda 2 for example ranges from 21.6 % to 70.4 %. Muda 1 varies between 13.7 % and 45.5 % and the value adding activities vary between 9.3 % and 49.6 %. Subsequently causes for deviations in the results are investigated. There are many different constraints that have an impact on the measured results. The three aspects observer and method of measurement, characteristics of the projects and trades involved and also country are identified as significant constraints.

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