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Uncovering and Visualizing Work Process Interruptions through Quantitative Workflow Analysis

Christopher Görsch[1], Alaa Al Barazi[2], Olli Seppänen[3], Hisham Abou Ibrahim[4]

Abstract

Question: Continuous improvement requires visualizing process constraints which interrupt workflows. Production control from a management perspective often operates at lower levels of information granularity than required at operational levels to perform work without interruptions. How can workflow interruptions in plumbing work be analysed and explained? How can an analysis of workflow interruptions help to close the information granularity gap between operational and management levels?

Purpose: The purpose of this paper is to evaluate methods for their fit in revealing and closing the information granularity gap between between operational and management levels.

Research Method: The paper examines workflows of plumbing work from video footage. This video data is classified and analyzed for frequency, causes, and effects of work interruptions.

Findings: Results indicate that value-supporting activities caused the largest proportion of interruptions. Moreover, the proportion of non-value-adding activities increases when durations of interruptions rise.

Limitations: The analyzed and tested data includes one working day of one worker in one certain construction project, which limits the meaningfulness of these results and explanations.

Implications: The conducted time-motion-study and its classified data set made it possible to develop an agent-based simulation model of construction workers

[1] Doctoral Candidate, Department of Civil Engineering, Aalto University, Espoo, Finland, christopher.0.gorsch@aalto.fi
2 Doctoral Candidate, Department of Civil Engineering, Aalto University, Espoo, Finland, alaa.albarazi@aalto.fi
3 Associate Professor, Department of Civil Engineering, Aalto University, Espoo, Finland, olli.seppanen@aalto.fi
4 Postdoctoral Researcher, Department of Civil Engineering, Aalto University, Espoo, Finland, hisham.abouibrahim@aalto.fi

behavior.

Value for authors: This paper provides a framework to examine workflow interruptions in craft work so that the information gap between operational and management levels is closed.

Keywords: continuous improvement, production control, time-motion study, workflow.

Paper type: Full paper

Introduction

On-site production in the construction industry comprises individual but interdependent units with different requirements, workflows and equipment that together create a product over time (Chua et al 2010). In such a dynamic, complex, and uncertain environment, adapting to unforeseen circumstances is key to ensuring coordinated and smooth operations. Deviations from schedules and standard processes cannot be completely prevented, although countermeasures are often taken at the management level and improvisation at the operational level (Hamzeh et al 2019).

Production control approaches like the Location-Based Management System and the Last Planner System aim to reduce waste, decrease variability, and increase productivity. Both are used to track completed tasks by comparing actual start and finish dates with planned milestones and adjusting accordingly through a technical or social process at trade and project levels (Kenley & Seppänen 2010). At trade levels, the detail of information required to perform daily or task-related work is of higher granularity than at a project level as in LPS and LBMS (Görschet al 2020; Grau et al 2020). Task orders at operational levels should include start and end dates as well as information on the products to be built, locations, materials, equipment, method, etc. (Song, Fischer, & Theis 2017). Production control, operating at a lower level of information, can be seen as a black box where the cause and effect of constraints remain unclear. However, to reduce variability and increase productivity, process inefficiencies in the form of waste must be made visible and eliminated accordingly (Koskela 2000). Time-motion studies enable collecting workflow information of individual workers in detail (Demirksen et al 2020) and reveal inefficiencies in the supporting environment.

The paper aims to analyse the revealed gap in information granularity (black box) by collecting workflow data from a time-motion study and analysing causes and effects of workflow interruptions. The study focuses on plumbing work, which is often considered complex. The paper aims to answer the research questions: 1) How can workflow interruptions in plumbing work be analysed and explained? 2) How can an analysis of workflow interruptions help to close the information granularity gap? Answering research question two leads to a discussion on how such a quantitative approach can be utilized in the future by a digital twin model to improve individual workflows and decision-making continuously in real-time (Sacks et al 2020).

Literature Review

Workflows and their efficiency have often been studied (Kalsaas 2010; Neve et al 2020; Thomas et al 1984) using work sampling methods observing on-site activities of workers either qualitatively (Grosskopf et al 2013) or quantitatively (Kalsaas et al 2014) Observations are often conducted over extended periods of time, but lack in considering long-term causes and effects Collected data points represent situational perceptions (snapshots taken at random or regular intervals) rather than ongoing work processes (Jenkins & Orth 2004).

Alternatively, video-based work sampling allows the application of time-motion studies. Time-motion studies are recognized as the combination of an industrial efficiency technique (time study) by Taylor (1911) and a labour process analysis technique (motion study) by Gilbreth and Gilbreth (1922). Activities needed to execute a task are continuously and directly observed, by tracking their time durations (Thomas et al 1991). Such studies are widely used for determining time needed to carry out tasks, finding most economical ways of executing work, smoothing workflows, standardization of methods, and work training (Barnes 1949; Meyers and Stewart 2002). Time-motion studies can examine workflows, including their share of direct work (Demirkesen, Sadikoglu, & Jayamanne 2020), and analyze causes of interruptions. Time-motion data can be seen as a quantitative and digital representation of an installers individual workflow based on real-time data. The analysis requires a high manual effort and is not done in real time. However, such a workflow representation allows comparisons between the as-designed, as-planned, as-built, and as-performed states of a construction project, which can be seen as a digital twin of a construction processes (Sacks et al 2020). This lean approach of a digital workflow visualization based on real-time data facilitates visualizing process inefficiencies and helps in selecting appropriate control for flow. This also allows production teams to prioritize their work to ensure a continuous subsequent flow of work (Sacks et al 2009).

Method

To observe an installer´s activities, a time-motion study was conducted. A video-based work sampling approach has been chosen to examine such a workflow in detail and study the causes of interruptions over the course of an entire workday. Before commencing research, the study was evaluated by the university's ethical committee and discussed with employee and employer unions. The concerns raised by labour unions and ethical committee led to muting audio tracks of all video material. Furthermore, face-blurring software was applied to anonymize personal data captured by cameras, such as faces, and car license plates. We conducted the study using helmet mounted cameras with attached safety equipment and power banks as shown in Figure 1.

Figure 1: Used camera and helmet equipment

The participant´s activities were filmed from an installer's point of view, covering an angle of about 180°. This gave the opportunity to continuously follow the worker's workflow. At the beginning of the data collection, the participant was skeptical about the approach, which clearly changed into a proactive attitude during the week. Due to the weight of the attached camera and power bank, the installer reported some discomfort at the beginning but dissipated over time. In addition, daily set up times for the camera was required, which accounted for 1,8 % of his total working time.

After recording on-site, the video footage was watched and simultaneously classified by researchers in excel, quantifying durations of activities and developing an understanding of its root causes. Based on previous research (Kalsaas 2010; Neve et al 2020; Pasila 2019), the video footage was classified according to 14 distinct categories. Table 1 describes these categories and shows whether the categories were considered as Value Adding (VA), Value Supporting (VS) or Non-value adding (NVA). Due to the muted video material, it was not possible to classify verbal conversations as VA, VS, or NVA. That is why "Discussions" have the value category "Unclassified" (UC). Additionally, break times and times due to research project related issues (helmet set-up, questions from participants to research assistants) have been excluded from the data set.

Table 1: Activity Classification Categories

Nr.	Category	Description	Value Category
1	Direct Work	Consist of activities, which increase the value of a building, component, or product.	VA
2	Inspection	Quality control measures that reduce the risk of recurrence.	VA
3	Work Preparation	All the preparatory work steps required to begin the work phase. Includes arrangement of tools and material on site (<= 5m from installation point). Includes a review of plans (as well as technical plans, material lists, schedules, etc.).	VS
4	Working with Material	Includes all work on material that prepares it for installation or holds it in place (e.g., cutting, joining with cable ties, etc.).	VS
5	Measurement	In addition to measurements, it includes recording measurement data in notebooks or on walls, for example. Includes small movements needed to take longer dimensions.	VS
6	Maintenance & Cleaning	Includes activities needed to continue working. For example, replacing tool batteries, repairing broken tools, cleaning during work, or cleaning after work.	VS
7	Hauling, short Distance	Transfer of material, equipment and tools, distance 5-30 meters from installation area.	VS
8	Hauling, long Distance	Transfer of material, equipment and tools, distance 30+ meters from installation area.	VS
9	Searching	Any activity looking for materials, tools, and equipment, which are not considered as work preparation (e.g., it takes a long time to find a missing tool).	NVA

Table 1: Activity Classification Categories (continued)

Nr.	Category	Description	Value Category
10	Movement	Any activity involving movement without a clear purpose and not included in other categories. For example, aimless movement without material, equipment, or tools.	NVA
11	Re-work	Activities that need to be done again. Usually related to an error in the installer´s work, previous work steps of others, or changed plans.	NVA
12	Non-work-related Actions	All other activities, which are not included in other categories. E.g., waiting times and times spent walking to the site, but not discussions (category 13).	NVA
13	Discussions	All conversations with other people (including phone conversations). The content of the conversations cannot usually be deduced due to muted recordings.	UC
14	Unclear	Activities, which cannot be identified due to low footage quality	UC

The classified data represents a continuous flow of all activities during the participants workday, rather than individual data points taken as snapshots in specific time intervals.

To build resilient processes that are protected from uncertainty, it is crucial to identify barriers to uninterrupted workflows in the form of activities that do not add value to the process (Grosskopf et al 2013). To understand workflow interruptions in more detail we explored the data set quantitatively on the number of activities, interruptions, and their average lengths. Causes of direct work interruptions were further investigated.

The research was conducted in spring 2021 in a hotel and office construction project. To answer the research questions and test the quantitative analysis approach, we focused on one working day of one worker (equivalent to 5 hours 20 minutes and 15 seconds). Data used in this paper are a subset of the data collected within a larger research project. The analyzed participant worked on plumbing tasks, installing copper pipes for warm and cold-water supplies. Overall, the construction project´s scope covered 22.000 sqm on eight floors and two underground floors. Additionally, two outside elevators were installed to reach off-site storage areas, which could impact movement on-site.

Results

The footage has been analyzed by classifying each activity by its category (Table 1) and duration. Figure 2 shows shares of time spent on activities based on the classification scheme.

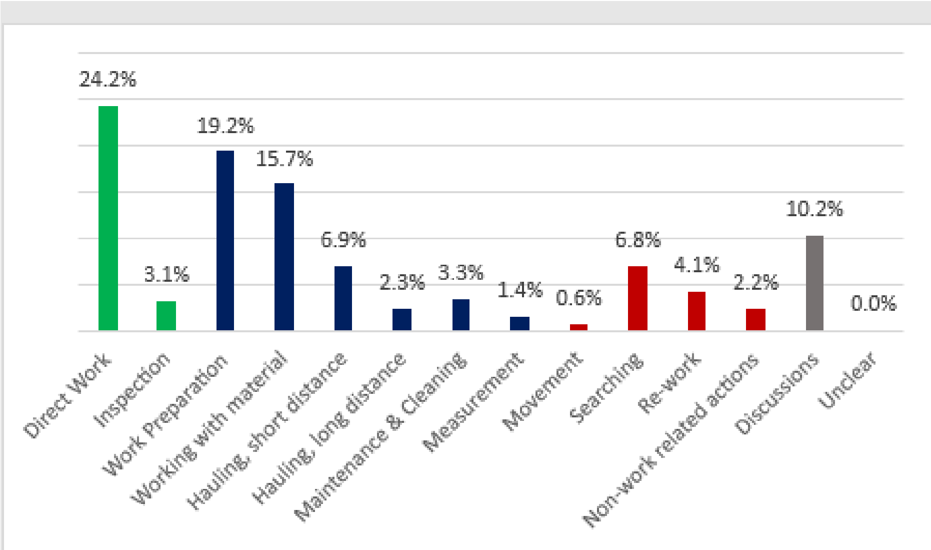

Figure 2: Share of Activities in percentage during one working day of plumbing work; Note: green bars = VA, blue bars = VS, red bars = NVA, and grey bars = UC activities

By adding up activity categories to value categories, figure 2 shows 27.3 % of time is spent on VA, 48.8 % on VS, 13.7 % on NVA, and 10.2 % on UC activities. Certain categories include wasteful activities. In this project, copper pipe work showed a high level of on-site customized solutions, resulting in high shares of "Work Preparation" (19.2 %) and "Working with Material" (15.7 %) inside the work location. Due to the high degree of customized solutions, direct work was often interrupted by workplace adjustments. These adjustments included the collection of tools, materials, and equipment relocations as well as other movement-related activities in the immediate vicinity of the installation area, even though the work area was constantly available and not occupied by other trades. In addition, 9.2 % of the installer's working time was spent on hauling activities, mostly within a radius of less than 30 metres. Although the storage areas were scheduled and accessible during working hours, there was a lot of movement due to frequent material and tool gatherings. Reasons for these frequent pickups were working with a step-by-step mentality, limited transport, and storage capacities and non-existent or insufficient work orders. Search activities (6.8 %) often arose due to the lack of material and tools during the actual task execution, as well as insufficiently organized storage areas. Other activities that reduced VA shares were "Discussions" with a 10.2 % share. Insufficient information flows were caused by e.g., outdated plans and schedules, and led to improvisation and the need of clarifications via face-to-face discussions, phone calls and instant messaging. Overall, these issues rarely prevented work, but led to improvisations and inefficient workflows.

Figure 3 visualizes the workers workflow by classified activities and their durations. From an installer´s perspective, workflow interruptions can be seen as the division of processes into individual activities that are supportive or unproductive in nature. Workflow interruptions are thought to occur when supporting processes and critical components are not managed (Ronen 1992). As a result, they can become a complex sequence of hand-offs between preparation, search, movement, physical and mental rearrangement, waiting, and improvisation inside and outside the work location.

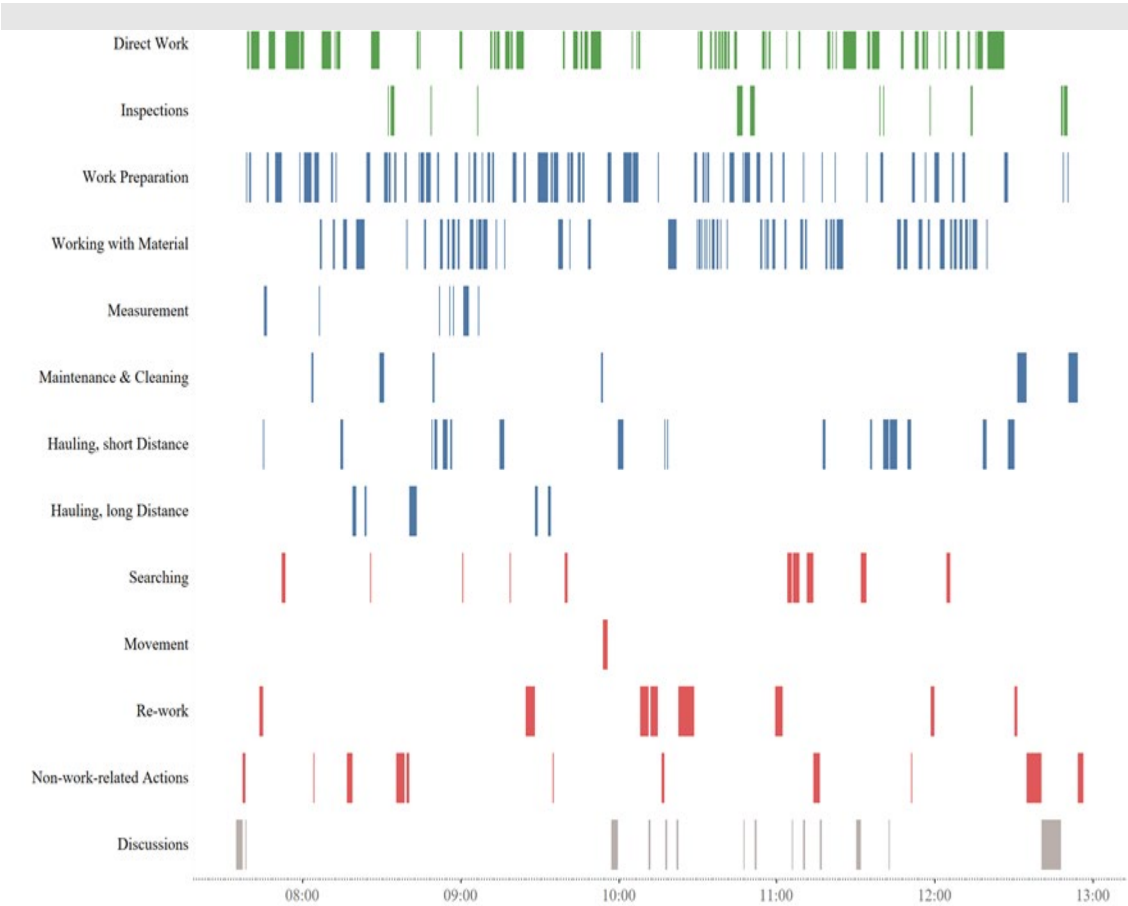

Figure 3: Classified & visualized Activities in plumbing Workflow; Note: green bars = VA, blue bars = VS, red bars = NVA, and grey bars = unclassified activities

The analyzed data shown in Table 2 contains 284 activities with an average duration of 68 seconds. This represents 283 activity changes within 5 hours and 20 minutes, approximately once a minute. Here, VS activities occur the most and show the lowest average duration per activity. “Work Preparation” and “Working with Materials” were the VS activities that were carried out the most. NVA activities and discussions appear to have the longest average duration per activity, but the lowest counts in occurrence. Furthermore, the data reveals a high number of other activities must take place before getting to “Direct Work”, here in the form of VS activities, as well as discussion and movement-related activities. Such activities are part of workers daily routines but often unanticipated when work gets planned on higher hierarchical levels and later hidden in low granularity levels of information utilized within schedules and plans.

Direct work is interrupted 60 times during the analyzed workday, most often caused by VS activities in the form of “Work Preparation” (27 times) and “Working with Materials” (23 times) as its successor. Interrupting direct work 61 times also mean starting it 61 times. Here, VS activities “Work Preparation” (27 times) and “Working with Materials” (34 times) were the most common predecessors to direct work, indicating the high degree of on-site customized solutions. The pipe fitting process ("Direct Work" and "Working with Material") included bending, cutting, drilling, screwing, levelling, welding. Due to the detailed level of customized work needed, the installers´ working position had to be constantly adapted in a tight working environment ensuring having all materials and tools constantly close by ("Work Preparation"). These supporting activities were managed by the worker himself and critical components had to be customized in-place, causing frequent workflow interruptions. Additionally, the coordination within the workspace was carried out by the installer. This coordination process often seemed unorganized and causing further interruptions, although work and storage locations were planned on higher hierarchical in advance.

Table 2: Duration of interruptions and contained share of activities

Classification	Share of Time	Average Duration	Number of Activities
Value Adding	27.2%	01:11	74
Value Supporting	48.9%	00:58	162
Non-Value-Adding	13.7%	01:41	26
Unclassified	10.2%	01:29	22
Direct Work	24.2%	01:16	61
Inspection	3.1%	00:45	13
Work Preparation	19.2%	00:57	65
Working with material	15.7%	00:52	58
Hauling, short distance	6.9%	01:10	19
Hauling, long distance	2.3%	01:29	5
Maintenance & Cleaning	3.3%	01:20	8
Measurement	1.4%	00:39	7
Movement	0.6%	01:50	1
Searching	6.8%	02:44	8
Re-work	4.1%	01:06	12
Non-work-related Actions	2.2%	01:25	5
Discussions	10.2%	01:29	22
Unclear	0.0%	00:00	0

A closer look at different interruption sequences (Table 3), defined as a chain of activities between "Direct Work", revealed an average time of 3:29 min between “Direct Work” activities. A total of 59 sequences were observed and analyzed. These sequences were clustered according to their duration (D) of interruptions in minutes (<1, >1, <5, <10 min), considering the proportion of activities they contained. There were 23 (accountable for 19.4 % of total interruption time) sequences shorter than a duration of one minute, 24 with a duration between one and five minutes (23.5 %), 4 between five and ten minutes (12.4 %), and 8 longer than ten minutes (44.7 %).

Table 3: Duration of interruptions and contained share of activities

	D< 1 min	1min< D <5min	5min< D <10min	D> 10min
Inspection	0.04	0.02	0.14	0.02
Work Preparation	0.16	0.30	0.35	0.24
Working with material	0.14	0.32	0.15	0.20
Hauling, short distance	0.07	0.09	0.15	0.09
Hauling, long distance	0.00	0.00	0.00	0.07
Maintenance & Cleaning	0.15	0.00	0.03	0.03
Measurement	0.00	0.02	0.01	0.03
Movement	0.00	0.00	0.00	0.02
Searching	0.03	0.05	0.09	0.14
Re-work	0.01	0.16	0.00	0.03
Non-work-related Actions	0.04	0.01	0.00	0.04
Discussions	0.37	0.04	0.07	0.10

Within short interruptions (< 1min), the share of discussions is the highest. While working on the task the installer was constantly in discussions with another installer, on the other side of the corridor. Since recordings are muted, the content of these conversations is unknown, although activities and gestures while discussing suggest a high proportion of work-related issues. These activities indicate the need for on-site communication building understanding due to insufficient plans, directives, and schedules. Furthermore, the short interruption cluster is characterized by activities happening in the direct vicinity of the installation area. Here, VS activities "work preparation", "working with materials" and "maintenance and cleaning" have higher proportions than others, as the high degree of customized work on-site often requires rapid material and location adjustments. These aspects account for approx. 15 % of interruptions times, which is left to the installer´s individual workspace and process coordination.

The highest shares in medium-long interruptions (between 1 and 5 min & between 5 and 10 min) are “Work Preparation” and “Working with Material”. The various aspects of both activities (see Table 1) require shorter and longer time periods for their execution. That is why both are represented with high proportions in all clusters. Noticeable here the proportion of "rework" is extraordinarily high, which appears coincidentally due to the small size of the data set. Additionally, “Hauling, short distance” activities reach their peak with a share of 15 percent in the “5min< D <10min” cluster. An activity correlated to “Hauling, short distance” seems to be “Searching,” since its share starts rising within the same cluster. The installer needed often more supplies since he was often running short while on a task. Although his storage area was assigned close to his installation area, supply shortages led to more movement, especially because components had to be searched within the unorganized storage area. From this perspective, data indicates that these two activities are interdependent and happen often sequentially. Another activity peaking in the same cluster is “Inspection,” caused by the need to build more understanding of site and installation conditions, which is not made transparent by plans and schedules.

The long interruption cluster shows lower shares in “Work Preparation” and “Working with Material” activities than in the medium-long clusters. Noteworthy here is the peak in “Searching" activities at 15 percent, as well as the first and only occurrence of "Hauling, long-distance" activities. Overall, the longest interruptions sequences included the most NVA activities, which partly goes back to the longest average duration of NVA activities. The inclusion of high shares of "Hauling, long-distance" in combination with the highest shares of NVA activities, indicates that NVA activities happen more likely outside the installation area. Additionally, it initiates more “Discussions” since its share rises here again in comparison to the middle long clusters.

Discussion

Answering research question one, most frequent workflow interruptions have been caused by VS activities, ensuring the continuation of direct work. Although such activities seem to be logical and needed, the amount of them should be questioned and further analyzed for improvement strategies. A higher degree of prefabricated components and increased logistical support of workers on site can be seen as approaches for improvement.

Currently, VS activities are often informally squeezed into the installer’s schedule, although he is hired for simply installation work. This “informal squeezing” can be interpreted as the unawareness of needed process steps carrying out installation work from a management perspective. Such unawareness seems to lead to constraint analyses operating on lower levels of granularity than what is needed to carry tasks out without interruptions. This lack of awareness is at conflict with Lean principles, which calls for continuous validation and verification (Dehlin & Olofsson 2008).

The analyzed and tested data includes one working day of one worker in one certain construction project, which limits the meaningfulness of these results and explanations. However, the purpose of the paper was to present ways of analyzing workflows quantitatively and explaining them, rather than drawing conclusions on different hierarchical levels, due to the limited size of the tested data.

Future research can build on these analytical data structures and explanations. The analyzed data can construct a foundation for answering research question two. For example, utilizing an agent-based simulation approach based on probability functions from all classified activities can depict workers behavior. To utilize such an approach, it needs to be enriched with robust real-time data from field observations. Such data expansion could then answer questions of validity and reliability at trade, project, or industry level. In turn, it would raise questions of data handling, which currently relies on capturing real-time data (video material) without classifying and analyzing data in real-time. Thus, the utilization of information and communications technology systems to preform continuous time-motion analysis for workers and other resources need to be investigated.

Due to high portions of movement-related activities, increasing shares of VS and NVA activities, it seems reasonable to track movement patterns on-site to enrich an agent-based simulation approach with location data. This enrichment can support automized data collection and the possibility of real-time data analysis. Location data can be seen as a digital representation of up-to-date workflow information, which in combination with probability functions can be used as a feedback cycle to reflect the specificity of each construction site. Ultimately, enriching the simulation approach with additional resources e.g., location data, can contribute to observe current states of sites, predict next states, and hypothetical forecast future performance and states by altering some sets of parameters using “what if” scenarios. Such a proactive concept of analyzing and optimizing construction planning is referred to as the digital twin of construction (Rafael Sacks 2020).

Conclusion

This study shows ways of analyzing a quantitative plumbing workflow representation from video recordings by conducting a time-motion study, observing, and classifying an installer´s activities. Workflow interruptions are explained as time spent on other activities than direct work and can be analyzed based on classified activities during an installer´s working day. Due to the quantification of time spent on certain activities it is possible to analyze durations and causes of workflow interruptions. Results indicate the nature of on-site workflow patterns, frequencies of workflow interruptions in plumbing work (most often VS activities), and how certain inefficiencies affect the span of these interruptions. Due to the utilization of the developed data structure and the application of simulation approaches including up-to-date and reliable field data, “what-if” scenario evaluations can be extracted and the information granularity gap can be closed by opening the black box, which keeps cause and effects often undetected. Future research should extend the data sample, which could then be used to construct a foundation for a digital twin of workers' behavioral algorithms per construction site and reduce the amount of waste in the form of workflow interruptions.

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References

Barnes, R. M. (1949). *Motion and Time Study* (3rd ed.). New York: John Wiley & Sons, Inc.

Chua, D. K. H., Yeoh, K. W., & Song, Y. (2010). Quantification of Spatial Temporal Congestion in Four-Dimensional Computer-Aided Design. *Journal of Construction Engineering and Management*, *136*(6), 641–649. https://doi.org/10.1061/(asce)co.1943-7862.0000166

Dehlin, S., & Olofsson, T. (2008). An evaluation model for ICT investments in construction projects. *Electronic Journal of Information Technology in Construction*, *13*(Special issue Case studies of BIM use), 343–361.

Demirkesen, S., Sadikoglu, E., & Jayamanne, E. (2020). Investigating effectiveness of time studies in lean construction projects: case of Transbay Block 8. *Production Planning and Control*, *0*(0), 1–21. https://doi.org/10.1080/09537287.2020.1859151

Gilbreth, F. B., & Gilbreth, L. M. (1922). Process Charts and Their Place in Management. *Annual Meeting of The American Society of Meachanical Engineering*, 38–41.

Görsch, C., Seppänen, O., Peltokorpi, A., & Lavikka, R. (2020). Construction Workers' Situational Awareness – An overlooked Perspective. *28th Annual Conference of the International Group for Lean Construction, IGLC 2020*, 937–948. Berkeley. doi.org/10.24928/2020/0022

Grau, D., Abbaszadegan, A., & Assanair, R. (2020). Process versus operations workflow - Making the case for continuous monitoring of construction operations. *28th Annual Conference of the International Group for Lean Construction, IGLC 2020*, 563–572. https://doi.org/10.24928/2019/0197

Grosskopf, J., Menezes, A. S., & Santos, D. G. (2013). Proposal of activities that facilitate work in order to avoid workflow interruptions caused by making-do. *21st Annual Conference of the International Group for Lean Construction 2013, IGLC 2013*, 655–664.

Hamzeh, F., Faek, F., & AlHussein, H. (2019). Understanding improvisation in construction through antecedents, behaviours and consequences. *Construction Management and Economics*, *37*(2), 61–71.

Jenkins, J. L., & Orth, D. L. (2004). Productivity improvement through work sampling. *Cost Engineering*, *46*(3), 27–32. https://doi.org/10.4108/eai.14-10-2015.2261601

Josephson, P. E., & Bjorkman, L. (2013). Why do work sampling studies in construction? the case of plumbing work in Scandinavia. *Engineering, Construction and Architectural Management*, *20*(6), 589–603. https://doi.org/10.1108/ECAM-12-2011-0108

Kalsaas, B. T. (2010). Work-Time Waste in Construction. *Proceedings for the 18th Annual Conference of the International Group for Lean Construction*, 507–517.

Kenley, R., & Seppänen, O. (2010). *Location-Based Management System in Construction: Planning, Scheduling and Control*. London and New York: Spon Press.

Koskela, L. (2000). *An exploration towards a production theory and its application to construction*. Espoo: Finland: VTT Technical Research Centre of Finland.

Meyers, F. E., & Stewart, J. R. (2002). *Motion and Time Study: For Lean Manufacturing* (3rd ed.). New Jersey: NJ: Prentice Hall.

Neve, H., Wandahl, S., Lindhard, S., Teizer, J., & Lerche, J. (2020). Learning to see value-adding and non-value-adding work time in renovation production systems. In *Production Planning and Control* (Vol. 0). https://doi.org/10.1080/09537287.2020.1843730

Pasila, H.-J. (2019). *Impact of Lean-Intervention on Productivity*. Aalto University.

Ronen, B. (1992). The complete kit concept. *International Journal of Production Research*, *30*(10), 2457–2466. https://doi.org/10.1080/00207549208948166

Sacks, R, Treckmann, M., & Rozenfeld, O. (2009). Visualization of work flow to support lean construction. *Journal of Construction Engineering and Management*, *135*(12), 1307–1315.

Sacks, Rafael, Brilakis, I., Pikas, E., Xie, H. S., & Girolami, M. (2020). Construction with digital twin information systems. *Data-Centric Engineering*, *1*(6). https://doi.org/10.1017/DCE.2020.16

Song, M. H., Fischer, M., & Theis, P. (2017). Field Study on the Connection between BIM and Daily Work Orders. *Journal of Construction Engineering and Management*, *143*(5), 06016007-1-06016007–4. https://doi.org/10.1061/(asce)co.1943-7862.0001267

Taylor, F. W. (1911). *The principles of scientific management*. New York & London: Harper & Brothers Publishers.

Thomas, B. H. R., Maloney, W. F., Smith, G. R., Handa, V. K., & Sanders, S. R. (1991). *Modelling Construction Labor Productivity*. *116*(4), 705–726.

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