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THE ROLE OF SLACK IN STANDARDIZED WORK IN CONSTRUCTION: AN EXPLORATORY STUDY

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ABSTRACT

Standardized work (SW) is a type of action-oriented procedure that sets a basis for continuous improvement in the Toyota Production System. However, the usefulness and applicability of this practice to construction is still unclear. Furthermore, while some studies have addressed the key elements of SW, the role played by the concept of slack as a fundamental element of operations design is rarely discussed in an explicit way. This is a drawback since slack resources allow for the system to cope with variability from different sources.

Considering the context of the construction industry, the aim of this study is to carry out an exploratory investigation of the role played by slack in SW. This analysis is mostly based on a matrix that checks strategies for the deployment of slack resources against sources of variability in construction. Results indicate that SW, in construction, should account for a broader range of slack resources in comparison to what is accounted for in manufacturing. In addition, we propose that slack resources and the corresponding variability sources be explicitly anticipated when designing SW for construction operations.

KEYWORDS

Slack, Standardized Work, Variability.

INTRODUCTION

Standardized work (SW) is a type of action-oriented procedure that is an essential element of lean management systems (Ohno, 1988). As such, SW is a specific type of standardization, which may or may not be jointly adopted with other standardization

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approaches described in literature (Gibb, 2001). SW aims to reduce variation in operations and establishes a basis for continuous improvement(Martin and Bell,2011).

Although SW is commonly applied in the manufacturing industry, existing literature indicates that the same does not happen in construction. There are no reported examples in which the same standardization method originally devised for manufacturing was implemented in construction projects (Mariz et al., 2012). In this respect, Liker and Meier (2007) point out that SW requires a certain basic stability of production processes, which is difficult to be achieved in construction projects. However, adapted applications of SW to construction are known for the reduction of wastes in activities such as waterproofing (Fernandes et al., 2015), masonry and ceramic floor tiles (Saggin et al., 2017).

This paper explores the role played by slack in SW when applied in construction, and it is based on the assumption that slack is relevant for SW because it can be used to absorb variability from different sources. Furthermore, in lean literature the concept of slack has been explicitly addressed only in terms of time, capacity and inventory of materials. This narrow conceptualization can contribute to the unintended removal of slack resources as part of lean implementation, once it is not always possible to distinguish slack from waste (Saurin, 2017).

Considering the context of the construction industry, the aim of this study is to carry out an exploratory investigation of the role played by slack in SW. This analysis is mostly based on a matrix that checks strategies for the deployment of slack resources against sources of variability in construction.

BACKGROUND

WHAT IS SLACK?

According to Safayeni and Purdy (1991), slack is a mechanism for reducing interdependencies and minimizing the possibility of one process affecting another – i.e. slack makes processes loosely-coupled. Slack can also be defined as a cushion of current or potential resources that enable an organization to successfully adapt to internal or external pressures (Bourgeois, 1981). Righi and Saurin (2015) suggest that slack is an asset for resilience in complex systems, as it provides resources for performance adjustment and the maintenance of the system´s core functions during both expected and unexpected situations.

Fryer (2004) suggests that a cushion of resources does not necessarily mean extra or idle resources, because it may contain existing and strictly necessary resources that can be reallocated and used in different ways. Saurin and Werle (2017) also highlight that, if not by design or opportunistic intentional use, any resource can contribute to slack in a certain context. Therefore, chance can play a role in transforming a resource into slack.

Sometimes a slack resource designed for tackling a certain source of variability can, unintentionally, offer protection against other variability sources (Saurin and Werle, 2017). Thus, it is important to identify the possible sources of variability that each slack resource is intended to cope with. Hollnagel (2012) suggests that there are three sources of variability in a system: (a) internal variability, which refers to the variability of the activity itself; (b) external variability, which refers to the variability of the work environment; (c) upstream variability, which refers to the variability of the output from upstream activities.

SLACK RESOURCES IN LEAN PRODUCTION

According to Saurin (2017), besides work-in-process and safety stocks, some practices often adopted in the Toyota Production System indicate the existence of other subtler instances of slack resources. For example, according to Shingo (1989,92),“workers must be taught to help each other, because individual differences in work times, caused by physical conditions, will be absorbed by the first worker in the process”. In other words, Shingo is referring to a situation in which the use of multifunctional and cross-trained workers could be a slack resource.

The concept of “help chain” is another example of slack in lean system, as presented by Spear and Bowen (1999,101): “if our seat installer, for example, needs help, that too comes from a single, specified supplier. And if that supplier cannot provide the necessary assistance, she, in turn, has a designated helper. In some of Toyota´s plants, this pathway for assistance is three, four or five links, connecting the shop floor worker to the plant manager”.

Toyota has also applied some practices that could be regarded as cognitive slack (Shulman, 1993), such as: (i) the consideration of several alternatives for solving complex problems, delaying the final decision to the last possible moment, as presented by Shook (2008); and (ii) the “set based design”, strategy for product development, which considers a broader range of possible designs and delays certain decision longer than other car companies do (Sobek et al., 1999).

STANDARDIZED WORK:

DEFINITION AND BASIC ELEMENTSIN MANUFACTURING

Standardized work (SW) can be defined as the current best-known method for accomplishing the work (Martin and Bell, 2011). According to Liker and Meier (2007), the primary purpose of SW is to analyse a task for the identification of waste and to systematically eliminate it. Ohno (1988) suggests that there are basic elements necessary for SW that must always be present in one form or another. These elements are:

- Takt time: it corresponds to the rhythm at which a product must be completed to satisfy customer demand in the time we have *allotted* to do so (Dennis, 2002). It is computed by dividing *allotted* time by the quantity required per day.
- Work sequence: it refers to the specific order or sequence of operations in which an operator processes items. Thus, it is different from the order of processes along which products flow (Shingo, 1989).
- Work in Process (WIP): it is the minimum amount of items required in the process that allows for the operator to work efficiently (Ohno, 1988).
- Cycle time: it is the time that takes between one component and the next to leave the same process. In other words, cycle time is the frequency with which a part is completed (Rother and Shook, 1999).

Table presents some relationships between slack resources and the SW elements, based on the literature. As Table suggests, if there were no slack between cycle time and takt time there would be no time available in the system to recover from delays, equipment or material failures (Rother and Harris, 2002).Although not presented in this Table, the slack resources previously mentioned (i.e. “multifunctional team”, “cross-training” and “help chain”) also play a role to deal with variability and therefore they can support the application of SW.

Table 1: Relationships between slack resources and the basic elements of SW

Basic Elements	Slack resources	LP approach	Variability
Takt and Cycle Time	Time	Cycle time for a process should be calculated as 80% of Takt time to ensure that any difference in setup or performance of workers or machines can be absorbed (Rother and Harris, 2002).	Internal variability
Takt Time	Capacity	Toyota assembly lines operate in two eight -hour work shifts with a four-hour interval between them. This interval allows for Toyota to increase capacity whenever the production quotas for a shift are not met in normal working time. (Hopp and Spearman, 2004).	Internal variability
Work-in-Process	Safety stocks	The stock of a completed part that is planned for protection from disruption in the flow of the product (Martin and Bell, 2011).	Upstream variability

UNDERSTANDING THE BARRIERS TO STANDARDIZED WORK IN CONSTRUCTION

The distinctive characteristics of construction in relation to the manufacturing industry are well-known, such as one-of-a-kind production, long lead times and temporary organization (Koskela, 2000; Bertelsen, 2001; Koskela et al., 2013).In fact, construction projects are complex socio technical systems, to the extent they have features such as a large number of elements in dynamic interactions, non-linear interactions, unanticipated variability and resilience (Koskela, 2000; Bertelsen, 2003a; Bertelsen, 2003b).

As such, the basic SW elements, described above, which were originally devised for application in assembly lines and cells, need to be adapted into the construction context:

- Takt time: this concept is regarded as the pace that a trade should complete their elements of work in a certain physical area (zones) of the site (Frandson et al., 2013). This emphasis on limited physical areas is necessary, otherwise the takt time would be equal to the total time that it takes to build a single building (Martin and Bell, 2011).
- Cycle time: it corresponds to the sum of task durations for concluding a work zone by a trade. Cycle time does not cover overlaps between activities, butincludes the sum of queue times (Ballard, 2001). Although cycle time can be

equal to takt time, it is recommended that the cycle time be lower than the takt time, and a time buffer is designed to protect the system against variability sources.

- Work in progress: it is usually associated with the number of simultaneous work zones in a given site (Bashford et al., 2003; Sacks et al., 2010). In other studies, this concept appears implicitly associated to unfinished work (Fireman et al., 2013; Ibarra et al., 2016).
- Work sequence: differently from lean production in which it refers to a sequence of detailed operations, in construction it is usually associated with the order or sequence of aggregate groups of operations (Bulhões and Picchi, 2011; Fernandes et al., 2015; Saggin et al., 2017).

Furthermore, differently from repetitive manufacturing operations with short cycle times, activities in complex adaptive systems such as construction tend to have a wider gap between "work-as-done" and "work-as-imagined" (Hollnagel, 2012). For example, in complex systems the number of interdependencies between activities tends to be large and as a result some preconditions for starting work may not be met. In turn, this triggers workarounds detrimental to both safety and quality (Hollnagel, 2012).Work done under suboptimal conditions is ubiquitous in construction sites (Formoso et al., 2017), this creates a kind of waste known as *making-do* (Koskela, 2004).

SLACK AS A BASIC ELEMENT OF SW IN CONSTRUCTION

In construction, buffer and contingencies are terms more commonly used than slack. These usually refer to specific resources such as material, capacity, time, backlog of made-ready work packages, money or even work in process (Gonzalez et al., 2006; Sacks et al., 2010; Ortiz-Gonzalez et al., 2014; Russeal et al., 2012). However, the extant literature on complex socio-technical systems suggests that slack can be interpreted as a broader concept, which is not limited to any specific type of resource or deployment strategy (Saurin and Werle, 2017). In this sense, Saurin and Werle (2017) identified five strategies for the deployment of slack in complex socio-technical systems, such as construction, which are not limited to specific types of slack resources. Table 1 presents examples of how these five strategies could be applied in construction by using different slack resources.

The importance of slack to support SW in construction becomes more evident when the slack deployment strategies are explicitly checked against the high variability involving the availability and quality of the necessary preconditions for starting a construction task. According to Formoso et al. (2017), there are at least eight types of preconditions for a construction task: construction design, components and materials, workers, equipment, space, connecting works, external conditions and work infrastructure (water, electricity). The availability and quality of these preconditions is usually subjected to high variability, and thus the probability of interrupting a sequence of work is high (Koskela, 2000).

Table 1: Strategies for the deployment of slack in construction
(adapted from Saurin and Werle 2017)

Strategy	Definition	Examples of application
Redundancy	It is divided into four sub-categories: (i) standby redundancy, which is redundant resources not immediately involved in the task at hand; (ii) active redundancy, which means redundant resources that is involved in the task at hand; (iii) duplication of functions; and (iv) redundant procedures or redundant inspections across process stages.	1.Redundant equipment/tools 2.Creating formal or even informal leadership redundancy to distributed authority when necessary
Work in Progress	Refers to stocks of raw materials, partially finished products and finished products.	1.Several simultaneous work zones 2.Stock of materials
Margins of maneuver	It is characterized by autonomous or coordinated strategies that create margins through reorganization of resources.	1.Multifunctional workers 2.Layouts that allows for different trades share or change space for inventories and flow of workers when necessary 3.Capacity and time buffer
Cognitive diversity	Refers to divergence in analytical perspectives among members of an organization	1.Short-term meetings involving different team leaders to identify and solve problems of previous week 2. Cross-training
Control slack	Refers to individual degrees of freedom in organizational activity, with some range of individual action unconstrained by formal coordination or command.	1.Supervisors allow for experienced subordinates to improvise when the action adopted is consistent with the overall goals of the process

Table 2 consists of a matrix, which indicates that the variability of preconditions can be dealt with by all of these five strategies, especially by the margins of maneuver and redundancy. These are some examples of the application of margins of maneuver in construction: (i) use of safety tolerances in construction design; (ii) work in different shifts, daytime and night time, which allows for different trades to use space, equipment and temporary facilities on the same day; (iii)use of general purpose machines;(iv)scheduling of a backlog of tasks without pending constraints so that crews can perform these during adverse weather conditions or when the weekly work packages have to be interrupted due to the lack of any prerequisites.

These are some examples of redundancy: (i) incorporation of redundant inspections into construction design to minimize errors; (ii) redundant equipment, materials or work infrastructure; and (iii)stand-by workers or areas that are intentionally left idle to deal with unexpected variability.

It is worth noting that there may be a trade-off between the redundancy and control slack strategies. Redundant inspections or redundant procedures should not be in excess, because this may weaken the effectiveness of the strategy control slack, and thus, reduce the freedom and flexibility of the organization.

Table 2- Interaction matrix between strategies for deploying slack and variability of preconditions for a construction task

	Variability of preconditions for a construction task							
Strategies	Construction Design	Components and materials	Workers	Equipment/ Tools	Space	Connecting Works	External conditions	Work Infrastructure
Redundancy	X	x	X	X	X			X
Work in progress		x				X		
Margins of maneuver	X	x	X	X	X	X	X	X
Cognitive diversity	X		X					
Control slack		x		X	X	X		X

Regardless of WIP being the most well-known strategy and also one of the basic elements of traditional SW, Table 2 indicates that it needs to be applied jointly with other strategies, because it only copes with two variability sources. As an additional drawback in construction this strategy is not usually implemented in a controlled way: the number of simultaneous workstations is not properly monitored, and there is much unfinished work.

Cognitive diversity also needs to be applied jointly with other strategies, because it directly covers just variability from construction design and workers performance. These are some examples of the application of cognitive diversity: (i) use of multidisciplinary teams during development of the construction design; and (ii) application of cross training enables a worker to perform more than one job.

CONCLUSIONS

This paper presented an exploratory discussion on the role of slack in SW in construction and the relationships between slack and the basic elements of SW in lean production. A matrix for assessing whether strategies for the deployment of slack can cover different sources of variability in construction was developed. This matrix indicates that, although the strategy of using WIP may be the most known, it needs to be jointly applied with other strategies to support SW in construction. This matrix also makes it possible to identify that two slack strategies (i.e margin of maneuver and redundancy) play a key role to coping with variability arising from the preconditions of a construction task. Thus, these two strategies of slack should probably be explicitly in corporated into the list of basic elements of SW in construction.

As for future research, we propose: (i) the development of a conceptual framework to distinguish slack from waste; (ii) the development of empirical studies to test and refine the set of strategies for slack in construction sites; (iii) the development of new methods for the design of SW that explicitly account for a broader range of slack resources and the corresponding variability sources; and (iv) the assessment of strategies for slack used in long, medium and short term planning and control.

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