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Empirical validation of the time accuracy of the novel process language Human Work Design (MTM-HWD®)

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ABSTRACT
This paper presents the empirical validation of the time accuracy of the process building block system MTM-HWD® (Human Work Design). The analysis is based on process data collected from 62 different workplaces in German manufacturing companies. The accuracy of the process system is analyzed by studying the frequency of employed process building blocks in the data collection procedure. Subsequently, the differences between the MTM-HWD® and MTM-1 cycle times are evaluated. The findings show that there is no significant difference from samples of prior MTM-1 studies with respect to the frequency of employed MTM-1 process building blocks. It is shown that there is a systematic difference and a linear relationship between the MTM-HWD® and MTM-1 time data. However, it is demonstrated that the relatively larger MTM-HWD® times do not differ more than 5 % from the MTM-1 times when considering the 95 % confidence interval of the mean. These results meet the development aims in terms of the defined accuracy of the method of ± 5 % in comparison to MTM-1.

1. Introduction
Predetermined time systems (PTS) are employed to estimate the required time for conducting tasks in various domains (e.g., manufacturing, service, clerical areas) (Shell, 1986). One of the most popular PTS is the Methods-Time Measurement (MTM) process building block system (Genaidy, Agrawal, & Mital, 1990). The MTM process language is widely employed for consistent productivity management within the value chain, for modeling human movements and the design of productive as well as healthy work conditions (e.g., Baraldi & Kaminski Paulo, 2011; Busenbach, Link, Füssel, & Ortner, 2011; Das, Shikdar, & Winters, 2007; Zandin, 2001). The required time for a certain task is determined by dividing manual operational procedures into elements of motions and considering the work conditions simultaneously. These motion elements are coded, assigned to time standards, and amount to the basic time of the overall work procedure (e.g., Freivalds & Niebel, 2014; Groover, 2014; Zandin, 2001).
The foundation of motion analyses go back to the work of Gilbreth and Gilbreth (1919). It was concluded that human movements can be divided into 17 different elementary movements called ‘therbligs’ (Freivalds & Niebel, 2014). However, no time values were assigned to the movement elements. In 1948, Maynard, Stegemerten, and Schwab (1948) published the Methods-Time Measurement System MTM-1. This system included standard time values for the single process blocks that were derived from time studies in industry. Following behind, various aggregated MTM analysis systems for different work environments have been adopted from the modular block structure of the basic MTM system. For example, in this context, MTM-2, MTM-3, MTM-UAS, or MTM-MEK were developed (Matias, 2001). The historical development of MTM and the specific methods are described in detail in, for instance, Freivalds and Niebel (2014), Zandin (2001), or Matias (2001).

However, the design of human-centered workplaces requires both determining cycle times and an ergonomic design. In the past, the description and evaluation of work times and ergonomic aspects (e.g., work postures of operators) had to be conducted in separate procedures (Laring, Christmansson, Kadedors, & Örtengren, 2005; Laring, Forsman, Kadedors, & Örtengren, 2002). A variety of ergonomic methods for assessing exposures to risk factors for work-related musculoskeletal disorders are available, and were compared, for example, in Li and Buckle (1999) and Takala et al. (2010). For application in operational practice, mostly observation-based methods are used. In particular, the European Assembly Worksheet (EAWS) by Schaub, Caragnano, Britzke, and Bruder (2013) combines ergonomic fundamentals of the standards EN 1005 series, ISO 11226, and ISO 11228 series, as well as several other standards offering basic ergonomic guidance and research of preliminary developments like New Production Worksheet, DesignCheck, and Automotive Assembly Worksheet. Thus, research on several observational methods well-established in practice was integrated. These include, but are not limited to, Key Indicator Method, NIOSH lifting equation, Occupational Repetitive Actions, and Rapid Upper Limb Assessment, which provide the basis of the above-mentioned standards. Using digital human models the ergonomic assessment or work processes can also be automated and integrated seamlessly into the design process (e.g., Caputo, Greco, Fera, & Macchiaroli, 2019; Schaub et al., 2012).

Although systems like EAWS attempt to quantify the combination or interaction of different risk factors in the hope of obtaining an overall exposure value, epidemiological evidence is insufficient to support the pattern of combinations between risk factors as proposed in these systems (Takala et al., 2010). Even if there are still gaps in research from an ergonomic perspective, such as on the interaction and superposition between exposures (Hellig, Mertens, & Brandl, 2018), the representativeness of data collection (David, 2005), or the sample size for sufficient data collection (Allread, Marras, & Burr, 2000), practical benefits result from the combination of working time and ergonomics analysis. In particular, when defining a data collection strategy for ergonomic analyses, the combination offers advantages because the compromise between the conflicting requirements of data collection effort and data reliability no longer has such a strong impact (Brandl, Mertens, & Schlick, 2017).

First attempts to combine these procedures can be found in the ErgoSAM (Laring et al., 2005) and Ergo-UAS (Vitello, Galante, Capoccia, & Caragnano, 2012) approach. The novel process language MTM-HWD* (Human Work Design) is an integrative method that
systematically combines the assessment of work times and ergonomic aspects. Compared to the previous approaches, MTM-HWD* delivers three results in just one step: sequential description of the process and the human motions, basic time, and the so-called ergo declaration. Based on this declaration, the ergonomic assessment (load index) built on EAWS, for instance, can be calculated (Kuhlang, Ostermeier, & Benter, 2018). As a digital process language, MTM-HWD* will be the basis for connecting and translating digital motion data (from planning, simulation, or capturing systems) into real work systems and human labor.

To present the validation procedure of MTM-HWD*, this article is structured as follows. In this next section, the novel process language is introduced. Moreover, the results of another study on MTM-HWD* by Finsterbusch et al. (2016) (referred to as verification study in the following) are outlined. Then, the validation procedure is explained, the sample described, and the analysis results presented. The results of the verification and validation studies are compared and discussed. The paper ends with a conclusion of the findings.

2. The process language MTM-Human Work Design

The process language MTM-HWD* was developed on behalf of German MTM Association by Deutsche MTM-Gesellschaft mbH in cooperation with Audi AG, Daimler AG, Volkswagen AG, and Miele & Cie. KG, as well as the scientific partners Institute of Ergonomics (IAD) of the Technical University of Darmstadt and Institute of Industrial Engineering (IAW) of RWTH Aachen University (Finsterbusch & Kuhlang, 2015).

On the one hand, the developed method employs aggregated MTM-1 process building blocks and considers time-determining factors such as distance classes, grasp types, or weights. On the other, the method includes an ergonomic description, like in terms of trunk rotations, trunk bending, finger forces, or positions of hands, arms as well as shoulder joints (Kuhlang et al., 2018). As an integrative method, MTM-HWD* allows for simultaneously assessing time and physical exposures (e.g., in combination with EAWS). Therefore, an intuitive notation language with pictograms was developed. This notation language requires the user to match basic chronological ordered motions and existing influencing factors that also include ergonomic factors (Finsterbusch & Kuhlang, 2015; Kuhlang et al., 2018). By doing so, an ‘exhaustive anthropological motion model of the human worker’ is created and complete motions are described (Finsterbusch et al., 2016, p. 150). An extract of the description form is presented in Figure 1.

MTM-HWD* uses certain actions (OBTAIN, DEPOSIT, RETRACT, APPLY PRESSURE, MOVE LEG, and CHECK) not only to describe human movements in general, but also to describe the actual postures within work processes. In this context, further building blocks, such as HOLD or WAIT, were developed (Finsterbusch & Kuhlang, 2015).

MTM-HWD* is applied as follows (Finsterbusch et al., 2016): the individual influencing factors are described and coupled to the standard time catalogues of a certain company. For assessing the physical workload of the working person, all risk factors that are necessary to derive a score value according to EAWS are included in the process description (i.e., working postures for lower/upper limbs, trunk, head/neck, movement distances, weights and forces, and further process conditions). The inputs are processed and a load index derived based on the ergonomic assessment methods. A first implementation was done
Figure 1. Excerpt of the description form of the building block system MTM-HWD® (Finsterbusch et al., 2016, p. 149).
using EAWS in order to consider the physical workload of the working person. Alternatively, company specific assessment methods can be applied to reflect adjusted evaluation processes. This approach and the three results in one step imply a straightforward and speedy, practical application of MTM-HWD®. This ease in practical application not only was requested by the developing companies but also from a couple of – mainly global – manufacturing companies like Robert Bosch GmbH, B/S/H, and Siemens.

In the previous study, described in detail in Finsterbusch et al. (2016), a verification of the time accuracy of MTM-HWD® was conducted. As basis of comparison, the MTM-1 process block building system was chosen, since on the one hand it is the most basic one and provides very fine granularity, yielding accurate process times. On the other, MTM-1 is a widely used and accepted system for time determination in the industry. Furthermore, a desired time accuracy of ±5% was formulated against MTM-1 by the MTM-HWD® project group during the development process. In the following, the findings of the verification study are summarized: In total, 43 workplaces were analyzed via the MTM-1 and MTM-HWD® process building block system within the MTM-member companies. By doing so, 12,499 process building blocks were obtained. The analysis procedure included a comparison between the modelled MTM-1 and MTM-HWD® cycle times. The findings showed a significant deviation of the MTM-HWD® cycle times from the MTM-1 times by +3.8% \((t(42) = 6.08, p < .001, r = .68\)). Moreover, the Pearson correlation coefficient of \(r = .997\) indicated a strong and positive linear relation of the cycle times with the respective analytic methods \((R^2 = .994)\). The findings were used to develop a basic linear regression model that represents the relationship between the MTM-HWD® (dependent variable) and MTM-1 times (independent variable).

While the analyses in the verification study were conducted by members of the development team, the analyses for this validation study were executed by prospective applicators. Therefore, the validation study is a field study. The analysis procedure and the results of the study are presented in the following section.

3. Validation of the time accuracy of MTM-HWD®

In order to validate the time accuracy of MTM-HWD®, a field study was conducted within the MTM-member companies. Thereby, external experts of these companies, who were trained in MTM-1 and MTM-HWD®, carried out the MTM analyses used for this validation.

3.1. Method

The concept of the validation is based on the verification found in Finsterbusch et al. (2016) and consists of two statistical studies. Both studies rely on the MTM-HWD® and MTM-1 analyses of industrial workplaces in various industrial sectors. The scope of the validation is based on the process typological scope specified for the new process building block system, such as cycle durations of 30 to 120 seconds (Finsterbusch et al., 2016).

In the first study, the MTM-HWD® and MTM-1 cycle times are compared statistically by means of the paired \(t\)-test using a level of significance of \(\alpha = 0.05\), yielding general insights about the time deviation of MTM-HWD®. In order to obtain a broad understanding of the
time accuracy in regard to the temporal length of the analyses, the MTM-1 analyses were split into smaller units using the division into work steps defined by the MTM analysts. These units were regrouped into new process typological cycles that were coherent in form and content. The new cycle times targeted on durations between 15 s and 120 s with an increment of 15 s. Thereby, cycles deviating more than half of the increment were rejected, in order to not bias the group results and to avoid an overlap of the groups. The mean cycle time of each group was compared statistically using the corresponding mean time of the MTM-HWD* analyses as well as the 95 % confidence intervals.

The second study examines the correlation between the cycle times of MTM-HWD* and MTM-1 using the coefficient of determination. As the coefficient showed a strong linear relationship, linear regression analysis was applied afterwards to detect the relationship between both process building blocks in detail. A general linear regression model was derived at a level of significance of.

The descriptive statistics of the sample are outlined in the following section. In addition, the distribution of the MTM-1 movements of the current sample is compared to the prior sample of the verification as well as the sample used to develop the process building block system MTM-2 (Eady, 1986). This helps with judging the representativeness of the current sample. For comparison the $\chi^2$-test was applied at a level of significance of.

For all statistical tests, the effect size $r$ (Field, 2014) was computed. According to Cohen (1988, 1992), the effect is classified as ‘small’ ($0.1 \leq r < 0.3$), ‘medium’ ($0.3 \leq r < 0.5$), and ‘large’ ($r \geq 0.5$). The statistical analyses were conducted with MATLAB 2017b software.

### 3.2. Sample

The sample comprises MTM-1 and MTM-HWD* analyses of 62 industrial workplaces that include 8,032 and 3,938 process building blocks, respectively. The corresponding work processes originate from the sectors white goods assembly and vehicle manufacturing. The operations that were observed comprise assembly actions being typical for the application area of MTM-HWD*, such as screwing, clipping, checking, applying electrical contacts, and assembling standard parts. There is no overlap with the workplaces of the verification study. The mean cycle time of the MTM-1 analyses is 1,031.6 TMU (37.1 s; $SD = 479.0$ TMU), whereas the MTM-HWD* analyses last 1,058.2 TMU (38.1 s; $SD = 490.2$ TMU) on average. Hence, the current sample includes more workplaces, but they have fewer process building blocks and consequently lower mean cycle times. Figure 2 depicts the temporal distribution of the MTM-1 cycle times of the current sample compared to the verification.

All relevant process building blocks are represented within the validation sample, except some special body movements that are very workplace specific. The most frequently MTM-1 movements are MOVE (28.7 %), GRASP (20.5 %), and REACH (14.3 %). Accordingly, all relevant MTM-HWD* actions are present, whereas the most frequently ones are DEPOSIT (58.5 %) and OBTAIN (29.3 %).

During the development of the process building block system MTM-2 a study was conducted by the Swedish MTM Association in the USA, Sweden, and Great Britain covering more than 22,000 MTM-1 movements (Eady, 1986). As this study does not report any data for the process building block ‘PT’ (process time) and aggregates the eye and body
movements, the distribution of the current sample’s movements was adjusted accordingly for this comparison (see Table 1). Based on these corrections, there is no significant difference between the frequency distributions of the MTM-1 process building blocks of the validation and the development of MTM-2 ($\chi^2(10) = 7.88; p = .641; r = .85$).

In contrast to the previous observation, the comparison between the current sample and the sample of the study by Finsterbusch et al. (2016) is based upon the original data distribution, whereas the verification is assumed to be the valid ground truth. According to the Chi-square test, no significant difference can be found between the frequency distributions ($\chi^2(20) = 19.05; p = .519; r = .95$).

In summary, for the current sample no difference of the distributions of the process building blocks can be found neither with respect to the verification study nor to the study of the development of MTM-2. The sample can thus be considered as representative for usual workplaces and the results of both validation and verification can be compared.

By splitting the MTM-1 workplace analyses into their work steps, 406 cycles are obtained with a mean cycle time of 157.5 TMU ($SD = 160.9$), which were then

![Figure 2. Distribution of the MTM-1 cycle times of the validation sample compared to the verification sample.](image)

| MTM-1 movement | Validation (this study) | Verification (Finsterbusch et al., 2016) | Development of MTM-2 (Eady, 1986) |
|----------------|------------------------|--------------------------------------|---------------------------------|
| Reach (R)      | 14.5                   | 15.7                                  | 14.0                            |
| Grasp (G)      | 20.8                   | 18.8                                  | 17.0                            |
| Move (M)       | 29.2                   | 30.5                                  | 31.0                            |
| Position (P)   | 11.0                   | 6.6                                   | 8.0                             |
| Release (RL)   | 13.1                   | 13.3                                  | 13.0                            |
| Apply pressure (AP) | 2.2            | 1.1                                   | 5.0                             |
| Disengage (D)  | 0.4                    | 0.2                                   | 1.0                             |
| Turn (T)       | 0.5                    | 8.8 $^a$                             | 0.4                             |
| Static constant (SC) $^b$ | 0.9                  | 1.6                                   | 5.0                             |
| Eye movements (ET/EF) $^c$ | 2.1                | 0.2                                   | 1.6                             |
| Body movements $^c$ | 5.2                | 3.3                                   | 4.0                             |

$^a$The high difference for T is due to the fact that not time determining T-movements are usually omitted in operational practice.

$^b$Used to get control over weights larger than 1 kg.

$^c$Aggregated values

Table 1. Adjusted relative distribution of the MTM-1 movements for the comparison between the samples of the validation, verification, and development of MTM-2.
regrouped according to the aforementioned procedure. For cycle times between 15 s and 120 s, the number of newly created process typological cycles ranges from 16 to 119 (see Table 2). For cycle times longer than 15 s, only few process typological cycles were omitted due to their deviation from the target cycle time. Due to the low mean cycle time of the work steps, the new cycle times could be achieved with high accuracy. Nearly all cycle times (except for 15 s and 60 s) are included in their respective 95 % confidence intervals.

### 3.3. Results

#### 3.3.1. Comparison of cycle times

In order to compare the MTM-HWD® cycle times to those of MTM-1, the deviation of each workplace analysis was derived. As shown in Figure 3(a), the deviation usually is positive and within a range of 0 % to 6 %. It is to be noted that large relative deviations especially occur for workplaces having small total cycle times, because here even small absolute deviations denote large relative deviations. Compared to the verification study a similar behavior of deviation can be observed, albeit the distribution of the deviations is slightly shifted to the left, to lower values.

The 95 % confidence interval of the mean cycle times is given by [912.4 TMU; 1, 150.8 TMU] for the MTM-1 cycle times and [936.1 TMU; 1, 180.2 TMU] for the MTM-

| Cycle time [s] | 15 | 30 | 45 | 60 | 75 | 90 | 105 | 120 |
|---------------|----|----|----|----|----|----|-----|-----|
| n_valid ^a    | 119| 71 | 44 | 34 | 27 | 23 | 21   | 16   |
| n_invalid ^b  | 3  | 1  | 6  | 4  | 3  | 1  | 4    |      |
| M_{MTM-1}     | 14.4| 29.8| 45.0| 61.2| 74.5| 89.4| 104.2| 120.0|
| SD_{MTM-1}    | 2.6 | 3.2 | 2.7 | 3.0 | 3.2 | 3.0 | 3.0  | 2.4  |
| M_{MTM-HWD}   | 14.8| 30.5| 46.2| 62.7| 76.6| 91.5| 106.7| 123.4|
| SD_{MTM-HWD}  | 2.7 | 3.6 | 2.8 | 3.7 | 3.6 | 4.0 | 3.4  |      |

^a process typological cycles included in the further analyses
^b process typological cycles deviating more than ± 7.5 s of the target cycle time

![Figure 3](image-url)

Figure 3. Relative deviation of the MTM-HWD® cycle times from the MTM-1 cycle times (a) and mean cycle times (b) for all 62 workplace analyses.
HWD® cycle times (see Figure 3(b)). The paired t-test shows a significant difference between the MTM-1 cycle times ($M = 1,031.6; SE = 60.8$) and the MTM-HWD® cycle times ($M = 1,058.2; SE = 62.3; t(61) = 5.802; p < .001; r = .596$). Thereby, the MTM-HWD® cycle time deviates by on average +26.6 TMU (i.e., +2.6 %) from the MTM-1 cycle time. The 95 % confidence interval for this deviation is given by [17.4 TMU; 35.7 TMU] and [1.7 %; 3.5 %], respectively. The effect size $r = .596$ states a large effect indicating a result that does not depend on the sample.

In order to examine the deviation over cycle time in detail, the workplace analyses were split into their work steps and regrouped to new process typological cycles that are both valid in terms of the MTM syntax and coherent regarding the MTM movements. The MTM-HWD® cycle times are (as expected) higher than those of the MTM-1 analyses. Figure 4 shows the mean relative deviations of MTM-HWD® with respect to the cycle time. Despite some bias, the deviation of MTM-HWD® is nearly constant with about +2.6 %. Even the length of the 95 % confidence interval only slightly varies between ± 0.9 and 1.2. In other words, for the time range considered here the MTM-HWD® cycle times are about 2.6 % higher than the MTM-1 cycle times, independent of the cycle duration. This observation confirms the results from the first comparison between the complete workplace analyses.

### 3.3.2. Correlation analysis

The MTM-1 and MTM-HWD® cycle times of the 62 workplace analyses show a strong linear relationship according to the Pearson correlation coefficient ($r = .9975$). The coefficient of determination amounts to $R^2 = .9950$. Therefore, a linear model is used for the further regression analysis, which is also reasonable, given that the optimal relationship between MTM-HWD® and MTM-1 would be an exact accordance (at least with respect to the slope).

Using regression analysis, a linear model

![Figure 4](image-url)  
**Figure 4.** Mean relative deviation of MTM-HWD® cycle times from MTM-1 cycle times with corresponding 95 % confidence interval with respect to the cycle duration.
was fitted in order to narrow the relationship

\[
E(t_{MTM-HWD} | t_{MTM-1}) = \beta \cdot t_{MTM-1} + \alpha
\]

of the ground truth, whereas \(t_{MTM-HWD}\) and \(t_{MTM-1}\) denotes the cycle times of MTM-HWD* and MTM-1, respectively. Special interest is put on the slope \(b\) that determines the development of the linear model over time, while \(a\) describes the constant offset of MTM-HWD* that is independent from the cycle time. Based on the current sample, the linear model can be derived as

\[
t_{MTM-HWD} = 1.0208 \cdot t_{MTM-1} + 5.1714.
\]

In theory, the optimal relationship between MTM-HWD* and MTM-1 would be an exact match, meaning the MTM-HWD* cycle times do not differ from the MTM-1 cycle times (\(t_{MTM-HWD} = t_{MTM-1}\)), requiring optimal parameters \(b^* = 1\) and \(a^* = 0\). Using inference statistics based on the \(t\)-test, a significant deviation \((p < .001)\) can be found between \(b\) and \(b^*\), whereas the 95 % confidence interval for \(\beta\) amounts to \([1.0020; 1.0395]\). For the coefficient \(a\) no significant difference from \(a^*\) could be found \((p = .628; 95 \text{ % }, \text{ confidence interval: } [16.0732; 26.4159])\).

In other words, this means that in repeated regression analyses, the MTM-HWD* cycle time would be slightly higher than the corresponding MTM-1 analysis time. Furthermore, the absolute difference between both cycle times increases while, at the same time, the relative deviation decreases. The linear model of Equation (3) is depicted in the scatter plot of Figure 5. The dotted line indicates the theoretical optimum given by \(t_{MTM-HWD} = t_{MTM-1}\).

---

**Figure 5.** Linear regression model for the cycle times of the 62 industrial workplaces (dotted line indicates theoretical optimum where MTM-HWD* follows MTM-1 exactly).
4. Discussion

While Finsterbusch et al. (2016) studied the time accuracy of MTM-HWD® under laboratory conditions, there was a need for a field study to validate MTM-HWD®. For being able to compare both studies, it is important to apply similar methods and have comparable samples. In case of the present validation study, the procedure was left the same except for the target cycle times, which were fitted to the current sample for regrouping the work steps. Furthermore, the sample shows no significant difference from prior independent samples, hence the current sample can be considered as representative for typical MTM application scenarios.

This validation study revealed a reduced cycle time of the workplace analyses compared to the verification study. However, this does not impact the results, but meets the original target cycle time of MTM-HWD® more appropriately. MTM-HWD® shows further (on average) an immanent offset of the cycle times compared to MTM-1. This is due to the principle of aggregation that was used to develop MTM-HWD®. By grouping MTM-1 movements, calculating their average time value, and rounding up to the final time value, some process building blocks are more sensitive to time deviations than others. Nevertheless, MTM-HWD® also achieves an overall time accuracy of about +2.6 % with respect to MTM-1 in the validation study. Thereby, the field study met the 5 % limit targeted by the MTM-HWD® project group (Finsterbusch et al., 2016) and also used for other comparisons of MTM process building systems. The current study reveals even more accurate results than the previous verification with an accuracy of +3.6 % (Finsterbusch et al., 2016).

Regarding the linear regression models of Equation (3), the results of the verification and validation study differ slightly from each other (see Table 3). Two differences between the regression models are noteworthy. On the one hand, the regression coefficient \(a\) differs in that the difference between MTM-1 and MTM-HWD®, which is independent of the cycle time, is much smaller in the validation. On the other, the cycle time dependent coefficient \(b\) is in a similar size range as in the verification study. However, based on the 95 % confidence interval, the slope does not include the value 1. Thus, there is always a positive deviation between MTM-1 and MTM-HWD® based on this regression model. These deviations between the models are assumed in the sensitivity of the linear regression analysis to the respective data distribution. The wider range of cycle times in the verification as well as the higher cycle times in general show an increased (absolute) deviation.

| Model parameter | Validation (this study) | Verification (Finsterbusch et al., 2016) |
|-----------------|-------------------------|----------------------------------------|
| \(a\)           | 5.1714                  | 52.5175                                |
| 95% CI for \(a\) | \([-16.0732; 26.4159]\) | \([2.7857; 100.2493]\)                 |
| Hypothesis test \(*\) for \(a_{opt} = 0\) | \(p = .628\) | \(p < .05\) |
| \(b\)           | 1.0208                  | 1.0056                                 |
| 95% CI for \(b\) | \([1.0020; 1.0395]\)    | \([0.9817; 1.0294]\)                   |
| Hypothesis test \(*\) for \(b_{opt} = 1\) | \(p < .001\) | \(p = .638\)

\(*\) based on t-test
5. Conclusion

MTM-HWD® represents an important step towards a new era of modeling manual work processes. Instead of collecting data multiple times, the work process is modelled only once using MTM-HWD®. This model is used to derive indicators for evaluating both time and ergonomics. Therefore, MTM-HWD® was built upon MTM-1 and extended by ergonomic influencing factors.

This paper presents the validation of the time accuracy of MTM-HWD® with respect to MTM-1 following a previous verification. A field study with 62 industrial workplaces coming from different industrial sectors was conducted and evaluated regarding two main aspects. First, the MTM-HWD® cycle times were compared to the MTM-1 cycle times. The study shows a significant ($p < .05$) increase of 2.6 %, which is within the 5 % limit defined by the MTM-HWD® project group. This is especially valid for the application time of 30 s to 120 s targeted by the project group for this new process building block system. Second, the cycle times show a strong linear relationship yielding an accurate linear regression model. As the sample of the current validation study shows no significant difference to previous studies, the chosen 62 workplaces can be assumed to be representative to typical MTM application scenarios. This includes also other industrial sectors in which typical movements of manual work processes occur, as these are reflected by the workplaces of the study presented here.

Currently, there is discussion – at least in Germany – of a renaissance of ergonomic research and practice for manual assembly systems (Brandl, Mertens, Luczak, & Nitsch, 2018). Inspired by the developments around assistance systems, the combination of working time and ergonomics analyses by MTM-HWD® can be an important step towards the creation of good work systems in terms of a human-oriented rationalization. In the future, the analysis results of MTM-HWD® can also be used to further improve work design, for example, in combination with current industrial engineering and ergonomics research fields on human-robot collaboration (Petruck et al., 2019), exoskeletons (Kim & Nussbaum, 2019), workload-optimizing job rotation (Brandl, Mertens, Bützler, & Schlick, 2014), learning prognosis (Jeske & Schlick, 2012), or motion capture (Dutta, 2012).

Note

1. Time Measurement Unit (TMU) is the time unit of all MTM process languages (1 TMU = 0.036 s).

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