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# BREAKDOWN WORK SAMPLING

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## ABSTRACT

The Work Sampling (WS) technique has been used in the construction industry since the 1960s to understand how workers spend their time. However, the WS categories have exhibited variation throughout history due to interpretation and application discrepancies. This lack of consensus on what represents Value-Adding-Work (VAW) and Non-Value-Adding-Work (NVAW), has hindered the use of data from previous WS studies for further analysis. For this reason, this research aims to understand how the data obtained from the WS application can be analyzed to discuss value. To address this question, the authors adopted a case study as the primary research strategy. The phenomenon of the present study comprises the activities involved in the renovation process in residential buildings. The phenomenon is studied through the application of the WS technique. The authors adopted previous analyses from the existing literature and proposed new types of analyses. The discussion section presents various kinds of analysis based on a breakdown of categories into codes: (1) general analysis; (2) a category breakdown analysis; (3) one single component/material analysis; (4) recategorized activities analysis; and (5) correlation analysis. The proposal of a detailed code classification, named breakdown work sampling, represents the main novelty of this study.

## KEYWORDS

Work sampling, construction site, waste time, direct work.

## BACKGROUND

Work sampling (WS) is a technique first introduced in 1920s by the British industrial engineer Leonard Tippett in which work can be observed and the amount of time spent on various tasks can be determined (Barnes, 1968). WS was initially referred to as the "snap-reading method" due to its instantaneous observation nature (Tippett, 1935). The snap-reading method was executed at random time intervals using the first random table invented by Tippett (Tippett, 1935). In 1940, R. L. Morrow, who often is credited with importing the method to America, renamed the snap-reading method to the ratio-delay survey (Heiland & Richardson, 1957). In 1952, the ratio-delay survey evolved into "Work Sampling" and began to gain increased popularity during the mid-twentieth century by industrial engineers (Gouett et al., 2011).

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In the construction industry, in the 1960s, H. R. Thomas (1991) conducted one of the first WS studies. The author provided relevant insights on how a WS study could be planned and how the data could be analyzed. Currently, WS is being used by a few large construction companies to benchmark their projects so that improvements can be made and quantified. Some contractors have productivity departments that complete these studies (Gouett et al., 2011).

WS consists of a quantitative approach of intermittent, random, and instantaneous observations of work activities of multiple workers by independent observers (Barnes, 1968). The theory of WS is based on the laws of probability, which indicate that observations taken at repeated random times will have the same distribution. Hence, random observations can be translated into percentages of time spent in existing activities (Barnes, 1968).

WS can estimate the proportions of the total time spent on a task in terms of various work categories. The WS categories have exhibited variation throughout history due to interpretation and application discrepancies. Before 1985, WS studies adopted the two-category classification of direct and non-direct work. This partially reflects Ohno's (1988) understanding of work as divided into Waste Work (WW) and Value-Added Work (VAW). However, Ohno clarified that the VAW category must be further understood as consisting of Direct Work (DW) and Non-Value-Added-Work (NVAW), which does not add value but is needed under the present work conditions. The DW category is generally understood as the amount of direct, physical, and output producing work. It can be seen as the time a worker spends producing tangible output, e.g., square meters of bricks installed (Choy & Ruwanpura, 2006). In general, most WS studies agree on this definition of DW (Wandahl et al., 2021). However, for the NVAW category, a considerable inconsistency in concept and terminology appears. Some research categorizes all NVAW as WW, while other studies have a more detailed view of NVAW as several subcategories like preparatory work. Generally speaking, NVAW is in WS referred to as Indirect Work (IW), resulting in WS having three categories of time DW, IW, and WW (Wandahl et al., 2021).

The non-direct work or unproductive work category is the opposite of DW and has traditionally been quite inconsistent and included everything besides DW, such as supportive work (e.g., transporting bricks to the final destination by hand) and waiting time (e.g., waiting to receive bricks in the place of execution). The non-work definitions have fluctuated throughout the history of WS and often have been broken down into subcategories. After 1985, research generally applied the categories of DW, IW, and WW, however, with different names and subcategories, e.g., transport, travel, instruction, personal time, delay, etc. (Gong et al., 2011).

The most comprehensive version of WS in the construction sector is Activity Analysis (AA) (CII, 2010). AA differs from the conventional WS technique as it provides for a greater analysis potential due to a more consistent definition of DW, IW, and WW categories. AA groups activities of the monitored construction operation into one of seven categories. One category of DW: (1) direct work. Three categories of IW: (2) preparatory work, (3) tools/equipment, and (4) material-handling. Lastly, three categories of WW: (5) waiting, (6) travel, and (7) personal, all of which adhere to consistent definition parameters. AA is advantageous on sites that require a more detailed depiction of the construction operation without investing in the personnel for full-time direct observations (CII, 2010). Based on this idea, (Kalsaas, 2010, 2011) proposed adopting a detailed work sampling method to measure workflow efficiency.

It has been difficult to establish an accurate picture of DW, IW, and WW definitions. In general, practitioners tend to wrongly perceive IW (e.g., material handling) as value-adding, thus DW. However, this has no consistency with previous WS. Hence, it is noteworthy that it is necessary to understand work activities classification and the relationship between VAW and NVAW to better analyze previous data. Table 1 aims to summarize the main work categories used in WS literature.

Table 1: WS categories adopted by previous studies.

| References | Work Sampling categories adopted | | |
|---|---|---|---|
| | **Direct Work (DW)** | **Indirect Work (IW)** | **Waste Work (WW)** |
| Handa and Abdalla (1989) | Direct Work | Transportation; Waiting; Travel; Tool & Materials; Receiving Instructions; | Combined rates of Breaks & Personal & Late Starts; Unexplained |
| Oglesby et al. (1989) | Direct Work | Transport; Travel; Instruction; | Personal time; Delay |
| Hammarlund and Rýden (1990) | Direct work, | Transporting material and equipment; Planning | Waiting; Unused time |
| Thomas (1991) | Direct Work | Indirect Work | |
| Lee et al. (1999) | Value-added | Non-value added but necessary | Non-value added and unnecessary |
| Allmon et al. (2000) | Productive actions, picking up tools, measurement, holding material, inspecting, clean-up, putting on safety equipment | Supervision, planning, instruction, travel, getting materials) | Waiting, standing, sitting, non-action, personal time, late starts, early quits |
| Agbulos and AbouRizk (2003) | Value-adding process steps | | Non-value adding process steps |
| Jenkins and Orth (2004) | Installation, fabrication, testing, demolition | Materials handling, design, communication, safety, positioning equipment | Waiting, personal needs, inspections, rework |
| Diekmann et al. (2004) | Value-adding | Non-value adding | Pure non-value adding |
| Thune-Holm and Johansen (2006) | Productive Time | Indirect time | Change-over time; Personal time |
| Strandberg and Josephson (2005) | Direct Work | Indirect work; Material Handling; Work planning; | Waiting; Moving between working spots; Unexploited time |
| Choy and Ruwanpura (2006) | Direct work | Preparatory; Material Handling; Tools | Travel; Personal; Waiting |
| Alinaitwe et al. (2006) | Building, Handling materials; Clean-up, Unloading | Supervision; Material distribution, setting out, testing | Absent; Waiting, Not working |
| Kalsaas (2010) | Direct Work | Personal Time; Coffee and lunch breaks; Handling material; Work planning; Waiting; Cleaning up; Reworking; Rigging; Unloading; Inspection | |
| Espinosa-Garza et al. (2017) | Productive | Preparation; Work supplements; Administrative; Unusual elements | Unproductive; |
| Sheikh et al. (2017) | Direct Work | Preparatory Work and Instructions; Travelling; Tools and Equipment; Material handling | Personal; Waiting |
| Neve et al. (2020) | Production | Talking; Preparation; Transportation; | Walking; Waiting |

According to the terminologies identified in the WS literature, the term DW has been used in all the different classifications for WS application without exception. Some authors (Allmon et al., 2000) included activities in the DW category such as holding material, measurement, and inspections, traditionally considered IW (Ohno, 1988). The IW category represents the category that has been broken down into most subcategories. The IW subcategory that appears in most of the classifications is transport, also called material handling (Sheikh et al., 2017; Strandberg & Josephson, 2005) or material distribution (Alinaitwe et al., 2006). Some authors employed the term travel to differentiate a walking activity from a transportation activity (Oglesby et al., 1989; Sheikh et al., 2017). This term, in many cases, causes a misunderstanding, making construction academics use the term travel to include walking with and without materials. The subcategory waiting represents the category that generates more controversy among the studies. This category was initially considered an IW task (Oglesby et al., 1989); however, it has recently been considered as waste (Choy & Ruwanpura, 2006; Neve et al., 2020; Sheikh et al., 2017). This interpretation is also in line with Ohno's (1988) definition of waste.

This brief literature review revealed that the problem, also pointed out by Wandahl et al. (2021) after reviewing 474 WS studies, caused by the lack of consensus on what represents a VAW and NVAW work activity during the application of the WS technique, had hindered the use of data from previous WS studies for further analysis. Consequently, in this study, the Research Question (RQ) is represented by the following question: How can the data obtained from the WS application be analyzed to discuss value?

To address this question, the authors adopted a case study as the primary research strategy since this research strategy is helpful for answering "how" and "why" questions and where in-depth research is needed using a holistic lens (Yin, 2003). This study differs from previous AA studies or detailed WS applications due to the breakdown classification of the work categories considering all tasks conducted in one single construction process.

# RESEARCH STRATEGY

A case study is an empirical inquiry that investigates a contemporary phenomenon in depth and within its real-life context, especially when the boundaries between phenomenon and context may not be clearly evident (Yin, 2003). The authors studied the phenomenon through the application of the WS techniques. In this research, the WS procedure followed the following steps: (1) selecting the construction project and the construction process; (2) clarifying the categories of the activities to be measured; (3) developing data collection forms; (4) data collection; (5) deciding the confidence interval and the accuracy desired and calculating the number of observations needed; and (6) data analysis.

## STEP 1: SELECTING THE CONSTRUCTION PROJECT AND THE CONSTRUCTION PROCESS

The phenomenon of the present study comprises the activities involved in the renovation process of internal walls, ceilings, windows, and balconies in residential buildings. The phenomenon actors are the carpenter trade's 22 workers. The real-life context is represented by the construction renovation project located in the city of Odense, Denmark. This project consists of four-floor-story buildings; each floor presents two apartments, and there are a total of 587 housing units. The buildings were established around the year 1950. During the renovation work, tenants have the right to use their apartments. Hence, not all of the story buildings were undergoing renovation work at the same time. This agreement affected the construction site logistics, as the contractor had a restricted area for the construction activities. For this reason, the logistical aspects played an essential role in this project.

## STEP 2: CLARIFYING THE CATEGORIES OF THE ACTIVITIES TO BE MEASURED

Two of the three authors of this paper were the observers in the study. The study lasted 10 days. During the first day of the job site visits (Day 1) the two observers developed the breakdown work codes. A total of 41 WS codes were developed within six categories (Figure 1Figure 1): (1) Production (13 codes); (2) Talking (2 codes); (3) Preparation (10 codes); (4) Transportation (10 codes); (5) Walking (3 codes); and (6) Waiting (3 codes). The six-category classification was adopted to keep consistent with previous WS studies carried out by the research team as part of a long-term research project.

| Category | Code | Description |
|---|---|---|
| Production | C101 | Installing steel profiles |
| | C102 | Installing insulation on windows |
| | C103 | Installing steel sill on windows |
| | C104 | Grouting around windows |
| | C105 | Demolishing old bricks (hammering) |
| | C106 | Installing insulation |
| | C108 | Installing green plastic and wall nets |
| | C109 | Installing wood panels |
| | C110 | Installing gypsum panels |
| | C111 | Installing windows |
| | C112 | Installing fire proofing plates |
| | C113 | Installing door frames |
| | C114 | Installing tiles on balconies |
| Walking | C301 | Walking for having a break |
| | C302 | Walking for materials and tools |
| | C303 | Walking without (known) purpose |
| Waiting | C601 | Waiting for material |
| | C602 | Waiting for a coworker |
| | C603 | Waiting without any (known) purpose |
| Talking | C501 | Talking about the process |
| | C502 | Talking without any (known) purpose |
| Preparation | C201 | Measuring with laser |
| | C202 | Measuring with ruler |
| | C203 | Preparing steel profiles |
| | C204 | Cutting insulation |
| | C205 | Cutting gypsum panels |
| | C206 | Cutting wood panels |
| | C207 | Preparing the hole for the window installation |
| | C208 | Removing temporary supports for balconies |
| | C209 | Cleaning |
| | C210 | Preparing tools |
| Transport | C401 | Transporting gypsum panels |
| | C402 | Transporting tools |
| | C403 | Transporting support equipment |
| | C404 | Transporting step ladder |
| | C405 | Transporting steel profiles |
| | C406 | Transporting window frames (plastic) |
| | C407 | Transporting wall nets |
| | C408 | Transporting insulation |
| | C409 | Transporting waste |
| | C410 | Transporting wood frames |


Figure 1: The 41 WS codes developed and four examples of WS codes used for carpenters' tasks.

## STEP 3: DEVELOPING DATA COLLECTION FORMS

The development of the data collection form aimed to maintain control and consistency of the data to be gathered. An Excel spreadsheet was developed, which included the 41 codes. For gathering data, the authors adopted the smartphone application "Counter – Tally Counter" by Tevfik Yucek. This application allowed the researchers to digitally record each observation with an exact time stamp and to export this data in a .csv-format for further processing.

## STEP 4: DATA COLLECTION

For gathering data at the construction site, the two observers conducted nine days of job site visits (8 hours/each) from Day 2 to Day 10. The data collection period was the same as the construction workers' working hours, from 06:30 to 14:30. Lunch break was from 10:30 to 11:00. Digital devices such as mobile phones and tablets were used for data collection at the construction site during random tours. These devices allowed the research team to gather data to take photos and videos of the construction processes studied.

## STEP 5: DECIDING THE CONFIDENCE INTERVAL AND CALCULATING THE NUMBER OF OBSERVATIONS NEEDED

To achieve statistically significant process variables, enough random observations were conducted for the workers' crew (N=22) performing the activities under study. The formula that describes the relation between the number of observations needed and the desired accuracy is presented in Equation 1.

$$n = \frac{p * (1 - p)}{(\sigma)^2} \tag{1}$$

Where:
n = the total number of observations during the first day of data collection
p = expected percent of time required by the most important category of the study (e.g., DW)
σ = standard deviation percentage

The authors conducted nine days of WS observations on the job site (represented by the nine different blue colors used in Figure 2) within the eight working hours (horizontal axis in Figure 2). The working time was divided into hourly study periods, from 06:00-07:00 until 14:00-15:00, resulting in eight study periods per day (number of bars in Figure 2), totalizing 72 study periods, each representing a random tour around the site. The authors collected a homogeneous sample resulting in an average of 26 observations per study period (secondary vertical axis in Figure 2). A stabilization curve of the share of observations of the production codes (DW codes) was created to provide a visual check of the accuracy of the collected data (Figure 3). The curve stabilizes at 29% after around 1,200 observations, i.e., after Day 6. Upon completion of nine days of data collection, a total of 2,100 samples (n) were recorded (horizontal axis in Figure 3) with a 95% (p) confidence interval of ± 2% (σ).

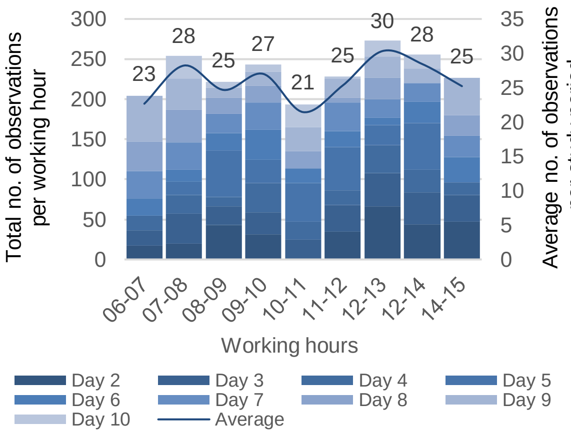


Figure 2: Frequency distribution of observations throughout the day (n=2,100).

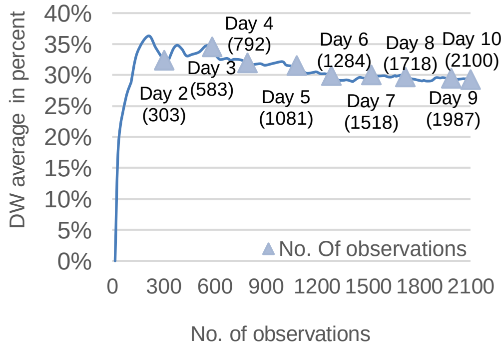


Figure 3: Stabilization curve of the DW observations (n=2,100).

## STEP 6: DATA ANALYSIS

The analysis and explanation of the phenomenon of this study set out to stipulate a presumed set of causal links about it and "how" it happened. For this reason, the analysis of data collected during the case study aimed to explain how the data obtained from the WS application can be analyzed to discuss value. The authors adopted previous analyses from the existing literature and proposed new sorts of analysis, such as: (1) general analysis, to understand how the time was spent on VAW throughout the workday and the days of data collection; (2) a code category breakdown analysis, to understand which kind of activity is the most time consuming of each main category; (3) single component/material analysis, to understand the distribution of the time for a given task; (4) recategorizing activities, to be able to compare data to previous studies where observations have been categorized differently; and (5) correlation analysis, to examine the internal relationship between the different codes.

# FINDINGS

## GENERAL ANALYSIS

Several general analyses can be conducted looking into the results of the 6 main WS categories. Most previous research studies have focused on presenting the average percentage obtained from each WS category. These numbers can be seen in the "average" columns in Figure 4 (a) and (b). Production and preparation each account for 29% of the observations, talking for 13%, transportation for 17%, walking for 10%, and waiting for the remaining 3%. In this study, Figure 4 (a) and (b) can lead to two types of further discussion; the distribution of the time spent on VAW throughout a workday and throughout the days of data collection. The distribution among the 6 main categories changes throughout the day. This change is shown in a general way in Figure 4 (a). A different representation of the change is shown in Figure (a) and Figure (b), using two pie charts for two of the workhours. Most of the observations in the first workhour of the day are of transportation and preparation, whereas in the middle of the workday, from 11:00 to 12:00, most observations are of productive work.

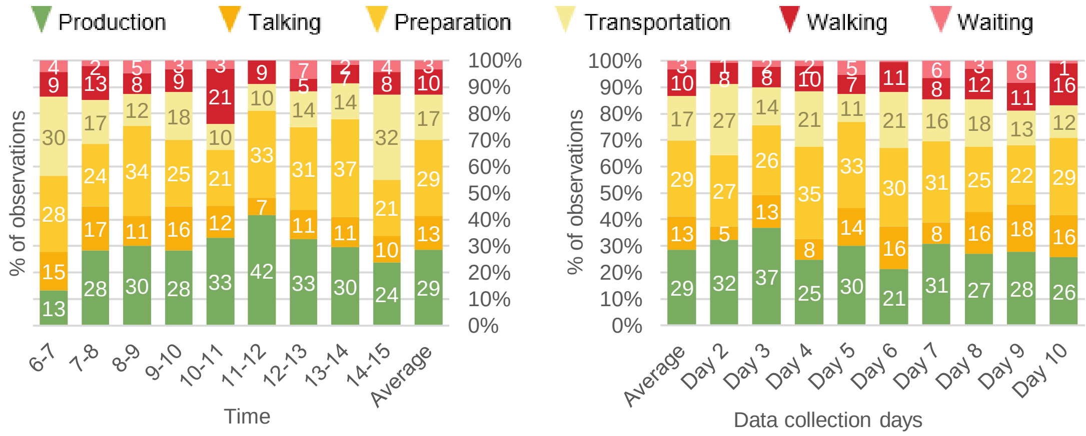


Figure 4 (a): Distribution of observations throughout the workday (n=2,100).

Figure 4 (b): Distribution of observations throughout the days of data collection (n=2,100).

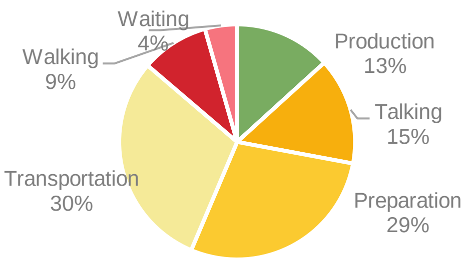


Figure 5 (a): Distribution of observations during the first working hour (n=204).

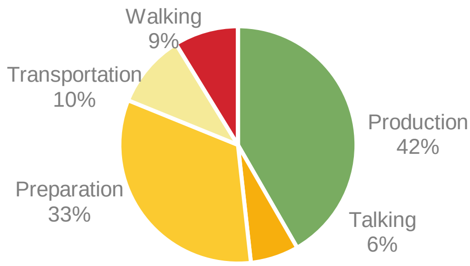


Figure 5 (b): Distribution of observations during the period of 11:00 to 12:00 (n=228).

## BREAKDOWN ANALYSIS

Figure visualizes how the breakdown of the 6 main WS codes into the 41 detailed codes can be used for analysis. The Detailed Distribution of Observations (DDO) seen in Figure (a) shows that the most frequently observed productive task was C110 (installing gypsum panels) with 9% of total observations, followed by C101 (installing steel profiles) and C109 (installing wood panels), which each accounted for 4% of the total observations. Figure (b) shows that measuring with a ruler (C202) was the by far most observed task within the preparation category and also the most observed contributory task, with 10% of the total observations being of C202. C402 transporting tools were observed almost as many times asv C202 and was the task within the transportation category that was observed most times, accounting for 9% of the total observations.

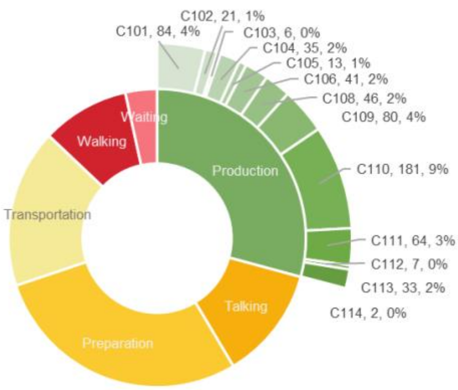


Figure 6 (a): DDO on productive tasks (n=613).

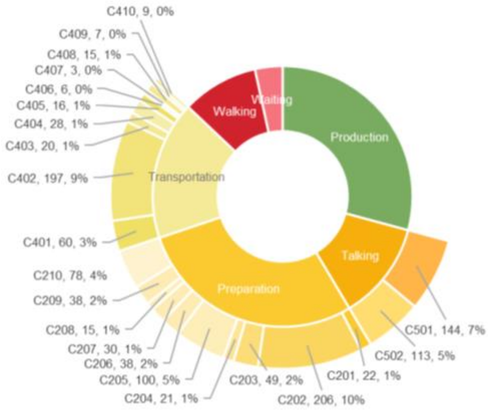


Figure 6 (b): DDO on contributory tasks (n=1,215).

## ONE SINGLE MATERIAL/COMPONENT ANALYSES

The detailed taxonomy of WS codes makes way for several opportunities for data analyses. Besides breaking down the DDO within each main category, it is possible to extract information about a single component, as shown in Figure (a) and (b).

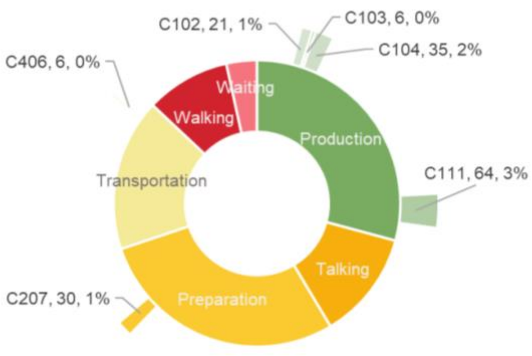


Figure 7 (a): DDO on windows (n=162).

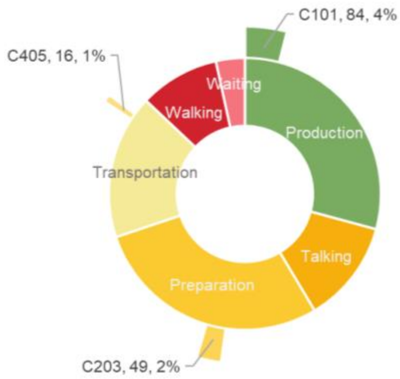


Figure 7 (b): DDO on steel profiles (n=149).

Figure (a) shows the observations of codes related to installing new windows, including C102 installing insulation around windows, C103 installing steel sill below windows, C104 grouting around windows, C111 installing windows, C207 preparing the hole for window installation, and C406 transporting temporary window frames (plastic). In the same way, codes regarding steel profiles for the drywall have been extracted in Figure (b); C101 installing steel profiles, C203 preparing steel profiles, and C405 transporting steel profiles.

## RECATEGORIZING ACTIVITIES

Another possibility for analyzing the data is to move codes from one main category to another. As different interpretations between categories exist among researchers and practitioners, this represents a transparent way of manipulating the data that can be useful when comparing data to previous studies, where observations have been categorized differently. Two examples are shown in Figure (a) and (b). In Figure (a), all tasks concerning measuring and cutting are recategorized from preparation to production. Consequently, the share of observations of productive tasks raises from 29% to 50%, and preparation decreases from 29% to 8%. In Figure (b), observations of transportation of tools and support equipment are considered as preparation instead of transportation. This results in the transportation category shrinking from 17% to 6%, and the preparation category increasing from 29% to 40%. Going forward, it will be useful to break down the WS codes even further so that when extracting information on single materials or components, fractions of observations from other codes such as measuring and transporting tools can also be included.

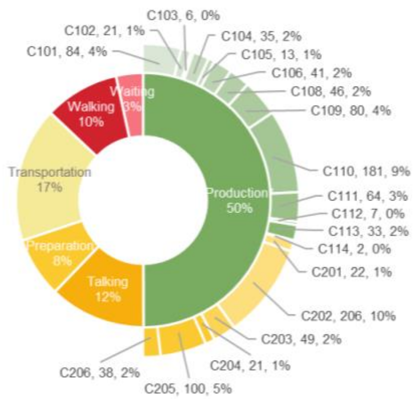


Figure 8 (a): DDO of productive tasks considering measuring and cutting tasks (n=1,049).

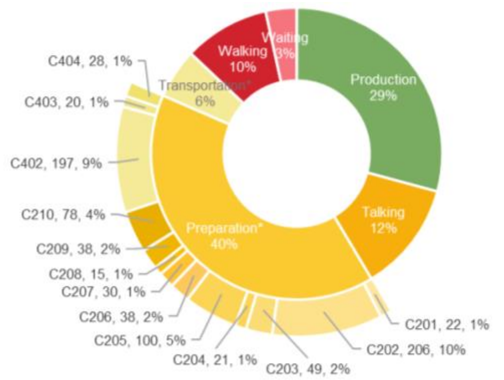


Figure 8 (b): DDO of preparatory tasks considering transporting tools and equipment (n=842).

## CORRELATION ANALYSIS

To examine the internal relationship between the different observations, correlations were conducted between all of the WS codes using the total number of observations from each hour of the workday of each code. A visual representation of the correlation coefficients (R) can be seen in Figure 9. The following will discuss pairs of codes that exhibited a correlation stronger than ±0.80, and the implications of these results on the construction operation studied. There are 9 pairs of codes that have a correlation stronger than ±0.80. The strongest correlation is seen between C203 and C405, with a coefficient of 0.91. These codes represent two closely connected tasks; "preparing steel profiles" and "transporting steel profiles", thus it is not unexpected that the correlation is strong. The second strongest relationship with a coefficient of 0.90 is between C202 and C205, i.e., "measuring with ruler" and "cutting gypsum panels". This is the strongest correlation between C202 and any other code, which indicates that measuring with a ruler was applied more when preparing gypsum panels than when, e.g., preparing steel profiles or insulation.

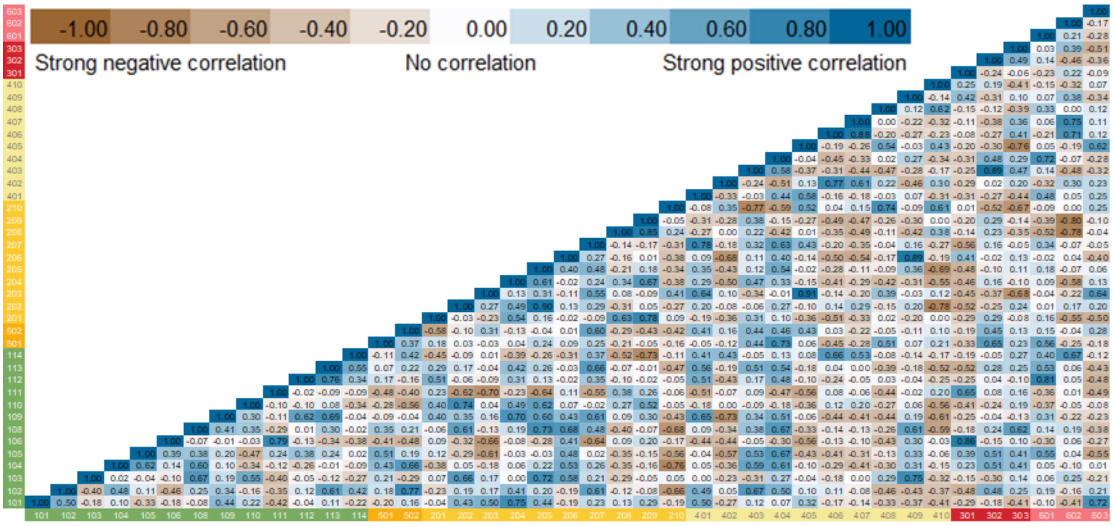


Figure 9: Correlation (R) of all WS codes.

## CONCLUSIONS

This research addressed the RQ of how the data from the WS application can be analyzed to discuss value. The authors presented different possible analyses using the data gathered from a real case study. The WS was applied on the carpenter's trade on a renovation project. Carpenters spend their working hours renovating internal walls, ceilings, windows, and balconies. During the WS application, a total of 2,100 observations were made throughout ten days of job site visits through eight hours daily. This study suggests that the time spent in VAW in the renovation process studied, set of multiple operations, can easily be analyzed by performing a compilation of data divided into tasks. Whenever possible, identifying all activities or procedures will lead to a comprehensive understanding of how the workers spend their time on VAW and NVAW.

The proposal of a detailed code categorization represents the major novelty of this study as it provides for a more significant analysis potential. Adopting a breakdown classification is advantageous for field studies no matter which activities practitioners understand as a value-adding. The lack of standard terminology of VAW and NVAW would not attenuate the use of the WS data as each researcher/practitioner will be able to move codes from one main category to another. In this study, the authors developed a detailed WS form of 41 codes. In future steps, a suitable decomposition of activities fitting to the Work Breakdown Structure (WBS) of the project will be tested in a new case study. Moreover, an additional type of information, such as location, will be added to codes to provide a more comprehensive understanding of the nature of the activities.

The development of the breakdown classification for WS purposes presents some limitations that should be addressed in future research. An important limitation is related to the data collection process at construction sites during the development of the WS form. This requires a deep knowledge of the process to be studied. Moreover, this comprises a very time-consuming activity, and several workers' tasks cannot be observed during the period of the form development. Consequently, new codes will have to be added during the course of the application of the technique. Finally, statistical techniques to carry out the analyses of the WS study were not discussed in this paper.

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