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EFFECTS OF LEAN WORK ORGANIZATION AND INDUSTRIALIZATION ON WORKFLOW AND PRODUCTIVE TIME IN HOUSING RENOVATION PROJECTS

Ruben Vrijhoef[1]

ABSTRACT

This paper presents work aimed at improved organization and performance of production in housing renovation projects. The purpose is to explore and demonstrate the potential of lean work organization and industrialized product technology to improve workflow and productive time.

The research included selected case studies that have been found to implement lean work organization and industrialized product technology in an experimental setting. Adjustments to the work organization and construction technology have been implemented on site. The effects of the adjustments have been measured and were reviewed with operatives and managers. The data have been collected and analyzed, in comparison to traditional settings.

Two projects were studied. The first case implied am application of lean work organization in which labor was reorganized redistributing and balancing operations among operatives of different trades. In the second case industrialized solution for prefabricated installation of prefabricated roofs. In both cases the labor productivity increased substantially compared to traditional situations. Although the limited number of cases, both situations appeared to be representative for other housing projects. This has led to conclusions extrapolated from both cases applicable to other projects, and contribution to the knowledge to improve production in construction.

KEYWORDS

Lean methods, productive time, workflow, housing renovation, industrialization.

INTRODUCTION

In construction, particularly housing, clients and builders are searching for solutions for fast and productive working to decrease cost levels. Particularly renovation projects have been found a target area. Various clients such as housing associations and contractors have been experimenting with lean work organization and industrialized renovation concepts. Innovative methods are not just applied to lower costs of renovation but also lean working, process optimization and industrialization

[1] Researcher, Delft University of Technology, Professor, University of Applied Sciences Utrecht, PO Box 5043, NL-2600 GA Delft, The Netherlands, +31639251420, r.vrijhoef@tudelft.nl

are aimed at changing the work and mentality of workers to lower the costs (Höök, 2008). The lean aim is a balanced improvement that affects both the product, work organization and the attitudes of workers.

ISSUES OF WORKFLOW AND PRODUCTIVE TIME

LEAN PRINCIPLES OF PRODUCTION AND WORKFLOW

Construction has been characterized by a high number of non-value adding activities, which results in low productivity (Koskela, 1992). According to Botero et al. (2004), construction companies are among the least performing industries due to its lack of effectiveness and productivity. Sometimes these problems are caused by design errors and lack of specifications. Other sources are design modifications during the construction process, lack of supervision on workers, overcrowding of workers, high labor turnover and poor industrial safety conditions (Loera, et al. 2013).

These factors lead to disorganized work and hampered workflow, high rates of accidents, inadequate distribution of materials, equipment and tools, re-work activities, cost overruns and late delivery of projects (Jarkas, 2010).

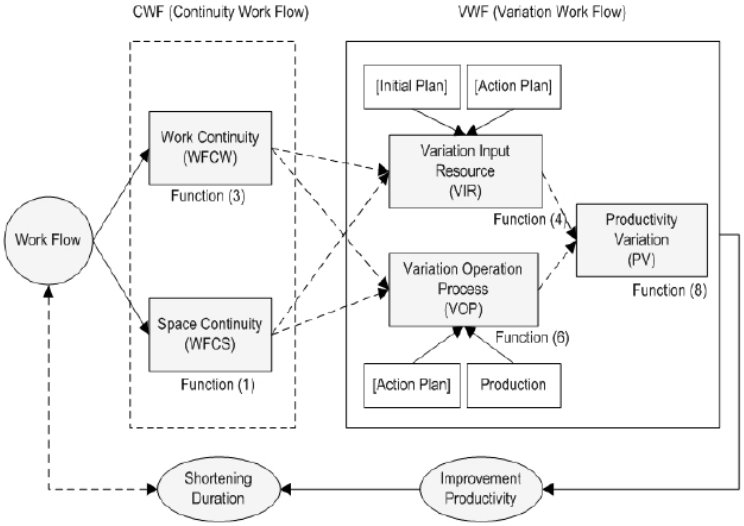

Figure 1. Relation between Work Flow Variation and Productivity (Chun & Cho, 2015).

Variation in work flow influences construction productivity and duration (Chun & Cho, 2015) (figure 1). When there is continuity of workflow, there is a reduction of variation in input resources through continuous work and improvement of productivity and learning effects (Chun & Cho, 2015). Workflow variations thus influence production and productivity.

This impacts largely the efficiency of construction labor. Construction labor costs typically represent 30% to 50% of the total project costs in most countries (Jarkas, 2010). Therefore productivity is an important target to improve efficiency and performance in construction. However roughly 40%-60% of working hours are actually spent on work, and thus 60-40% of working hours would be unproductive (Forbes, et al. 2010). According to Jarkas, (2010) various causes for this can be

pointed out, including lacking skills, shortage of materials, dysfunctional communication between site management and labor force, lack of site managers' leadership capabilities and weather conditions.

VIEWS ON PRODUCTIVITY AND PRODUCTIVE TIME

There is no agreement about the precise definition of productivity (Yi & Chan, 2014). The definitions differ in which elements productivity includes and they differ in what is meant by high productivity. Economists and accountants define productivity as the ratio between total input of resources and total output of product. Resource input includes the elements labor, materials, equipment, and overhead (Hanna, Taylor & Sullivan, 2005).

Productivity has been defined as "the power of being productive", "efficiency" and "the rate at which goods are produced" (Yi & Chan, 2014). While the construction industry is a labor-intensive industry, the workforce is the dominant production factor, and according to this, the construction productivity is primarily dependent on human effort and performance (Jarkas, 2010).

Labor productivity issues are a great challenge confronted by many construction firms. Indeed it has been lower than that for other industries; for example in United States construction productivity increased between 1966 and 2003 by only 0.78% per year (Forbes, 2010).

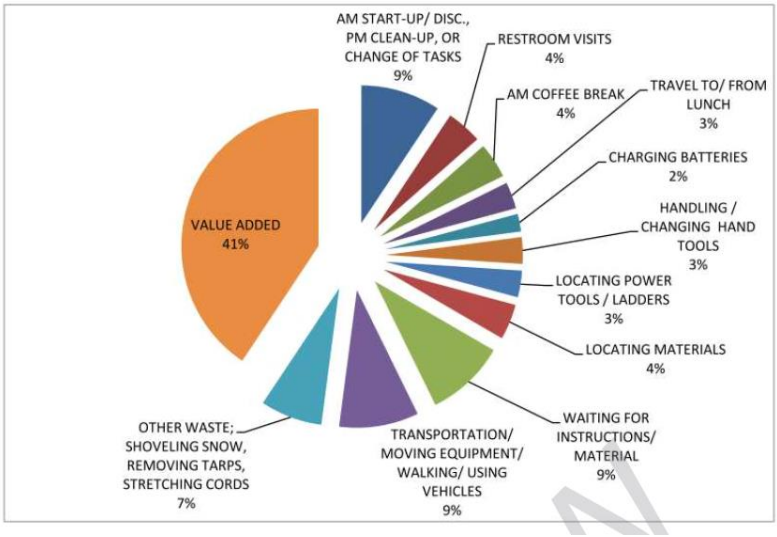

Figure 2: Value-added versus Non-value added activities in a typical workday (Asmar, 2012)

Only about 40% of time spent by workers in a typical workday is value added and more than 50% is wasted (figure 2). Waste is defined as 'anything that is not required to create value for the client or end-user' (Mossman, 2009). Waste is also including: transportation, overproduction, waiting time, inventories, too much machining, moving, and making defective parts and products (Koskela, 1992). Waste and non-value adding activities must be regarded as unnecessary costs (Aziz & Hafez, 2013).

ASPECTS OF WORK ORGANISATION AFFECTING LABOR PRODUCTIVITY

Previous studies differ in explaining how productivity if influenced (Park, Thomas, & Tucker, 2005). Nasirzadeh and Nojedehi (2012) have found groups of causal relations affecting factors of labor productivity such as lack of working area, skillfulness and project management efficiency (Figure 3) (Nasirzadeh & Nojedehi, 2012).

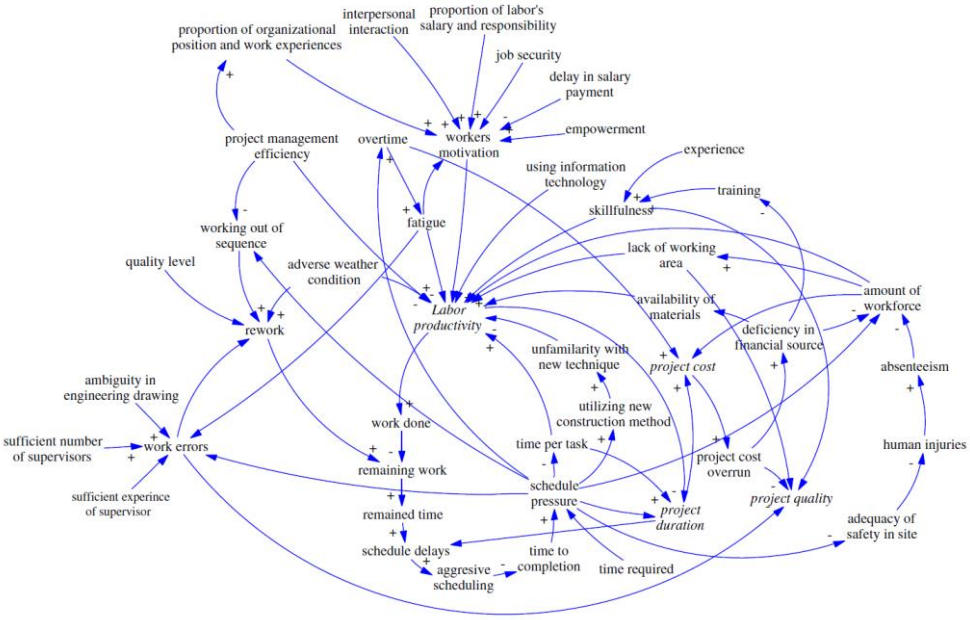

Figure 3:Conceptual model of causes of increased or decreased labor productivity (Nasirzadeh & Nojedehi, 2012).

These influences on labor productivity represent aspects of work organization and could be categorized in three groups (Shehata & El-Gohary, 2011):

- Industry related factors such as complexity and repetition of design, laws and regulations, job duration, work size and type, weather conditions, site location.
- Management related factors such as planning and scheduling, leadership, motivations and communication.
- Labor related factors such as labor skill, motivation and labor availability.

LEAN METHODS AND INDUSTRIALISATION AS POTENTIONAL SOLUTIONS TO IMPROVE PRODUCTION

Workflow, productive time and productivity can be influenced by lean methods and industrialization. In fact, various lean methods particularly aim at these aspects, and so do aspects of industrialization.

AIMS AND EFFECTS OF SELECTED LEAN METHODS

In this study a selection of lean methods have been applied as interventions to improve production, particularly in case 1 (see below). These include the following lean principles:

1. Continuous Flow. Work-in-process smoothly flows through production with minimal (or no) buffers between steps of the process. It eliminates many forms of waste (e.g. inventory, waiting time, and transport). Continuous flow is linked to Planning and Production Control. Four aspects are critical in the implementation of continuous flow; stability, interdependence, takt time and work division (Etges, et al. 2012).
2. One piece flow. Components and materials are being processed directly from one work station to the next, and so on, one piece at a time. This means that the product flows through the work stations. Or vice versa, in construction, the activities flow through each product e.g. a house at a time. The construction process is organised in such a way the workmen can proceed and finish their work per house without waiting, and after that they can proceed to the next without delay, following takt time.
3. Heijunka (Level Scheduling). This form of production scheduling purposely produces smaller batches by sequencing (mixing) product variants within the same process. In construction, activities are often rescheduled among workmen and trades in order to achieve balanced workloads per workman pr day, for smooth production, work flowing, without inventory.

AIMS AND EFFECTS OF ASPECTS OF INDUSTRIALIZATION

Further in this study, a selection of aspects of industrialization has been studied and their potential to improve production as well, particularly in case 2 (see below). These include the following aspects:

1. Standardized Work. The industrialised (and standardized) product requires the work to be standardized too. Documented procedures for manufacturing and installing product components on site including the time to complete each task forces operatives to follow the production system. In the production system errors and rework and thus waste have been eliminated.
2. Offsite production and prefabrication. Conditioned work and shielding the production environment increase the progress of work and minimising the part of the work that has to be done on site and thus reducing the chance of disturbance.
3. Quality management and Poka-Yoke (Error Proofing). Industrialization including standardization and prefabrication prevent design and manufacture errors, and prevent operatives of making mistakes because of the intelligence in the design of components and interfaces and connections. The goal is achieving zero defects, and preventing inspection and correction of defects or mistakes in the production.

CASE STUDIES:

METHODOLOGICAL APPROACH TO THE CASE STUDIES

The above lean methods and aspects of industrialization have been applied as interventions and subjects of analysis in two respective case studies. The lean methods have been particularly applied as interventions to improve workflow and productive time in below case 1. The aspects of industrialization and their improvement potential

have been studied particularly in case 2 improving workflow and productive time as well (see below).

In both cases the effects on workflow and productive time have been studied in two ways. Records of practical effects have shown the improvement of the workflow. Measurement of numerical effects in the planning in particular have demonstrated the improvement of productive time. Both cases are presented below.

CASE 1: LEAN WORK ORGANIZATION

Case description.

This housing renovation included 69 social rented houses and 30 social rented small apartments. The renovation was commissioned by the client being an housing association. The project consisted of renewing the bathroom, the toilet, the electrical installations and the kitchen.

Application of lean methods

As the project is was demand driven, the inhabitants were asked when they wanted the refurbishment and if they wanted the bathroom and toilet, only one or none, but at the end all the inhabitants decided to refurbish. Additional on the site managers' house there is a space where the inhabitants can go and relax or cook while the refurbishment takes place at their homes.

Further lean tools were applied to multi-skilled teams included transfer of activities between workers, coaching among workers, balancing of work, reallocation of activities, collaboration between workers, just in time delivery, security of materials, autonomous self-controlled teams.

Effects on workflow

The continuous workflow and one-piece-flow approach also included coaching and taking over tasks among trades, so virtually the trades could be 100% productive. For example the first day of refurbishment is done by the demolition workers, who learned some basic electrician tasks to be able to have a whole productive day, so transfer of activities is an important subject for workflow in this project.

Additional the project culture is of collaboration between workers, for instance the plasterer had one extra hour at the end of the day, so he uses it for cleaning and organizing the houses for a smooth workflow the next working day.

The planning of the project was done in a modular way, in which each day they start a new house and the workers know exactly where they are in the planning, what they have to do each day and how the projects is doing.

Effects on productive time

Pull Planning and level scheduling resulted in bathroom renovation taking seven days, the toilet four days and the kitchen five days within those seven days, so in total the renovation of each house took seven working days and in total there are ten workers in the project.

Each day or half day one trade took over all activities of other trades (see below; each color in the bar chart represents a particular trade). This resulted in in "full days" or "full half days" of work for all trades, and less transport, less fragmented work, and less times of preparation of their workplace.

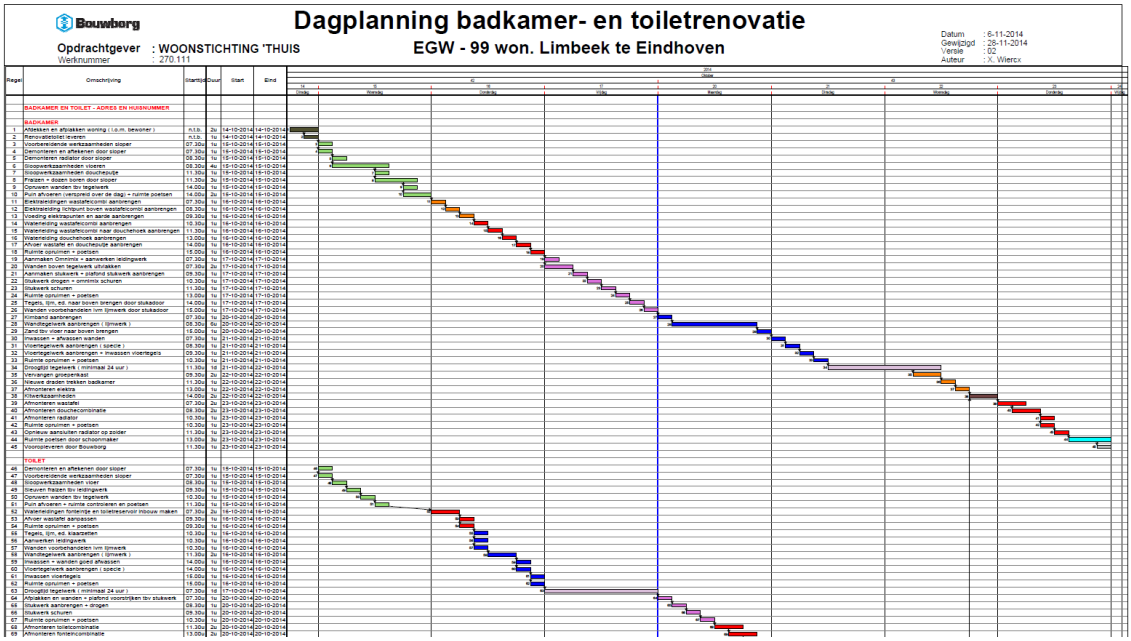

Figure 4: Level scheduling in the project, planning each trade fully productive per day or half day (each color represents a trade per day or half day) (planning in Dutch).

CASE 2: INDUSTRIALIZATION

Case description.

In this case 109 houses were renovated. The industrialization included prefab elements for roofs and façades.

Figure 5: Installing prefabricated roof and façade elements (Sav, 2014).

Aspects of industrialization

This roof and façade system has been fully produced and pre-engineered in a factory allowing to be installed for two houses in one week, including all interior work being done in the same week. The interior work had not been industrialised however.

Effects on workflow

The prefabricated elements and the systematic delivery of elements to site, as well as the high quality level of elements and connections improved workflow and speed of installation of roofs and facades.

To improve the interior workflow as well, the trades worked in multi-skilled teams. Those teams did most of the work in a house with a high level of interdependency and joint coordination. Interviews with the trades revealed several advantages (Mulder, 2016): reduction of disturbance, increase of workers motivation, reduction of schedule pressure, and higher sense of responsibility among workers.

Effect on productive time

Production time analyses of the project showed that the expected renovation time of one house had decreased from traditionally 15.9 days to 5.0 days due to the industrialization efforts. The industrialization of the roof (as well as the façade) also led to a reduction of labor hours needed for the renovation (Table 1).

Table 1: Comparing labor hours between traditional renovation and industrialized renovation of a roof (Berben 2015)

	Task	Traditional renovation	Industrialized renovation
1a	Demolishing roof	7.5	7.5
1b	Preparation prefab roof	0	0.88
2a	Mounting bearing structure	4.72	2.58
2b	Adjustment for prefab roof	0	0.80
3	Mounting roof	13.63	3.26
4	Mounting gables	5.28	2.13
5a	Fitting sheet	0	1.68
5b	Waterproofing	0	1.38
	Labor hours on site	31.13	20.21
	(Pre)fabrication hours wood work	0.17	0
	(Pre)fabrication hours roofing sheets	1.0	0
	Prefabrication hours roof	33	16
	Total	64.30	36.21

Case study comparison and combination

In the first case the production and productivity improvement have been based on lean work organization and aimed at interior work. In the second case the production and productivity improvement have increased spectacularly by prefabricating the roofs and façades, and partly due to altering work organization. This increase can be explained largely by the prefabrication of the product, influencing factors such as work speed, error proofing and standardization.

In addition to the lean work organization particularly the multi-skilled teams delivered several advantages leading to increased labor productivity. However interestingly enough the second case did not deliver such evidence that working with multi-skilled teams on the industrialized concept this would not necessarily lead to increased labor productivity. Further research has to show in what situations and under what conditions working in multi-skilled teams will increase labor productivity.

Both cases of this paper have showed different as well as same kind of effects and aspects of improved and lean work organization, while the second case was aimed at product industrialization primarily, this case also showed evidence of additional lean methods applied. The effect on workflow and productive time for the interior of the renovations were comparable too. The effect on productive time for the exterior work (roof and façade) was obviously different in both cases while in case 1 this was not part of the work, nor was an industrial approach part of the renovation. However if the exterior had been part of the renovation in case 1 this would have been combinable in this case too probably, as applied in case 2.

DISCUSSION AND CONCLUSIONS

Applications of lean work organisation and industrialization appear to have their effects on workflow and productive time. Although these are advancements in their own right they do not automatically point towards each other nor always combine in construction practice. However in theory both concept of lean and industrialization, and the routes they both suggest towards smoother workflows and reduced productive time, and increased productivity, are often part of the same conceptualisations of either lean construction or industrialized construction. In theory they are quite interconnected.

Both concepts could be rejoined into one probably, if this would be based in the same kind of effects and aims both have. Because apparently both concepts have taken another route towards the same effects and aims. This would strengthen both concepts, in practice as well as conceptually and theoretically, and their effect on such issues as workflow and productivity as discussed in this paper.

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