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Publication date
2019

Document Version
Final published version

Published in
Proceedings of the 35th Annual ARCOM Conference

Citation (APA)
Vrijhoef, R. (2019). Studying Time Presence on Site as an Indicator of Productive Time Use by Construction Workers. In C. Gorse, & C. Neilson (Eds.), *Proceedings of the 35th Annual ARCOM Conference* (pp. 204-213). ARCOM, Association of Researchers in Construction Management.

STUDYING TIME PRESENCE ON SITE AS AN INDICATOR OF PRODUCTIVE TIME USE BY CONSTRUCTION WORKERS

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Productivity in construction is relatively low compared to other industries. This is particularly true for labour productivity. Problems that contribute to low labour productivity are often related to unorganised workspace, and inefficient organisation of work, materials and equipment. In terms of time use, site workers spend time on various activities including installing, waiting, walking etc. In lean production terms time use should be value adding and not wasteful or non-value adding. The study reported in this paper has endeavoured to measure the time use and movement applying an automated data system. The case study reflected a limited application to a specific kind of activity, namely doors installation. The study investigated time use and movements based on interviews and on automated detection of workforce. The interviews gave insights in the time build-up of work and value-added time use per day. The automated tracking indicated time intervals and uninterrupted presence of site workers on work locations giving indications of value adding time. The time measurements of the study enable comparison of time use categories of site workers. The study showed the data system calculated the same amounts of productive and value adding time one would expect based on the organisation and characteristics of the work. However, the discussion of the results underlined that the particular characteristics of individual projects and types of team work organisation may well have an impact on productivity levels of workers. More application and comparative studies of projects and further development and extension of the automated data system should be helpful.

Keywords: Automated data capture, labour, productivity, presence, time use

INTRODUCTION

Productivity has been a long existing and much debated topic in construction. The deemed low levels of productivity have been a subject for comparison to other industrial and economic sectors. More recently increasing demand and construction activities in many countries with growing economies have put additional pressure on the issue of productivity.

Previous work in construction management and production research, such as lean construction, have also debated the root causes as well as solutions for improving low productivity. Categorisations of work types in value adding versus non-value adding have often been the basis for assessing productivity. In addition, time intervals of

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Vrijhoef, R (2019) Studying Time Presence on Site as an Indicator of Productive Time Use by Construction Workers *In:* Gorse, C and Neilson, C J (Eds) *Proceedings of the 35th Annual ARCOM Conference,* 2-4 September 2019, Leeds, UK, Association of Researchers in Construction Management, 204-213.

workers on work locations could be indicators of being able or unable to be productive (i.e. adding value) or either unproductive (i.e. non-value adding) in the available time on a work location. The rationale is that workers need a certain minimum amount of time on one location to be able to perform a task (i.e. uninterrupted presence).

Measurement of labour productivity in construction is a laborious and contextual matter. Productivity figures have therefore often been outdated, not present, disputable in other contexts, not very useful in daily situations, and to improve productivity in practical situations. Automated measurement and data capture of proper parameters on site may be a solution to raise the situational knowledge and awareness needed.

This paper presents a study applying such automated data capture and discussed the appropriateness and usefulness the information about productive and even value adding time use of site workers. The parameters for identifying and measuring the value of workers activities are represented by detecting time spent and uninterrupted presence of workers on work locations compared to total time on site verses time needed for value adding work. This approach to productivity relates to input productivity i.e. efficient time use by workers, rather than output productivity e.g. effectiveness of value delivery to the client. In general, this causes debate about the interpretation of productivity and what approach to productivity is most essential.

Theoretical Background

Previously construction work has been characterized by a high number of non-value-adding or unproductive activities, which results in low productivity (Koskela, 1992). Construction is deemed to be among the least productive industries (Botero *et al.,* 2004). For example, in the United States construction productivity increased between 1966 and 2003 by only 0.78% per year (Forbes, 2010).

There is no agreement about precise definitions of productivity (Yi and Chan, 2013). Various definitions differ in which elements of productivity are included and they differ in what is meant by high or low productivity. Productivity has been defined as the ratio between total input of resources and total output of product. Inputs include the elements labour, materials, equipment. Outputs have been defined in terms of numbers products or levels of turnover produced (Hanna *et al.,* 2005). Other approaches view productivity as “the power of being productive”, “efficiency” and “the rate at which goods are produced” (Yi and Chan, 2013). Also, production factors included vary. In the construction industry, the workforce is a dominant production factor, and according to this, construction productivity is largely dependent on human effort and performance and thus labour productivity (Jarkas, 2010).

Variation in workflow influences construction productivity and duration (Chun and 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 and Cho, 2015). Workflow variations thus influence production costs and productivity. This impacts the cost efficiency of construction labour. Construction labour costs typically represent 30% to 50% of the total project costs in most countries (Jarkas, 2010). Therefore, labour productivity is an important target to improve efficiency and performance in construction.

However roughly 40 to 60% of working hours are actually spent on work, and therefore 60 to 40% of working hours would be unproductive (Forbes *et al.,* 2010).

Only about 40% of time spent by workers in a typical workday is value added and more than 50% is wasted (Hanna 2010) (figure 2).

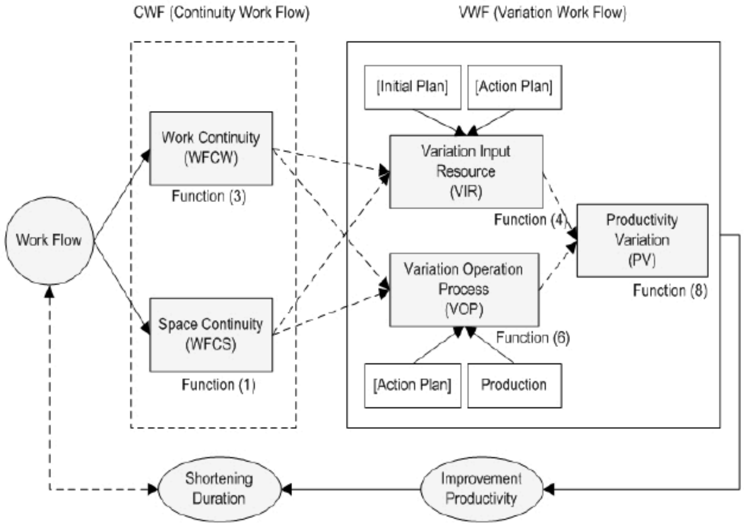

Figure 1: Relation between work flow and productivity variation (Chun and Cho, 2015).

Waste must be regarded as unnecessary costs (Aziz and Hafez, 2013). Waste includes non-value adding activities such as overproduction, waiting and unnecessary transportation and moving (Koskela, 1992).

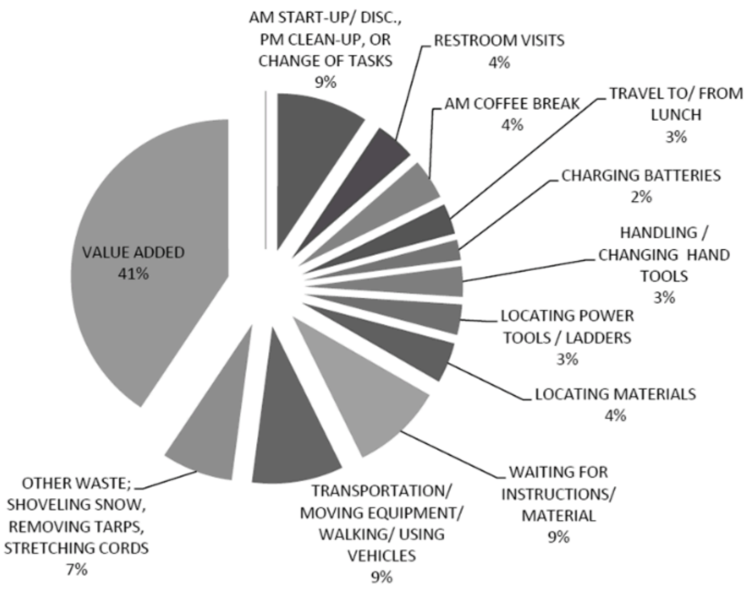

Figure 2: Value-adding versus non-value adding activities in a typical workday (Hanna 2010).

RESEARCH METHOD

The study reported was performed on one site of one firm. The aim was to study the presence of workers, and particularly the uninterrupted presence on work locations. Part of the data collection has been automated via the iCONS system of Aalto University (Seppänen *et al.,* 2019). Next the automated collected data was compared with work description and time build-up of the work via interviews with workers. The comparison between both demonstrated the extent to which automated time presence measurement could be an indicator of labour productivity in terms of productive time use by site workers.

The automated iCONS system provided the base set of data within the limited case study. The system is in development and tests on various case projects need to demonstrate the functionality of the system. The data system detects and stores data and gives insight in movements and presence of workforce (and materials and equipment) to be able to measure the status of productivity and indicate potentials for improvement measures (figure 3). Further cases are needed to find out what the actual improvement in productivity can be when cases are compared. The study reported is based on a single construction project. The results can be compared and reflected on related to other studies and cases, but not generalised.

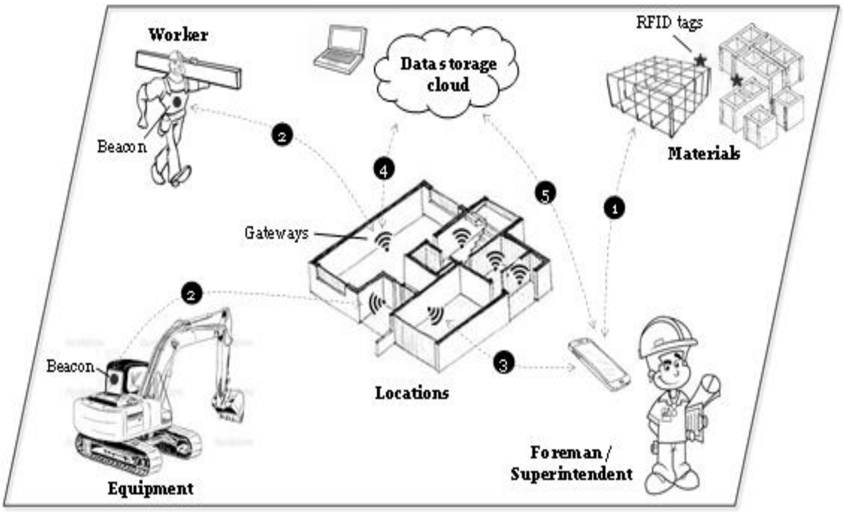

Figure 3: Overview of the iCONS system (Olivieri et al., 2017).

Figure 4: VR representation of the case project.

Case Project

The case used for the data collection within this study is the construction project of 'het Noordgebouw' in the city Utrecht in the Netherlands (figure 4). This is a building of 23,000 m2, accommodating offices, dwellings, retail spaces, a restaurant and a hotel. The project was delivered in December 2018.

Within this case project the iCONS system was applied to collect interval times of presence of workers on work locations in the building. This included two workers of the subcontractor installing the 226 interior doors in the building. The data collection took place to a limited number of 59 doors installed in week 46 to 50 (November 12 to December 11) in 2018.

In addition, the workers were interviewed to derive the logic of the activities of the workers. This logic served to understand, verify and validate the automated data captured as realistic indicators of productive time.

Data Gathering

Data Capture

For the automated data capture 15 gateways with 4G connection were installed in the building and the workers carried Bluetooth Low Energy (BLE) beacons on them in order to be detected by the gateways. For the power supply for the gateways power banks were applied along with a replacement schedule to prevent power issues that would hamper data flow (figure 5).

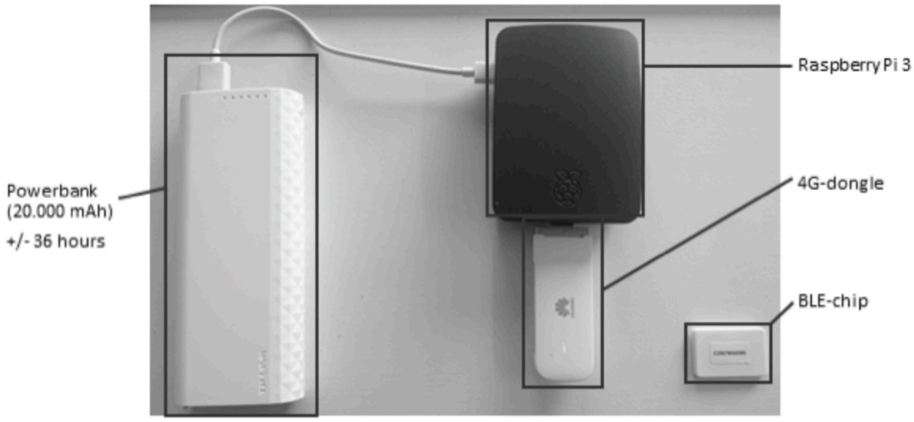

Figure 5. Data capture system incl. BLE beacon, BLE gateway with 4G connection, and power bank.

The gateways were put in place in predefined zones so that the gateway zones collectively covered all movements in the entire building. The floor layout in this case required three gateways per floor. All movements of workers from zone to zone could then be detected from the entering of the building, movements between the floors, movements on floors, and time presence on work locations.

Next the interviews with the workers provided the insights in their work and team organisation and the value adding time merely needed for installing the doors. Installing one door consisted of five standard sub-activities with a minimum of 10 minutes each, and summing up to 60 minutes, equally per door:

- preparing door frame: 15 minutes
- installing and fine-tuning door: 10 minutes
- drilling hole and putting in lock: 15 minutes
- installing and fine-tuning door closer: 10 minutes
- installing door handle and other finishing: 10 minutes

Data Processing

The iCONS system processed the detection data from the beacon real time via the 4G connected gateways to the cloud storage. The iCONS system returned the captured data of the workers' time spent information via an online dashboard representing the real time detected data.

Further data processing into useful information for further analysis was done manually. This resulted in overviews of spent time intervals per zone and floor. Ultimately the time presence intervals of the two workers on work locations could be concluded.

The interview data enabled to calculate the value adding time per work location based in numbers of doors per work locations, per zone, and per floor.

DATA ANALYSIS

Time Spent on Work Locations

Data heuristics were applied reviewing and improving the automated data. This has led to increased time spent figures, because of typical and specific omissions in the data captured after processing.

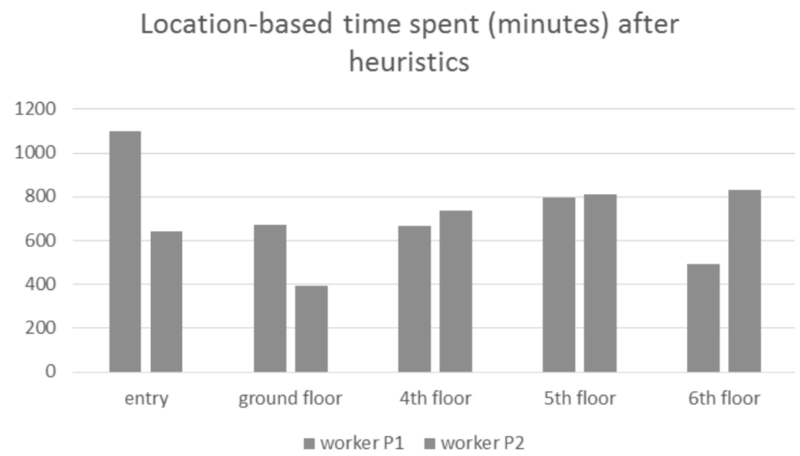

Figure 6: overview of time spent per floor for both workers after heuristics.

Now exact time spent per zone per floor per worker was concluded. In the data we can see the presence for worker P1 and P2 differs per floor. The difference was confirmed by the workers in the interviews, based on the agreed work division amongst them (figure 6):

- Worker P1 mainly worked on lower floors and took care of logistics, and thus spent more time on walking near the building entrance and ground floor.
- Worker P2 mainly worked on higher floors and was particularly focused on installing doors.

Based on the type of activity per floor in the particular weeks, roughly the time spent and movements on the higher floors corresponded to installing doors, so expectedly for larger this would include productive and value adding time. While the time spent and movements on ground level represented mainly logistics and support activities (coordination, transport, walk) which strictly speaking would correspond to unproductive and non-value adding time (table 1).

Table 1: Time spent by workers in building

	P1	P2	Total	Work on floors	Walk etc elsewhere
Entrance	1099	643	1742	-	X
Ground floor	670	395	1065	-	X
Floor 4	666	735	1401	X	-
Floor 5	796	812	1608	X	-
Floor 6	490	833	1323	X	-
Estimate added undetected	600	600	1200	-	X
Total	4321	4018	8339	4332	4007

Time Intervals Per Location

The second data representation for analysis is the divide in 4-time intervals per location. This representation identifies the time spent on work locations for 0-1 minutes, 1-5 minutes, 5-10 minutes, and >10 minutes (figure 7). The figure shows worker P2 has been present for a longer time in work locations and notably more than 10 minutes. This supported the interviews saying worker P2 has been doing most of the installation of doors. While worker P1 has been doing most of the supportive work, including logistics, and being less time on site.

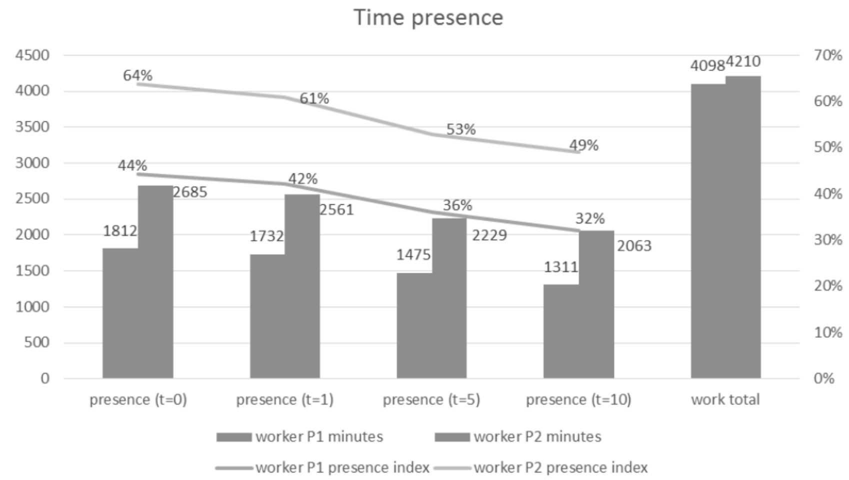

Figure 7: overview of time spent per floor for both workers after heuristics.

Notably the time spent interval of more than 10 minutes is of importance while this is the minimum time needed to be able to execute sub activities of door installation. All sub activities each take 10 minutes or more as mentioned above. The shorter time intervals will likely be walking or other kind of activities, and thus theoretically this represents 'non-productive' work i.e. non-value adding time spent (table 2).

Table 2: Uninterrupted presence of workers in building

	P1 minutes	P1 index	P2 minutes	P2 index	Total minutes
Presence 0-1 mns	1812	44%	2685	64%	4497
Presence 1-5 mns	1732	42%	2561	61%	4293
Presence 5-10 mns	1475	36%	2229	53%	3704
Presence >10 mns	1311	32%	2063	49%	3374
Total	4098		4210		8308

Based on the planning and the interviews with the workers amounts of doors and thus value adding time spent have be calculated (table 3).

Table 3: Value adding time spent by workers on doors installation

	Total doors	Doors in case study	Install Time per door	Install Time per floor
Floor 4	29	18	60	1080
Floor 5	31	21	60	1260
Floor 6	31	20	60	1200
Total	91	59		3540

Based on the above reasoning, if all aggregate time spent by category is compared, time spent for work on floors 4 to 6 takes 52% of total time spent by both workers in the building. Besides time spent on uninterrupted presence of 10 minutes or more (40%) nearly equals the value adding time for installing doors (42%) (table 4).

Table 4: Total time spent by workers per time category

	Location	Minutes	Portion
Total time spent	In building	8339	100%
Time spent on work	On floor 4 to 6	4332	52%
Uninterrupted presence >10 mns	At work location	3374	40%
Value adding time	Installing doors	3540	42%

DISCUSSION

Following the above correlations, one would expect to be able to predict productive time use and thus find indications of productivity in automated data systems as used in this study. However, data reliability is a major issue in this kind of studies. Undefined time spent and potentially undetected time also has influence on the data measurements and thus the data reliability to a certain extent.

Workers attitude to being detected may also cause some level of data unreliability. Workers could regard detection as an unwanted intrusion into their daily routine and this could have an effect on workers behaviour, work and movements. As a result, the motion tracking and thus the productivity assessment could be influenced, in a way comparable to the so-called Hawthorne effect (Mayo 1949).

In the case of this study the data analysis showed that the value adding time of 42% corresponded with the share of uninterrupted presence of 10 minutes and more of 40%. This is in line with the minimum time of 10 minutes needed for respective sub activities of doors installation in this case. This is confirmative while the sub activities generally require uninterrupted presence. The share of 40 to 42% also corresponds with existing productivity studies indicating productive or value adding time use in construction often around this figure, e.g. Hanna (2010) mentions 41%.

One could say the study demonstrated that the assessment of labour productivity correlates to time presence as a variable. To this aim work and tasks have been kept constant, and a limited and relatively standard type of work has been studied i.e. doors installation. This limits the interpretation and meaning of the study results. Further study would therefore be needed to shed light on the influence of more and other variables, and cases of less standard types of work, potentially leading to deviating results compared to this study.

Based on existing theories this study categorises findings regarding individual work in terms of productive and unproductive. However, in this study and elsewhere teams of workers apply defined and undefined division of roles and activities. For instance, in this study both workers agreed that worker P1 performed supportive activities and worker P2 performed mere installation. Strictly speaking worker P2 would therefore be more value adding than worker P1. However, worker P1 has enables worker P2 to be productive. In this case and elsewhere teamwork and team roles explain and condone one worker being more 'productive' than the other, in case the latter would be performing supportive tasks for the team as a whole.

In the debate around labour productivity in construction the premise is often that all workers need to be equally 'productive'. Although this is ignoring the necessity of having social, logistics and supportive roles in teams, in order to be productive as a team.

CONCLUSION

The study presented has shown that automated detection of time spent, and presence of workers is useful for indicating productive time and value adding time use. Limited application in small environments and low quantities tend to reflect reality and prove to be useful. Wider application in more complex environments will likely need more comprehensive detection methods and data heuristics in order to provide for reliable data.

The case presented included parameters of input productivity i.e. efficient time use in its own right. It is not necessarily reflecting output productivity i.e. effective time use based on output generated. One may assume productive time use per time unit will lead to more production and output. However, indications of increased output and favourable time presence do not necessarily mean that more value is generated by individual team members.

In conclusion, because of the limited case study, more applications and case studies are needed to enlarge data amounts and confirm conclusions in various contexts with different compositions of constants and variables. Also, more work is needed to improve accuracy of the data system and the conversion of time presence data into conclusions about productive time use, and ultimately value adding time use. Finally, the correlations between productive time use, value adding time use, and added value output will need further study.

ACKNOWLEDGEMENTS

The author is thankful for the collaboration with Alto University, the Volker Wessels company, Dura Vermeer company, and the subcontractor for the door installation for their efforts and willingness to be involved and contributing to this study.

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