MTM-Schriften Industrial Engineering
Release 18

Digitalization of MTM methods – Perspectives for designing productive and ergonomic work in production and logistics

Publisher: MTM ASSOCIATION e. V., MTM-Institut
Ao. Univ.-Prof. Dipl.-Ing. Dr. techn. Peter Kuhlang
Head of MTM ASSOCIATION e.V.
Managing Director of Deutsche MTM-Gesellschaft Industrie und Wirtschaftsberatung mbH
Head of MTM-Institut

MTM ASSOCIATION e. V., MTM-Institut
Eichenallee 11
15738 Zeuthen, Germany
Tel.: +49 33762 20 66-31
Fax: +49 33762 20 66-40
institute@mtm.org
www.mtm.org/en/research

Autors:
Prof. Dr. Peter Kuhlang, Dr. Martin Benter, Maria Neumann, Constantin Eckart

Kuhlang, P., Benter, M., Neumann, M., Eckart, C.:
Digitalization of MTM methods –
Perspectives for designing productive and ergonomic work in production and logistics. MTM-Series of Publications Industrial Engineering, Release 18. Hamburg: Self-Publisher MTM ASSOCIATION e. V., 2023.

Bibliographic information of the German National Library
The German National Library lists this publication in the German National Bibliography: detailed bibliographic data is available on the Internet at http://dnb.d-nb.de.

ISBN 978-3-945635-27-8

Self-Publisher and printing by MTM ASSOCIATION e. V.
Elbchaussee 352
22609 Hamburg, Germany
phone: +49 40 822779-0
fax: +49 40 822779-79
www.mtm.org

Cover pictures:
© vege - Fotolia.com;
© Joachim Wendler - Fotolia.com

Content

Figures and tables

Foreword

Peter Kuhlang

Dear Reader!

The 18th edition of the “MTM-Schriften Industrial Engineering” series highlights the digitalization of MTM methods with a focus on the design of productive and ergonomic work in production and logistics.

Among the most significant areas of responsibility established in the founding document of the MTM Institute are the ongoing development of MTM to expand its application, building networks, improving the prerequisites for application requirements, and public relations for the (work) scientific discourse and broader (popular) scientific impact. In line with this tradition, the "MTM-Schriften Industrial Engineering" series provides a platform to publish both application-oriented and theoretical work in the field of Industrial Engineering in a citable format.

The non-periodically published releases focus on the field of "Industrial Engineering" in a closer and broader sense, specifically related to MTM. They address new and further developments, practical applications in established and emerging fields, as well as theoretical insights and aspects to establish and disseminate MTM.

In the present edition of the series, the contribution of MTM to the development of work management in the context of digitalization is described. Specifically, in this context, MTM methods for designing productive and ergonomically sound work in the fields of production and logistics are discussed. In addition to introducing the MTM process building block systems MTM-LOG® (Logistics) and MTM-HWD® (Human Work Design), as well as ergonomic assessment using EAWS®, a major focus is on digital work design using MTMmotion®. This includes a specific examination of deriving MTM-UAS® and MTM-HWD® analyses from interface data. Finally, future developments in data capture using motion capturing and the derivation of MTM-analyses are outlined.

Finally, we categorize the automated application of MTM within a broader, future-oriented context.

Peter Kuhlang, October 2023

CEO MTM ASSOCIATION e. V. and Deutsche MTM-Gesellschaft mbH
Head of MTM Institute

1 Work design in production and logistics

Costs are a key target figure for companies in national or international competition. A relevant portion of these costs are labor costs, especially if the work is characterized by a high portion of manual work. Evaluating the temporal aspects of these processes serves a dual purpose: it aids in assessing capacity demands and, simultaneously, it serves as a tool to uncover opportunities for enhancement, ultimately facilitating the purposeful design of human work.

There are various methods for the temporal description, assessment, and analysis of work processes. Well-known methods include REFA time study[1], MTM[2] or Work Factor[3]. Each of these methods has its strengths and weaknesses. One of the significant advantages of MTM methods is the person-independent description of work processes. Different execution speeds, for example, are not considered, allowing for an objective evaluation of work content. Different MTM systems exist for various application areas, with the most well-known and widely used system worldwide being the MTM process building block system MTM-UAS® (MTM Universal Analyzing System).[4]

In addition to the consideration of time, ergonomics is becoming increasingly important in all areas of human work. Well-designed work avoids excessive biomechanical stress, maintains the health and performance of employees and promotes job satisfaction. Holistic workstation design that takes ergonomic aspects into account is therefore becoming increasingly important.[5]

To fulfill this tasks, companies usually use risk assessment methods, such as the "Ergonomic Assessment Worksheet"[6] (EAWS®). The aim of these methods is to identify ergonomic risks for employees in work systems. In addition, the assessment of risks due to biomechanical loads is mandatory for companies in many European countries.

Temporal and ergonomic analyses of work processes are thus essential components of work design. The analysis methods are used widely, especially in the areas of production (for example, in the automotive industry and manufacturers of white goods) and logistics (for example, logistics service providers and internal logistics), in which manual activities sometimes make up a large portion of the work processes. Basic work activities, which are currently the focus of labor policy efforts (keyword: last mile), can also be examined using these analysis methods.[7]

1 cf. REFA, 1997
2 cf. Antis et al, 1969; Bokranz & Landau, 2012; Maynard et al, 1948
3 cf. Quick, 1960
4 cf. Bokranz & Landau, 2012; MTMA, 2019b
5 cf. MTMA, 2022
6 cf. Schaub et al., 2012
7 cf. Bovenschulte et al., 2021

Knowledge and methods of work management do not stand still, but evolve with the requirements and general conditions.[8] Significant current developments arise in particular in the context of digitalization.[9] This issue of the series therefore describes in more detail the development of work management against the backdrop of digitalization. Specifically, MTM methods for designing productive and ergonomic work in the areas of production and logistics are treated in this context. In addition to the presentation of the MTM process building block systems MTM-LOG® (logistics) and MTM-HWD® (Human Work Design) as well as the ergonomic assessment by means of EAWS®, the focus is on digital work design using MTMmotion®. Here, the derivation of MTM-UAS® and MTM-HWD® analyses from interface data is specifically considered. Finally, future developments in the area of data acquisition using motion capturing and the derivation of MTM analyses are outlined.

8 cf. Mühlbradt et al., 2018
9 cf. Benter & Neumann, 2023

2 Work design with MTM

Different methods of time determination are used in work design. One of the most tried-and-tested is the MTM method, which allows processes to be evaluated in terms of time as early as the planning phase; a very significant advantage in times of digital work design. The method has been developed and established primarily in the field of assembly planning. However, the areas of application reach far beyond this. MTM works equally well in logistics (MTM-LOG®). By combining it with ergonomic methods such as EAWS®, workflows can also be evaluated ergonomically.

This chapter begins with an introductory discussion of the MTM process language and the MTM process building block systems. Subsequently, it explains MTM in logistics, ergonomic work design with EAWS®, and the human-centered approach, MTM-HWD® (Human Work Design).

2.1 The MTM Process Language

Especially in times of digitalization, the planning, modelling and design of productive and ergonomic work is based on methodical and software-supported models. Work systems and workflows are modelled using individual (model) elements and contain descriptions and evaluations of productive and ergonomic aspects. The process language MTM as a model of the workflow in the work system model acts as a translator of digitally generated data (e.g. motion capturing, 3D simulation) and enables a reproducible workflow description and evaluation and thus an understanding of human and machine motion sequences.[10]

2.1.1 The work system model

In the field of science, various models are used to represent systems. One well-known model in ergonomics and work science is the Work System Model, composed of elements such as work task, human, workflow, equipment, workplace, work environment, input, output, as well as their system boundaries and parameters.[11] The element "workflow" represents "the temporal and logical interaction of humans and work or material resources in the transformation of input into output."[12] The pursuit of a comprehensible and reproducible description of how these system elements interact is particularly important for designing workflows based on productivity and ergonomics. This requires a defined approach to capture, document, and evaluate workflows. To achieve this, process languages like MTM, value stream mapping, or flowchart analysis are applied, each with its characteristic notations.

10 cf. Kuhlang, 2018
11 cf. Schmauder et al., 2014, p. 23
12 cf. Bokranz & Landau, 2006, p. 777

2.1.2 The MTM Process Building Block and the MTM Workflow Model

The notation of the MTM process language is characterized by its own syntax and semantics. Syntax refers to the “elements/symbols/characters used and their representation, as well as the applicable arrangement rules." Semantics, on the other hand, pertains to the "meaning of the elements/symbols/characters." This provides not only a vocabulary but also a form of grammar that enables the creation of comprehensible process descriptions, often in the form of line analysis, using MTM process building blocks.[13] The MTM process building blocks of the MTM process language are clearly defined in terms of their permitted use.[14]

The notation of the MTM process building block is characterized by twelve language elements and their assignment to an application-neutral and an application-specific part (see Figure 1).

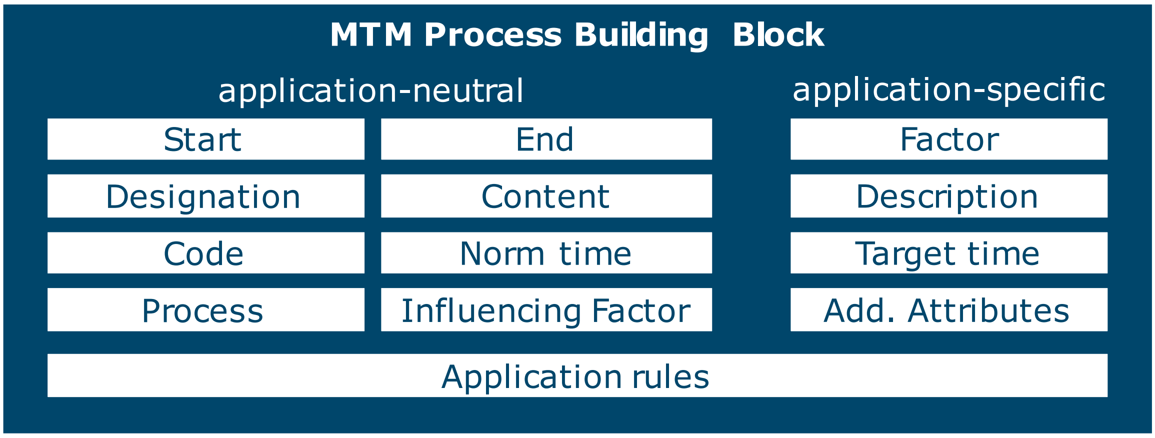


Figure 1: Language elements of the MTM process building block systems[15]

The application-neutral part of a (single) MTM process building block (e.g. with the code *R2A*) is defined once during its development. The MTM process building block *R2A* describes a reach motion of the fingers or the hand to a certain point. The language element "influencing factor" is assigned the motion length, the motion case and the type of motion course during Reach. The specific MTM process building block *R2A* covers a maximum movement of 2 cm either to an object on which the other hand is resting or which is in the other hand or always at a precisely defined location (e.g., button on a machine). Limitations of an MTM process building block are the clearly defined events "Start" and "End". An MTM process building block gets its name (description) from the language element "sequence" or the process. This in turn represents the scope of action of an MTM process building block. Depending on its granularity (hierarchic level; see Figure 3), this scope of action can range from a single finger or hand movement to an entire assembly process.[16]

[13] cf. Bokranz & Landau, 2012
[14] cf. Fischer et al., 2015, p. 95
[15] cf. Bokranz & Landau, 2012
[16] cf. Finsterbusch & Kuhlang, 2017

In addition to these descriptive language elements, the development of the MTM process building blocks included the assignment of evaluative language elements (e.g. the "standard time"). An *R2A* was assigned a standard time value of 2 TMU (Time Measurement Unit), based on a globally uniform reference performance: the MTM standard norm performance.

However, the application-neutral part of the MTM process building block only becomes concrete when the MTM process building block is used, i.e., it is completed by the application-specific part. For example, the language element “Factor” is determined by the quantity and frequency of occurrence in the specific workflow. Multiplying the factor by the standard time results in the target time (more precisely: the language element "target time").

In summary, an MTM process building block is a sequence that has been defined according to its content and its use, and to which a time standard applies.[17]

The connection of the application-neutral part with the application-specific part of an MTM process building block specifies the (work) content as well as the use of the process building block and represents a line in the MTM forms in the MTM typical process description (the MTM analysis). Taking into account the applicable application rules, this linking of the two parts is repeated and finally a description and evaluation (modeling) of a defined work content or an entire workflow is created. This resulting model of the workflow - the work method - follows the notation of the MTM process language and is now described as an MTM process building block or an “MTM analysis" (see Figure 2).

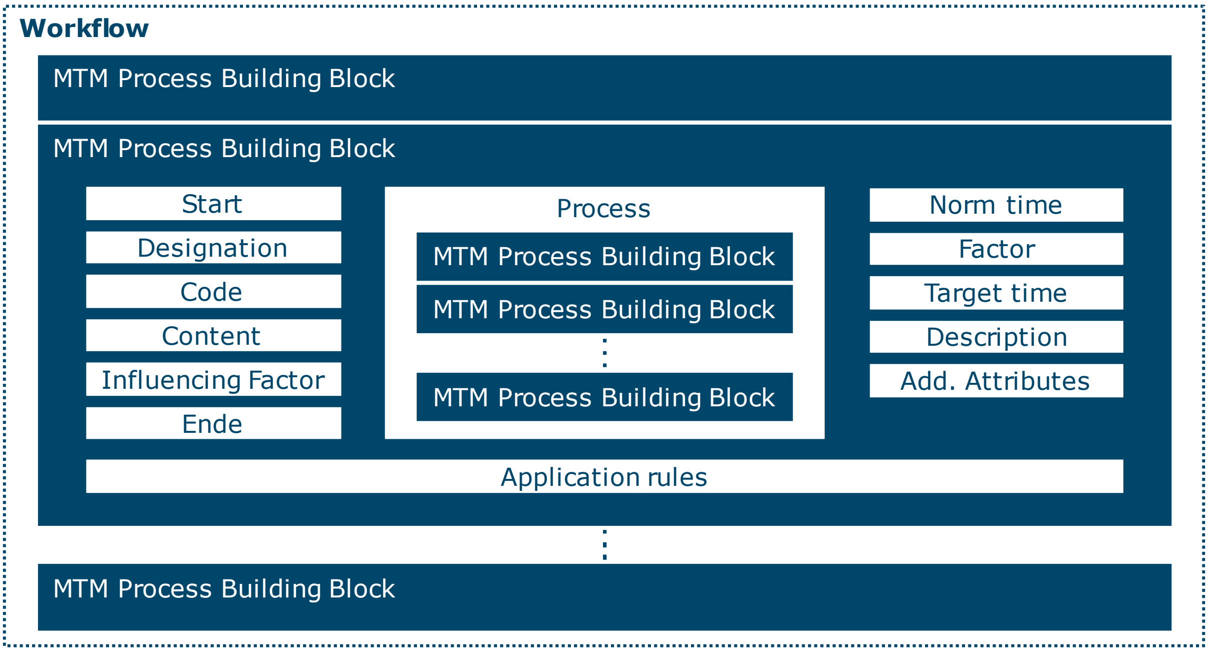


Figure 2: Workflow model according to MTM[18]

[17] cf. Bokranz & Landau, 2012, p. 386
[18] cf. Finsterbusch et al., 2017

In this publication, as in everyday use, a distinction is made between the terms "MTM process building block" and "process building block". For this reason, this distinction will be differentiated in the following.

Necessary prerequisites for MTM process building blocks are an intrinsic temporal evaluation based on a defined reference performance - specifically, the MTM standard performance - as well as the fulfillment of quality requirements and quality characteristics for MTM process building blocks or systems (stability, validity, economic efficiency).[19] It is sufficient that their application-neutral part can be found on MTM data cards of MTM process building block systems.

The term "process building block" (without the prefix "MTM") is generally used as a generic term for "a defined work content". More specifically, in the case of process building blocks, the language elements shown in Figure 1 are often not fully defined. Another characteristic is that process building blocks (without "MTM" as a prefix) are often based on other reference performances and often do not have an intrinsic temporal evaluation.

If MTM process building blocks are nested or used at different levels to describe and evaluate workflows or work content, and if clear rules and design principles (e.g., principles of aggregation) are followed, this approach is the basis for the development and application of industry-neutral and company-specific (MTM) process building block systems.[20]

2.1.3 The MTM Process Building Block Systems

Since 1948, a large number of MTM process building block systems were developed for various industries and sectors (mass production, serial production, single/job shop production), tasks(shopfloor, quality, office) and purposes (design, evaluation of physical loads, time determination). The following application-neutral MTM process building block systems are available:

[19] cf. Bokranz & Landau, 2012, p. 394
[20] cf. Kuhlang et al., 2017, p.98

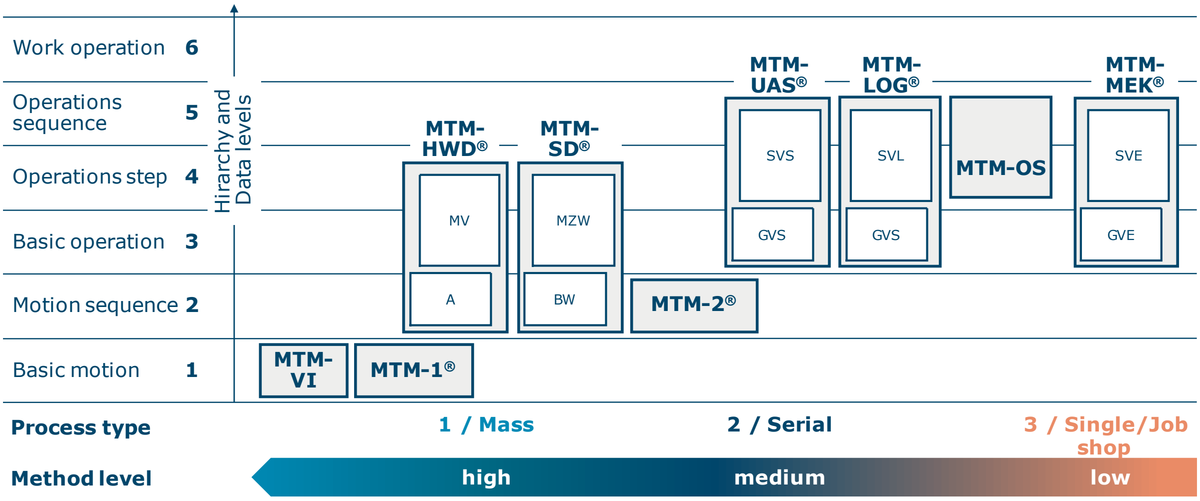


Figure 3: Systematics of the (application-neutral) MTM process building block systems[21]

Table 1: Legend MTM process building block systems

MTM process building block systems			
MTM-VI	MTM-Sichtprüfen / MTM Visual Inspection		
MTM-1®	MTM-1 (Basic System)		
MTM-HWD®	Human Work Design (HWD)	A MV	HWD-Aktionen (HWD Actions) HWD-Modellierungsvorlagen (HWD Modelling Templates)
MTM-SD®	Standard-Data (SD)	BW MZW	SD-Basiswerte (SD Basic Values) SD-Mehrzweckwerte (SD Multi Purpose Values)
MTM-2®	MTM-2		
MTM-UAS®	Universal Anlayzing System (UAS)	GVS SVS	UAS-Grundvorgänge Serie (UAS Basic Operations Series) UAS-Standardvorgänge Serie (UAS Standard Operations Series)
MTM-LOG®	MTM-Logistik / MTM Logistics	SVL	Standardvorgänge Logistik (Standard Operations Logistics)
MTM-OS	MTM-Office-System		
MTM-MEK®	MTM for Single and Job Shop Production (MEK)	GVE SVE	MEK-Grundvorgänge Einzelfertigung/Kleinserie (MEK Basic Operations Single) MEK-Standardvorgänge Einzelfertigung/Kleinserie (MEK Standard Operations Single)

The MTM process building block system is described as the sum of MTM process building blocks of a uniform hierarchy level or a uniform level of detail and with the same development basis, with which a consistent design of human motions or simple cognitive decisions is possible. The totality or overall structure of all (industry-neutral and company-specific) MTM process building block systems is described as the "systematics of MTM process building block systems" (see Figure 3).[22]

The process type or method level, which relates to the opportunity for routine development and the degree of individual operator method variation, determines the accuracy of the process description using MTM. The individual operator method variation, in turn, depends on the degree of practice – low practice results in high individual operator

[21] cf. Kuhlang, 2018
[22] cf. Kuhlang, 2018

method variation. The opportunity for routine development, in turn, depends on the frequency of repetition, which is influenced by cycle duration and the number of variations, as well as the work design and thus the degree of control of a motion.

MTM-1® (the MTM basic system) was the basis for the development and application of further modular systems. It was developed for manufacturing operations with a high repetitive character and short workflows, as typically found in mass production.

MTM-2® and MTM-SD® are designed for use in high volume or batch production. Typical areas of application are for example, supplier plants for vehicle construction or the electrical and electronics production. The MTM process building block system MTM-HWD® covers cycle times in the range of 30 to 120 seconds. Like MTM-1®, it is mainly used in mass production. A decisive difference to MTM-1® is that design measures are not only shown and identified under the aspect of productivity, but also under the aspect of ergonomics (based on the EAWS®).[23]

The MTM process building block system MTM-UAS® is based on the characteristic features of batch production and is primarily used for analyses in companies and supplier plants for vehicle construction, aircraft, appliance, electrical and electronics production and logistics industries. The field of application of MTM-MEK® (MTM for single and job shop production) is already clear from the explanation of the abbreviation. Typical application areas include machinery and steel construction companies, plant construction, aircraft manufacturing, as well as maintenance and repair, logistics, and setup and conversion work. In the MTM process building block systems MTM-UAS® and MTM-MEK®, standard operations for typical activities such as fasten, surface treatment, clamp and loosen, inspect or measure and assemble standard parts have been developed through aggregation.[24]

For the design, improvement and quantification of administrative business processes, an MTM process building block system has also been developed: the MTM Office system. It is suitable for determining the execution time of work tasks for planned activities. The system is mainly used in service companies, administrations or in the indirect areas of industrial companies. The MTM process building block system MTM for Visual Inspection is used for the planning, design and time evaluation of visual inspection activities that depend on human judgement and decision making. It also enables the rational selection of visual tools such as magnifiers, microscopes and monitors, as well as the design and evaluation of visual inspection activities using these tools. Typical areas of application include companies with a significant portion of visual inspection activities, such as visual control of soldering locations, painted surfaces, components or traces on printed circuit boards.[25]

[23] cf. MTMA, 2019a
[24] cf. MTMA, 2019a
[25] cf. MTMA, 2019a

For the correct application of MTM process building block systems, training is required (see training.mtm.org).

The MTM process building block system MTM-LOG® (MTM Logistics), which is described in detail below, is available especially for use in intralogistics.

2.2 MTM in Logistics

For logistics companies and smaller to medium-sized businesses, modern labor management in terms of systematic productivity management, modern work measurement, and the use of labor and time management methods has generally not been a significant focus. However, to accurately represent current time consumption and identify bottlenecks, time data plays a crucial role. It helps assess what their own processes (intralogistics, production, or assembly) can actually achieve.

Methods of time measurement are used for various tasks in areas such as tender management, logistics, process management, lean management, improvement management, and work planning. These tasks include designing efficient and ergonomically friendly work systems, processes, and value streams, identifying bottlenecks, determining cycle or transport times, optimizing physical strain, and calculating the impact of improvement ideas.[26] In recent years, the application of the MTM method has gained even more significance, particularly due to steadily increasing logistics costs.

On the one hand, the increased costs result from the high organizational, technical and personnel requirements that are placed on cross-company logistics today. On the other hand, the lack of precision in the consideration of logistical processes in which people are involved in the operative business makes it difficult to adhere to the planned and specified costs. This is exactly where the use of MTM - especially the MTM process building block systems MTM Logistics (MTM-LOG®) - can make a significant contribution to the design and improvement of logistics processes.

2.2.1 MTM Logistics Data

In general, MTM logistics data is used to describe and design various task areas mentioned above. These tasks include a high quantity of activities related to picking, transportation, as well as packaging and inspection, which are considered basic work (see Figure 4). The typical processes of intralogistics, which can vary in complexity, are described as standard operations in the field of logistics.[27]

[26] cf. MTMA, 2022
[27] cf. Sunk et al., 2014

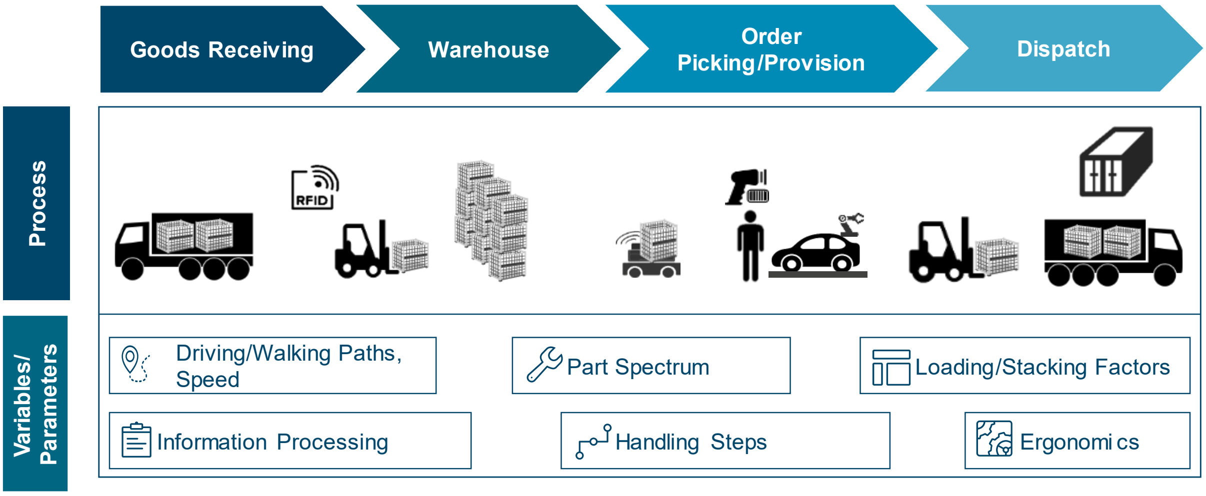


Figure 4: Typical application areas of MTM logistics data in intralogistics

MTM logistics data are mainly used to evaluate logistics processes and work systems in terms of time and ergonomics depending on influencing factors, variables and parameters. They are also used to evaluate existing and, above all, non-existing processes in a targeted and fact-based manner, to plan and increase productivity, and to determine the necessary personnel requirements (see Figure 5).[28]

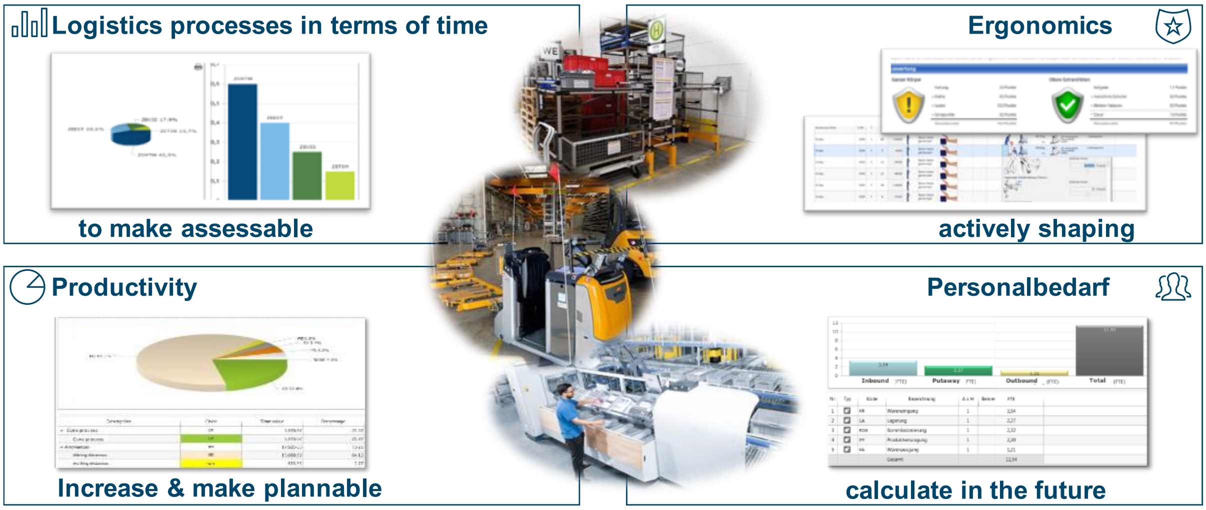


Figure 5: Goals of MTM application in logistics

The following general conditions apply to the use of MTM Logistics data:

- The usual work tasks are job-related. Some of them are repetition with a high frequency, so employees have the opportunity for routine training.
- Employees are provided with the appropriate work and transportation equipment for their jobs.
- The workstations are designed according to the range of work tasks.[29]

[28] cf. Kuhlang & Neumann, 2023
[29] cf. MTMA, 2019c

These conditions typically characterize the method level or process type of serial production and intralogistics processes or activities. This is why MTM logistics data is based on the basic operations of the MTM process building block systems MTM-UAS®.[30]

In practice, standard operations for handling and transport are of particular importance.

2.2.2 Handling of parts, cartons, containers

The standard operations Handling of Parts, Cartons, Containers are MTM process building blocks for the evaluation of standard operations with commercially available transport units that are frequently used in practice. The MTM process building blocks exist for the handling of parts, containers and cartons, for the opening and/or closing of packages, and for the associated information processing. Handling takes into account the number and frequency of variable Body Motions (Walk, Stoop, Sit and Stand) and the picking up, place aside at the point of use, and depositing of tools (equipment) with supplementary values.

The MTM process building blocks for handling parts, containers and cartons cover common work tasks that fall within the scope of basic work. They can be used to describe all the motions required to reposition, exchange or refill a container, carton or part from one location to another. For example, the quantity and weight of the objects to be handled, as well as their size, play a role in the correctly description of the workflow at hand.

The processes "Open packaging" and "Close packaging" already describe their content. They include all logistics-related tasks necessary to access items within containers or seal them using required tools and materials. The determining factors are the type of packaging, (i.e. folding carton, bag, or lattice box) and whether it has covers, lids, or intermediate trays.

Using the MTM logistics data card "Handling - Close Packaging", this section provides a straightforward application example. To demonstrate, let us take a pre-filled cardboard box measuring 30 x 25 x 20 cm and place it on a workbench. The parts within the box are then covered with a lid and sealed with two adhesive strips as shown in Figure 6.

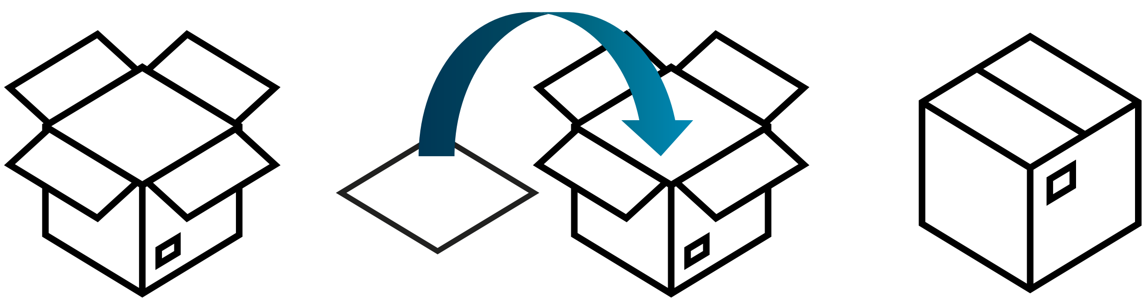
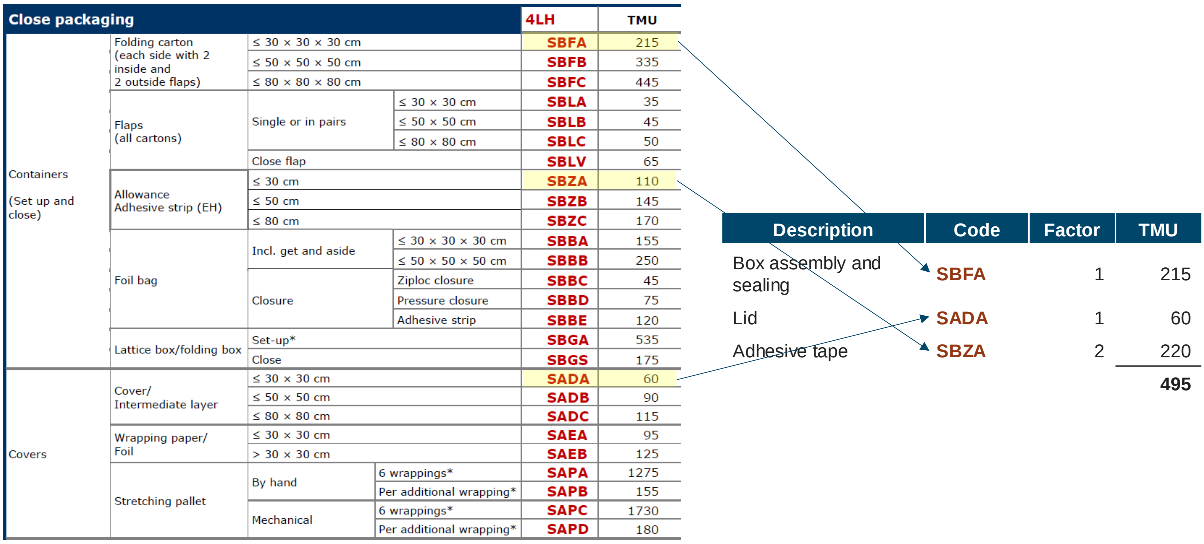


Figure 6: Example case: Close packaging

[30] cf. MTMA, 2019b

From the analysis of the close packaging example case (see Figure 7), it is evident that the coding *SBFA* for establishing and shutting a folding carton, with a maximum size of 30 x 30 x 30 cm, possesses a time value of 215 TMU (Time Measurement Unit, where 1 TMU is equal to 0.036 seconds), equaling approx. 7.7 seconds.

The insertion of the lid is described by the code *SADA* and the sealing of the box with the adhesive tape by the *SBZA*. SADA allows 60 TMU (approx. 2.2 seconds), while the time value allotted for the *SBZA* (110 TMU) is doubled for the use of two adhesive strips, amounting to 220 TMU (approx. 7.9 seconds). The total time analyzed with MTM (basic time t_g) for this small application example is 495 TMU, or approx. 17.8 seconds.



Close packaging				4LH	TMU
Containers (Set up and close)	Folding carton (each side with 2 inside and 2 outside flaps)	≤ 30 × 30 × 30 cm		SBFA	215
		≤ 50 × 50 × 50 cm		SBFB	335
		≤ 80 × 80 × 80 cm		SBFC	445
	Flaps (all cartons)	Single or in pairs	≤ 30 × 30 cm	SBLA	35
			≤ 50 × 50 cm	SBLB	45
			≤ 80 × 80 cm	SBLC	50
		Close flap		SBLV	65
	Allowance Adhesive strip (EH)	≤ 30 cm		SBZA	110
		≤ 50 cm		SBZB	145
		≤ 80 cm		SBZC	170
	Foil bag	Incl. get and aside	≤ 30 × 30 × 30 cm	SBBA	155
			≤ 50 × 50 × 50 cm	SBBB	250
		Closure	Ziploc closure	SBBC	45
			Pressure closure	SBBD	75
			Adhesive strip	SBBE	120
	Lattice box/folding box	Set-up*		SBGA	535
		Close		SBGS	175
Covers	Cover/ Intermediate layer	≤ 30 × 30 cm		SADA	60
		≤ 50 × 50 cm		SADB	90
		≤ 80 × 80 cm		SADC	115
	Wrapping paper/ Foil	≤ 30 × 30 cm		SAEA	95
		> 30 × 30 cm		SAEB	125
	Stretching pallet	By hand	6 wrappings*	SAPA	1275
			Per additional wrapping*	SAPB	155
		Mechanical	6 wrappings*	SAPC	1730
			Per additional wrapping*	SAPD	180

Description	Code	Factor	TMU
Box assembly and sealing	SBFA	1	215
Lid	SADA	1	60
Adhesive tape	SBZA	2	220
			495

Figure 7: Analysis for the example case close packaging

2.2.3 Transport with Forklifts, Pallet Trucks and Cranes

The standard operation for transportation encompass all the required MTM process building blocks for evaluating standard procedures using commonly used transport vehicles or transport carts in practice. These processes take into account various operating conditions and equipment configurations, along with relevant safety regulations. In addition to the general MTM process building blocks, there are specific operations steps and sequences for transportation, as well as additional data for other transport equipment and cranes.

The general MTM process building blocks are general and apply the same method for every MTM process building block, regardless of the type of vehicle. Technical term abbreviations are adequately explained upon their initial usage. These blocks comprise processes such as "Start and shut down the motors", "Put on and place aside the seat belt" or "Pull and loosen the parking brake".

The forklift operation steps and operation sequences pertain to the types of vehicles: forklift trucks, reach forklift trucks, and pallet trucks, with a distinction made for the latter between walk-behind and rider pallet trucks. The operation steps reflect transportation movements, for example such as "driving," "lifting/lowering," or "placing pallet into or removing from racks location." The operation sequences result from condensing and statistically weighting standard operations and encompass all typical driving options for Get and Place of pallets, containers, or similar transport aids using forklifts. Through detailed descriptions of these processes within the operation sequences, different transport methods, vehicle configurations, and performances can be depicted transparently and analyzed safely and with sufficient precision.

To better understand what has been explained, we will now describe the analysis of a simple example case using the logistics process building blocks of *Forklift Operations Steps* and *Operations Sequences*. A forklift truck is used to pick up a pallet from a height of 2.5 meters and place it on the ground over a distance of 100 meters (including 2 curves) (see Figure 8). For the sake of simplicity, it is assumed here that the operator is already seated on the forklift truck with the seat belt fastened and the transmission engaged.

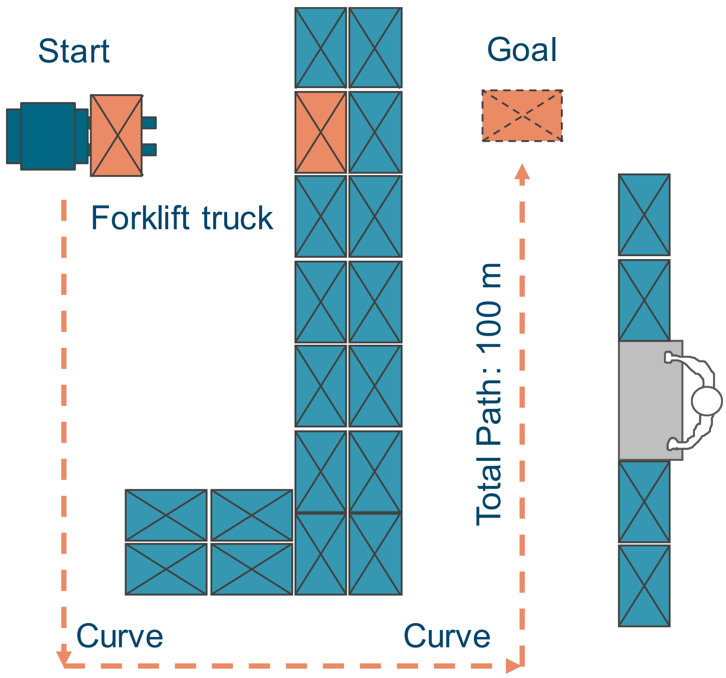
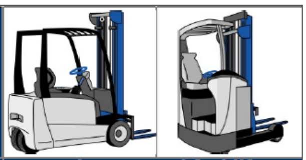


Figure 8: Example case 2: Standard Operations Transport

As seen in Figure 9, the data cads *Forklifts Operation Steps* and *Forklifts Operation Sequences* are used for the analysis. To Get and Place the pallet, the corresponding code *(SACAFM)* is taken from the *Forklifts Operation Sequences* data card. There are 1,080 TMU provided for this work step, which is approx. 38.9 seconds. Driving 100 meters (including 2 turns) with the forklift truck is read from the *Forklifts Operations Steps* data card. One meter of driving is represented by the code *SFISF*, which has a time value of 13 TMU. This is multiplied by 100, giving a total time of 1,300 TMU, or 46.8 seconds, for the travel time. Turning corresponds to the code *SFKSF*, which is multiplied by a factor of two, giving a time of 32 TMU (approx. 1.2 seconds). According to MTM, the entire sequence requires 2,410 TMU, or approx. 86.9 seconds (basic time t_g).



Lift	Place	Forklifts Operation sequences – Time values in TMU	Driver seated forklift – Forklift truck – Without	Driver seated forklift – Forklift truck – With	Driver seated forklift – Reach forklift – Without	Driver seated forklift – Reach forklift – With
		Align	Without	With	Without	With
		5LT	FO	FM	SO	SM
Floor	Floor	SAAA	603	833	718	983
	1.2 m	SAAB	751	981	903	1168
	2.5 m	SAAC	912	1142	1105	1370
	4.0 m	SAAD	1098	1328	1337	1602
1.20 m	Floor	SABA	854	934	1014	1084
	1.2 m	SABB		1082		1269
	2.5 m	SABC		1243		1471
	4.0 m	SABD		1429		1703
2.50 m	Floor	SACA	1000	1080	1160	1230
	1.2 m	SACB		1228		1415
	2.5 m	SACC		1389		1617
	4.0 m	SACD		1575		1849

Forklifts Operation steps		Time values in TMU	Code	Driver seated forklift – Forklift truck	Driver seated forklift – Reach forklift
Operation steps per forklift			4LT	F	S
Drive	Inside per m	Stable or empty	SFIS	13	13
		Unstable	SFIL	17	17
		Crawling speed	SFIK	40	40
	Outside area stable or empty		SFAS	7	9
	Curve 90°	Stable or empty	SFKS	16	16
		Unstable	SFKL	56	56
	Delay (start and stop)	Unloaded	SFVU	30	30
		Loaded	SFVB	56	56
Align 90°	to storage location	Stable or empty	SRLS	80	70
		Unstable	SRLL	130	120
	in direction of travel (reverse)	Stable or empty	SRFS	65	55
		Unstable	SRFL	115	105

Description	Code	Factor	TMU
Pick Up + Place 2.5 m - Floor	SACAFM	1	1080
100 m driving	SFISF	100	1300
2 curves driving	SFKSF	2	32
			2410

Figure 9: Analysis of standard operations Transport for example case 2[31]

Other means of transport" includes electric tractors, hand pallet trucks and transport carts, which are listed on separate data cards with their various influencing factors and their impact on travel time.

On the one hand, the crane data provides data for crane types that are frequently encountered in practice (monorail crane, bridge crane and column jib crane). On the other hand, the available building block architecture provides a good starting point for building your own custom crane data.

There are other logistics process building blocks, for example such as “Information processing", which can be used to describe other logistics activities. Process Information represents all the activities necessary to collect, process, and input information. Processes such as reading, writing or scanning data can be found here.

2.2.4 Areas of Application in Industry

How the MTM process building blocks of MTM logistics data are used in logistics practice is illustrated by the following examples.

Spare parts logistics

Volkswagen AG's Original Parts Center, or OTC for short, ensures the supply of spare parts to various companies around the world. Due to the variety of packaging, quantities,

31 MTMA, 2019c

weights and storage types, this is a great challenge for technology, organization and employees. With the introduction of the MTM-UAS® and MTM-LOG® process building block systems, it was possible to analyze all assigned workstations and map them transparently in a VW logistics system developed in-house. The resulting improvements in the logistics workstations and processes led to an average increase in productivity of ten percent to an ergonomic design of the workstations.

Contract logistics

The Solutions Engineering department of the German Kuehne + Nagel organization is responsible for planning and resource costing of new customer business in contract logistics. For this purpose, standard times based partly on MTM logistics data and partly on empirical values (time records) were used and planned. In addition, selected workstations in the manual picking area were examined and improved with regard to physical stress during handling and repositioning of loads. The resulting time catalog for resource calculation and an internal company data card with additions for load weights and postures were made available to Kühne + Nagel for future repositioning of their logistics solutions.

Tender calculation

Another example is the MTM application at Müller - LILA LOGISTIK. In its own logistics service centers, the company offers, among other things, the pre-assembly or assembly of assemblies and components. For the planning and calculation of an offer concept for a company in the automotive industry, planning data values for the pre-assembly of the selected products or product families were determined with MTM-UAS®. On the one hand, this leads to a valid data basis for the preparation of the quotation and on the other hand to an increased transparency of the processes. Another benefit is the identification of waste. In the course of the project, for example, ideas were generated on how to avoid multiple handling or how to arrange components, jigs, fixtures and tools in a process-oriented manner. In addition, design potential was identified in the provision of materials at the workstation.

Process time catalog for logistics activities

The project undertaken by DB Schenker aimed to create a custom process time catalog and standardize process times. The outcome was a dependable database that serves as a foundation for planning future approaches. The focus was on warehouse processes - from goods receiving to issuance - drawing from existing MTM logistics data and time modules at DB Schenker. The outcome comprised of process-neutral time modules which are employed based on the level of aggregation, for enhancing processes or for planning and costing. The developed process time catalog facilitates swifter and more precise work - both during analysis and planning. Subsequently, this results in increased planning and investment security in the long run.

Price and resource calculation

The project at TechnoCargo Logistik, a logistics service provider of the Vaillant Group, focused on standardizing price calculations. The cost structure was set prior to the project using the open-book method in collaboration with Vaillant Group employees. Nevertheless, the prices did not accurately account for the individual expenses of personnel and equipment in each area. Upon commencing the project, an analysis and documentation of all processes, ranging from the goods receiving of various heating, ventilation, and air-conditioning units, accessories, and spare parts, to the production and control of spare parts and goods issue, were conducted and documented via MTM. As a result, a novel pricing logic was created, and the implementation of a new process and effort calculation model resulted in enhanced capacity planning and cost prediction. Another positive outcome was a improved understanding of processes and a comprehensive identification of potential savings. The continuous comparison of prices along the supply chain enables a precise demonstration of the cost per package or pallet, thereby showcasing the process accuracy.

The MTM process building block system MTM-LOG® can make a substantive contribution to enhancing logistics processes. Through meticulous assessment and planning of workflows, firms can optimize their processes. The scope of this applies to several areas of application, including spare parts logistics, contract logistics, tender costing, and process time catalogs. To enhance the implementation of MTM in logistics, developers are creating MTM reference processes that chart out standardized workflows, allowing for quicker evaluation. Integrating MTM into logistics processes presents a road to streamlining procedures and boosting profitability.

2.2.5 Outlook MTM Reference Processes Logistics

To facilitate the evaluation of logistical matters with greater ease and speed, the MTM RPLs, also known as MTM Reference Processes Logistics, are a fitting solution. A brief explanation of these reference processes is provided below.

The reference processes outline generalized criteria for goods receiving (such as unloading trucks), storing cargo units, performing tasks in supermarkets, and selecting orders (for example including loading route trains), as well as packing or repacking activities, conveyor supply by route trains and material return, and finally, for dispensing goods (such as loading trucks with full-load carriers from collection points). They are based on standardized reference processes that combine MTM-UAS® and MTM logistics data to ensure the neutrality and reliability of the results.

The assessment of logistics processes is expedited and simplified due to the fact that, unlike with MTM logistics data, the application of this concept requires minimal MTM knowledge or training. The simplified approach involves querying variables that impact the process, such as distances (driving and walking), average speeds, and parameters like transport weights and load units. These variables are then combined with reference processes to calculate both time and ergonomic loads. This enables flexible responses to sudden process changes, including fluctuations in quantity, daily personnel requirements determination, and also give hints for potential improvement identification.

In general, the reference procedures pertain to the management of goods, encompassing goods reception, storage, retrieval, transportation, and release - in essence, the complete intralogistics process in a facility or warehouse.

When designing work processes, it is imperative to consider not only productivity but also ergonomic factors.

2.3 Ergonomic work design with EAWS®

Connections between ergonomics and method design with MTM exist specifically in the design, arrangement and dimensioning of parts, the work area, workstation and other elements that directly impact the workflow.

MTM, in particular the MTM process building block systems MTM-1® and MTM-HWD®, aid in identifying value creation and waste by considering a large quantity of time-relevant influencing factors. This process leads to optimized product and process design.[32] A largely waste-free work process with a low target time demonstrates effective process design. Process design is enhanced by identifying influencing factors, beginning with product design, such as the simplification of the positioning created by the designer, followed by workstation design, which reduces motion length, and logistics design, which improves gripping conditions during part removal.[33]

High-quality ergonomic design is necessary for long-term efficient and error-free work. Therefore, consciously designing for two-handed work and avoiding unnecessary biomechanical stress and necessary load changes are essential elements of good work design. An optimal layout can be achieved through avoiding excessive walking distances and better part arrangements, as well as minimizing stress, such as additional stooping.[34]

In summary, effective work management necessitates a holistic approach to the design of human work.[35] This requires a foundational focus on ergonomics assessment using EAWS® and, for further advancement, the most up-to-date process building block system MTM-HWD®.[36]

The EAWS® enables the identification of ergonomic deficiencies, not only in existing work systems, but also in the early stages of product development process, thereby reducing health risks. It is the sole procedure that records various stress types and integrates them

[32] cf. MTMA, 2019a
[33] cf. Kuhlang, 2018
[34] cf. Kuhlang, 2018
[35] cf. Schlick et al., 2010
[36] cf. Kuhlang, 2018

into complete stress. The load on the entire body is defined by the risk areas of posture, action forces and load handling. Furthermore, EAWS® assesses the impact on the upper limbs from highly repetitive activities.[37] These types of stress are documented and analyzed across five categories within EAWS® (see Figure 10).

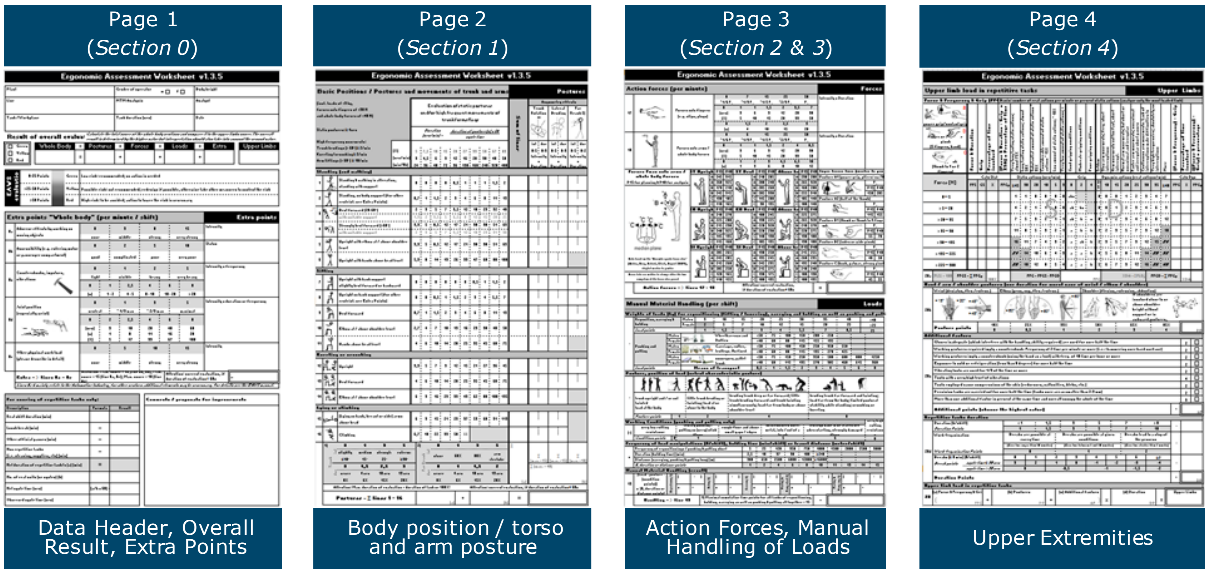


Figure 10: EAWS® Worksheet[38]

The evaluation starts with the collection of general and organizational data (e.g. cycle time, analyst, analysis date, evaluated workstation). In Section 0 - *Extra Points* - the evaluation of extra points takes place, which are given for example for moving objects, for poor accessibility of the workstation or for recoils, vibrations or impulses. In Section 1 - *Body Postures and Body Motions* - the stress level is considered by the type of posture (standing, sitting, squatting) in combination with the duration (based on cycle time). In Section 2 - *Action Forces* - the load level is determined according to specific rules depending on the type of force, the type of grip or body position and the direction of the force. The load duration or frequency (based on the cycle time) is also taken into account. In Section 3 - M*anual Load Handling* - the stress level depends on the weight of the load to be handled and the body posture during handling. It is also partially dependent on other influencing factors such as the duration of holding or the distance during pulling or pushing. The duration of the load is calculated here based on the duration of the shift. In Section 4 - *Load on upper extremity due to (short) cyclic repetitive activities* - the loading intensity is determined by taking into account the force level, the type of grip, unfavorable joint positions and any additional factors. The duration of the load is determined on the one hand by the frequency of the movement and on the other hand by the duration of the shift in combination with the work organization.[39]

37 cf. Lavatelli et al., 2012; Schaub et al., 2012
38 cf. DMTMV, 2014
39 cf. Kuhlang, 2017

To determine the physical or biomechanical load of an activity, it is essential to consider the duration or frequency of the load, as well as its level or intensity. The EAWS® index for biomechanical stress - the "stress index" (R) - is calculated by multiplying the "stress level" (intensity I) and "stress duration" (D). The EAWS® analysis determines a point value for each section area, specifically the total body and upper extremities. These values are evaluated using a traffic light scheme (green, yellow, red) as outlined in Directive 2006/42/EC.[40]

The load calculated from sections 0 to 3 is then assigned to the point value for the entire body, while that of section 4 is assigned to the point value for the upper extremities. By superimposing the loads, the result is obtained as both a point value and a color in the traffic light scheme.

Holistic design is a critical objective in ergonomic work design throughout all stages of product creation. EAWS® enables the identification of ergonomic deficiencies in the early stages of product development, design, and planning, which helps avoid health risks from the beginning. Additionally, EAWS® systematically records and evaluates pertinent influences on processes and work systems, which opens up the opportunity for a stronger focus on people in work design. The standardized objective assessment provides concrete starting points for product and process improvements.[41]

By combining the MTM basic system, MTM-1®, with ergonomics assessment, the new MTM process building block system, MTM-HWD®, was developed. This system enables the description and evaluation of workflows concerning both time and ergonomics.[42] By applying methods like EAWS® and MTM-HWD®, workstations, including basic workstations, can be designed with better ergonomics.

2.4 Temporal and ergonomic evaluation with Human Work Design

The MTM process building block system MTM-HWD® (Human Work Design) presents an innovative method for linking workflow, time and ergonomics in an inseparable manner.

The name was selected based on the guiding principle of prioritizing people in the planning and design of work. A human-centered approach, which considers current productivity management requirements during digitalization, as well as stress-optimized design for motion to preserve and improve human performance, must be considered. Today, ergonomic work design must go beyond reducing physical stress and embrace a stress-focused, employee-oriented approach that promotes healthy working and learning over an extended working life amidst demographic changes. This is especially relevant in the context of political debates and efforts to adapt the workplace to increasing average life expectancy. Properly applying MTM-HWD® can aid this objective.

40 cf. Schaub et al., 2012
41 cf. Kuhlang et al., 2017
42 cf. Finsterbusch, 2016

2.4.1 MTM-HWD®-Actions

The MTM process building blocks of the MTM process building block systems can be divided into hierarchic levels according to their granularity. The basic motions (MTM-1®) form the lowest level, followed by the motion sequences (e.g. MTM-HWD® and MTM-SD®), the basic operations (MTM-UAS® and MTM-MEK®) and other levels (e.g. standard operations)[43]. The composition of the contents is determined on the one hand by the logic (sequence of contents) and on the other hand by the principles of building block aggregation, i.e. the way in which MTM process building blocks are combined. For example, a motion sequence typically consists of a sequence of up to three basic motions.[44] Another feature is that there is usually no summary of a hand-arm system motion with all body motions.

MTM-HWD® uses a new kind of summarization. The basic motions (e.g. Walk, Bend, Stoop) are not considered as fixed MTM process building block (time value), but as an influencing factor with a defined scaling. As a result, the term motion sequence, as it is commonly used for the MTM process building blocks of MTM-2® and MTM-SD®, could not be used and thus the term MTM-HWD® actions was born.

Another feature of the MTM-HWD® actions is their English naming and thus the new terminology. In the nomenclature of the MTM process building blocks, the term PLACING is clearly defined. It is used in the MTM process building block systems MTM-2®, MTM-SD® and MTM-UAS® and includes at least the basic motions Move and Position. However, the English naming convention is different (MTM-2®: *PUT*, MTM-SD® and MTM-UAS®: *PLACE*). The MTM process building block system MTM-HWD® also has a "Place" process block, but in addition to Position and Move it also includes Release and possible Body Motions. Therefore, this MTM-HWD® process building block does not have the same name, but was given the description *DEPOSIT*. Figure 11 shows an overview of the MTM-HWD® actions.

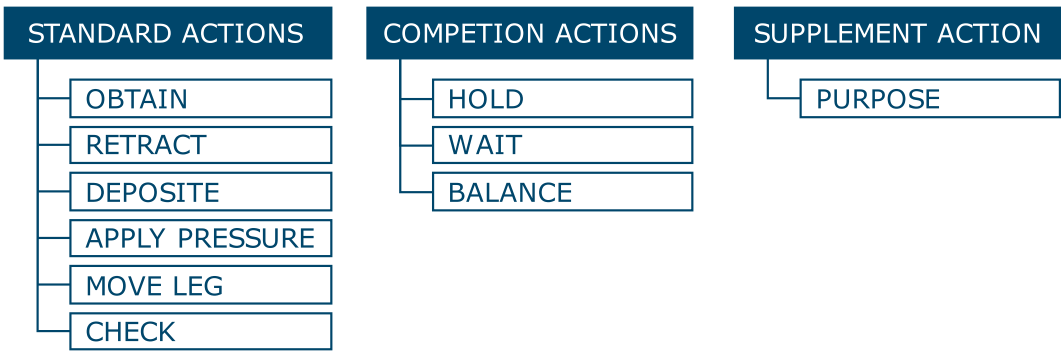


Figure 11: The process building blocks of MTM-HWD® - The MTM-HWD® actions[45]

---

43 cf. Figure 3
44 cf. Bokranz & Landau, 2012
45 cf. Finsterbusch, 2015

DEPOSIT is one of the so-called MTM-HWD® standard actions *(OBTAIN*, *DEPOSIT*, *RETRACT*, *APPLY PRESSURE*, *CHECK* and *MOVE LEG*). With these all time-limiting motions of the human workflow part, as in previous MTM process building block systems can be described. The "*completion* actions", which do not occur in previous MTM process building block systems, allow for the first time a complete (100%) description of a work cycle from the human perspective, as it is and must be taken into account in the evaluation of physical stress. Particularly noteworthy are the MTM process building blocks *HOLD* and *WAIT*, which are used primarily to describe the human being during time-limiting work (process time) of operating resources, and the process building block *BALANCE*, which is used to describe the time portion of the cycle compensation time.

From this fact, a new MTM doctrine can be derived. For the first time, the MTM process building block system no longer solely describes the activity time (t_t) of a workflow, but also includes the time components of the *completion actions* to fully describe the basic time (t_g). The supplement action *PURPOSE* is to use it when the underlying time for a motion sequence, a basic operation or a workflow has been collected using another MTM system, in another form of description, or in a supplement technique (e.g. MTM for Visual Inspection, time recording, comparison and estimation). This action becomes relevant during the early industrialization stages of a product and when describing special workflow modeling.

Depending on their definition (Start, Content, End), influencing factors and standard time values are assigned to each MTM-HWD® action. The application of said actions results in the creation of workflow models (descriptions), which serve as the primary outcome of an MTM-HWD® application. Subsequently, additional secondary results may be generated both partly and immanently. These are generated on the basis of algorithms (time evaluation by means of the time classification scheme, eHPV evaluation, EAWS® evaluation). A unique aspect of these algorithms is that a single factor determines multiple result factors. The algorithm selects the necessary input parameters from the description to calculate the result variable(s).

This is illustrated by the influencing factor weight, which influences the target time on the one hand and the load point value on the other. In addition, other influencing factors (e.g. head posture) have been integrated, which are required for a comprehensive description of human beings but are not yet taken into account by current ergonomics assessment methods (e.g. EAWS®). Process building blocks of the MTM process building block system MTM-HWD® are structured in such a way that influencing factors can be added in the future.

In summary, an MTM-HWD® analysis offers a minimum of three outcome measures simultaneous:

- a fully comprehensive description of the workflow and the ergonomic anthropometric parameters,
- a target time and

- a stress point value associated with a physical stress evaluation procedure.

Thus, comprehensive models of human workflow are created with MTM-HWD®.

2.4.2 Coding/pictograms

The use of pictograms in the MTM process building block system MTM-HWD® is an innovative approach. To eliminate the complexity of coding, each influencing factor scale level has been assigned a corresponding picture (see Figure 12). By doing so, the MTM process building block system is now accessible to a wider range of users. The concept of using symbols to describe human motion was introduced by Gilbreth, who developed the Therbligs scheme. Accurate consideration was taken when creating the pictograms to ensure clarity and ease of understanding.

- the pictograms are designed to be as gender-neutral as possible,
- the person depicted is attired,
- the detail to be described is in the foreground and
- a consistent design is apparent with matching colors and hatchings.

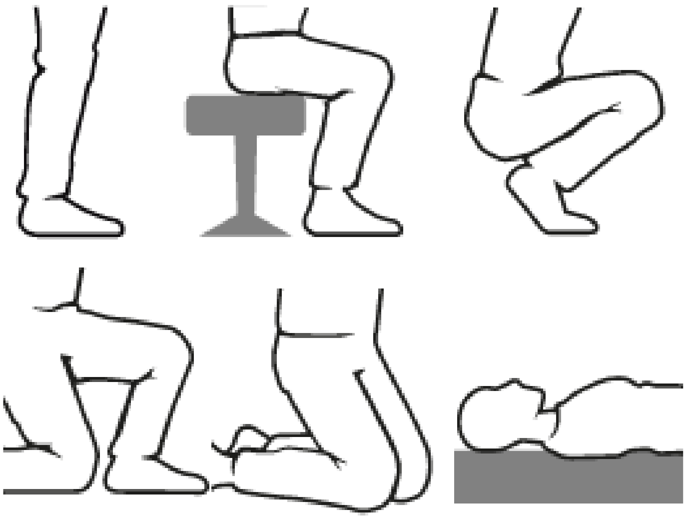


Figure 12: Influencing factor basic position - scaling standing, sitting, squatting, Kneel on One Knee, Kneel on Both Knees, lying down

2.4.3 MTM-HWD® description form

The traditional method of MTM analysis preparation involves using a data card and analysis forms (001-005F) with paper and pencil. MTM-HWD® allows for the same approach, but with a workflow description that is detailed on a form offered in three variations (00A, 00M, 00E).

An MTM-HWD® analysis follows a book-like structure, with information presented in a clear, logical sequence, from left to right. Three types of descriptions are utilized, including the starting posture, sequence description, and ending posture. The starting and ending postures indicate the body position at the beginning and end of each workflow, respectively. Each influencing factor is marked with a pictogram if the posture differs from the basic value, ensuring clear and objective language. A basic value was assigned to each influencing factor, represented by a colored pictogram. The analysis lines detail the workflow (of the work method) and consist of general information about the object, hands (left or right), and actions performed. Pictograms are utilized to illustrate the influencing factors of these actions, thereby describing movement execution and assumed postures. Depending on the chosen pictogram, the time values are summed and computed in order to ascertain the intended duration.

2.4.4 How MTM-HWD® works - A practical example

The practical example presented below explains MTM-HWD® by initially outlining its description, followed by an evaluation of the method.

This example illustrates an assembly workstation where a single employee assembles pumps to demonstrate MTM-HWD®. The subsequent steps of the assembly are omitted from this example, and the following explanations pertain to the initial activity of the assembly - Get and Place of the pump casing.

Figure 13 displays the workstation in plan view. The employee initiates the assessed task in an upright standing position (see Figure 14, starting position). Initially, the employee pivots towards the rear and acquires a casing from the material trolley (see Figure 14, to the casing). Then, he places the casing in a fixture located at the assembly spot (s. Figure 14, casing to fixture).

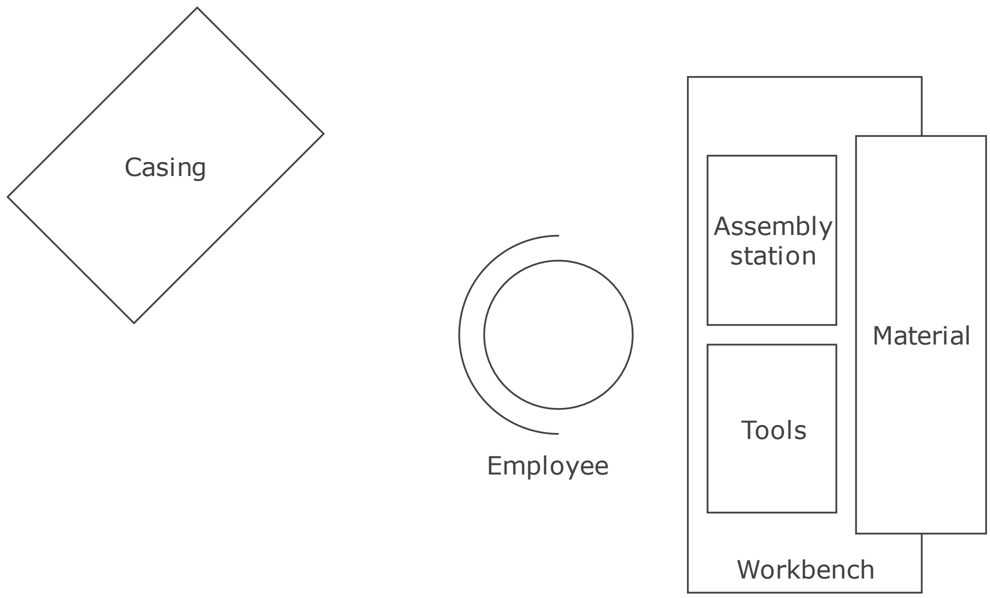


Figure 13: Workstation layout

Starting Position | to the casing | Casing to fixture

Figure 14: Representation of the activity

2.4.5 Description of activities with MTM-HWD®

The MTM-HWD® is used to explain the assembly process in the following example. It is important to note that not all influencing factors of the actions described in the example are discussed within its context.

In principle, in MTM-HWD®, after defining the actions, the hands involved and the objects, the isolated movements or activities are analyzed line by line by identifying the influencing factors or their characteristics. The analysis starts with the lower extremities and progresses to the trunk, head/neck, arms, weights, forces, and ultimately the hand. Corresponding pictograms are selected to document the recorded information.

Actions and objects

When conducting the analysis, the initial step is to document the motions or activities - referred to as actions - that the employee performs with their limbs and the objects utilized in the procedure (see Table 2). In the example given, the workflow begins with one motion towards the material trolley followed by simultaneously acquiring the pump housing with both hands *(Obtain)*. Subsequently, the employee conveys the casing to the assembly location and deposits it there *(Deposit)*. The parentheses in the second column indicate which actions take place simultaneously. In the example, the employee consistently uses both hands.

Table 2: Objects and actions

No.		Description	Object	Action	Active Extremity	Passive Extremity
1		Starting Position	-	-		-
2	(	to the casing	Part	OBTAIN	left Hand	none
3		to the casing	Part	OBTAIN	right Hand	none
4	(	Gehäuse vor Körper	Part	DEPOSIT	left Hand	none
5		Gehäuse vor Körper	Part	DEPOSIT	right Hand	none
6	(	to upright	Part	DEPOSIT	left Hand	none
7		to upright	Part	DEPOSIT	right Hand	none
8	(	Casing into fixture	Part	DEPOSIT	left Hand	none
9		Gehäuse in Vorrichtung	Part	DEPOSIT	right Hand	none
10		Endhaltung	-	-	-	-

Other potential actions would be, for example, the examination of components *(Check)* or the separation of two components *(Retract)*. Tools, actuators, or transport means may also be selected as objects for analysis. Additionally, activities that involve the use of only one hand or foot of the employee can be analyzed.

One horizontal analysis line in MTM-HWD® represents a single action, indicating the description of one motion. When combined vertically, these single motion analyses provide a description of the workflow, or work method.

For every action, the influencing factors and their characteristics are documented using the corresponding pictograms. The following explanations explain this using the example of analysis lines 1, 3 and 9 (see Table 3).

Influencing factors - lower extremities

The MTM-HWD® analysis starts by recording the initial posture of the observed person. If the process starts with the action "Obtain", the influencing factors of the "lower extremities" category should be described, specifically the influencing factor distance, execution conditions and leg posture (see Table 3). The contributing factor of "stability" is denoted as "stable."

Table 3: Influencing factors - lower extremities

No.	Distance	Execution Conditions	Basic Position	Leg Posture (left)	Leg Posture (right)
1	-	unhindered	standing	extended	extended
3	1 step 1 Side step	unhindered	standing	extended	extended
9	walking 2 m Walking : 2 meters	unhindered	standing	extended	extended

The influencing factor *distance* describes the distance an employee travels before using their arms or hands. For each characteristic such as walking, climbing steps, climbing, and crawling, the user specifies either the quantity of meters, steps or rungs covered. In the provided example, the employee first walks one step to the side to reach the casing, then walks two meters to reach the workbench.

The influencing factor *Execution Conditions* describes the condition of the ground when traveling the path and provides information about the required degree of control when walking. In the assembly example, the conditions are favorable because the ground is level and there are no obstacles in the way.

The influencing factor *basic position* determines the body's position at the end of a motion, whether the employee is standing, sitting, kneeling or crouching. The influencing factor *leg posture* then specifies whether each leg is extended or bent. In the example activity, the employee begins with a standing position and maintains extended legs at the end of each motion.

Influencing factors - trunk and head/neck

In the next phase of analysis, MTM-HWD® will examine the postures of the trunk, encompassing the influencing factors of trunk flexion, rotation, and tilt (see Table 4) as well as head posture, which is not discussed in detail in this study.

Table 4: Influencing factors - trunk and head/neck

No.	Trunk body bending	Trunk Body tilting	Trunk body rotation
1	excitement	no Trunk Body Tilting	no Trunk body rotation
3	strongly bent forward	Strong Trunk Body tilting	no Trunk body rotation
9	excitement	no Trunk Body Tilting	no Trunk body rotation

The influencing factors *torso flexion, turn* and *tilt* describe the posture of the upper body at the end of a motion. For example, one can still perform walking, bending or a lateral inclination of the upper body. *Trunk body bending* indicates how far the upper body is bent forward or backward, *trunk body tilt* indicates how much it is tilted to the side, and *trunk body rotation* indicates how much the trunk is rotated compared to the hips or whether a body turn is done using one or both feet. In the illustrated example, the employee's body starts in the neutral position, meaning the trunk is not flexed, rotated or inclined. To accommodate the casing, he then strongly tilt and rotate the trunk and moving it back to the neutral position. The head posture is described in a similar manner, capturing *head flexion, rotation* and *inclination*.

Influencing factors - arm and weight/force

After analyzing the posture of the trunk, the next step is to consider the arms as well as the applied force or the carried weight (see Table 5). Subsequently, the right arm is analyzed here.

Table 5: Influencing factors - arm and weight/force

No.	Upper Arm Posture	Hand Position	Arm Extention	Hand Posture	Weight / Force
1	Angle 0<x<20 °	below shoulder height	Extention 80%<x	neutral	no force
3	Angle x>60 ° oder x<0 °	below shoulder height	Extention 40%<x<80%	neutral	No force
9	Angle 20°<x<60 °	below shoulder height	Extention 40%<x<80%	Rotation to the side	Weight: 3,0 kg Weight Casing : 3 kg

The influencing factor *upper arm posture* describes the deviation of the arm forward, backward, or to the side. This deviation measures the displacement of the upper arm away from the trunk. In the example, when the employee is picking up *(Obtain)* the casing, they strongly deviate their right upper arm. When placing *(Deposite)* the casing in the assembly fixture, the upper arm is not deviated as strongly.

The influencing factor *hand position* indicates the height of the hand relative to the shoulder, whether it is held below, at, or above shoulder height. In the example, the hand is always positioned below shoulder height.

The influencing factor *arm extension* describes the distance of the hands from the shoulder joint. Possible expressions are close, partially extended, and fully extended. In the starting position, the employee holds his right arm fully extended. During the two actions, he then brings the arm into a partially extended positions.

Analogous to the trunk posture (see Table 4), the *hand posture* describes whether the wrist is rotated, flexed or inclined in relation to the forearm. In the starting position and when picking up the casing, it is in a neutral position, but when placing the casing, the employee must tilt the right hand to the side.

For the temporal and ergonomic evaluation of the activity, it is not only the posture of the body and limbs that is relevant but also the force that must be applied in that posture.

The influencing factor *weight / force* describes the load of the object to be handled or the force that needs to be exerted. In the example, the employee does not apply force but only delas with load weights, such as when transporting the casing *(deposit)* to the fixture.

Influencing factors - hand

In the MTM-HWD® method, the final step involves determining the motion of the hand. This includes, in particular, the distance covered by the hand or arm. Other influencing factors include the type of provision, placement accuracy, mounting position, joining conditions, grasping movement and grasping type (see Table 6). The influencing factor vibration occurs depending on the action and is consistently described as "none" in this example.

Table 6: Influencing factors - by hand

No.	Distance Class	Placement accuracy + Installation Position	Joining Condition	Grasping motion + Type of grasping
1	-	-	-	open hand without object
3	10	separate, portable	-	Encompass + 4-Finger Encompass
9	10	close placement, with alignment	Handle spacing Visibility obstruction	4-Finger Encompass

The influencing factor *distance* class describes the distance traveled by the wrist when picking up or placing an object. The user has different gradations of distances available. In the example, after bending and rotating, the employee moves the hand out of the body motion ten centimeters towards the casing. When placing the casing, he walks to the workbench and then has to move the casing over ten centimeters to the fixture.

The influencing factor *provision* describes the arrangement or position of the objects to be grasped. In the example, the casing are provided separately, and they are not always in the exactly the same location.

The influencing factors of *placement accuracy*, *installation position* and *joining conditions* describe how precisely objects need to be placed, whether symmetry needs to be considered, and whether the shape, texture or weight require additional effort. When placing the casing in the fixture, for example, the employee must fit the casing tightly with slight pressure, requiring alignment of the casing with the fixture. Additionally, the housing obstructs the view of the fixture, and the distance between the grip position an the positioning point hinders task execution.

Finally, the influencing factors *grasping motion* and *grasping type* describe the position of the fingers to gain control and hold the object. In the starting position, the employee initially has the fingers of the right hand open. To pick up the casing, he performs a gripping motion and then maintains control over the casing with a 4-finger grip, that he continues to use until the end of the joining process.

2.4.6 Evaluation of activities with MTM-HWD®

After all the influencing factors have been recorded line by line, the temporal evaluation of the activities is automatically calculated. Table 7 shows the time assessment for the example provided. It results in a time requirement of 53 TMU (approx. 1.9 seconds) for a motion to the casing and 89 TMU (approx. 4.6 seconds) for transportation to the assembly fixture. The entire process, considering all analysis lines, takes 183 TMU.

Table 7: Time rating

No.	Lower Extremities	Trunk + Head/Neck	Arm + Weight/Force	Hand	Sum
1	-	-	-		
3	16 TMU	29 TMU	0 TMU	8 TMU	**53 TMU**
9	53 TMU	0 TMU	2 TMU	34 TMU	**89 TMU**

Simultaneously, the so-called ergonomics declaration is generated, both for each line and for the entire workflow, essentially automatically in the background. Based on this, along with the incorporation of organizational data from the work system (cycle time, shift duration, break schedule), the ergonomics point value is calculated using one of the specified ergonomics assessment methods. The MTM ASSOCIATION e. V. typically employs EAWS® for this purpose as a standard approach.

2.4.7 MTM-HWD® at Miele & Cie. KG

In April 2015, an initial trial phase was conducted at an assembly line in the Miele & Cie. KG plant in Gütersloh. “There were two primary reasons that motivated the company to participate in this development project. Firstly, the management of the family-owned company, Miele & Cie. KG, considers the health of its employees as a central management responsibility. Secondly, the company recognized the challenge posed by the aging workforce due to demographic changes, and the need to maintain productivity with an older workforce. The company’s management anticipated that the application of the MTM process building block system MTM-HWD®, would provide valuable insights into how ergonomic work design and productivity development can be harmonized."[46]

By December 2017, the use of MTM-HWD® had evolved into a large-scale pilot application in series assembly. Differences between the previous results of MTM-UAS® and

[46] cf. Graute, 2016

EAWS® analyses were closely monitored. The comparison of the analysis results demonstrated that the values only differed insignificantly from each other.

In this chapter, an introduction to the MTM-HWD® (Human Work Design) process element system, which links workflow, time, and ergonomics, was provided. The importance of human-centered planning and work design in the era of digital and demographic changes was emphasized. MTM-HWD® actions describe motions, with influencing factors being more flexibly considered. Pictograms on the analysis form facilitate the coding process. In practice, the MTM process building block system has been introduced, enabling the integration of ergonomics and productivity.

How existing methods in work management can be integrated with modern digital tools to enhance their application is presented in the following chapter.

3 Digital work design with MTMmotion®

With the increasing digitization in work management and various technological and conceptual advancements, it's becoming increasingly possible to digitally support or partially automate analyses and planning.[47] This offers significant benefits for businesses. In particular, data-based and quality-assured work management is made considerably easier, even for small and medium-sized enterprises (SMEs) and international production sites.

Digitalization affects all functions within a company, including work management. It deals with the description and analysis of the productivity and employee health within organizations. A systematic planning of work systems and methods remains the key to achieving excellent productivity and humane working conditions in industrial processes, even in the age of digitalization. While detailed planning often involves significant effort, in the future, the use of digital technologies and tools will make the planning of human work processes more efficient and detailed.[48]

3.1 Simulation analyses

The connection between the digital world and real human work is established, among other things, by translating digitally available information, such as motion data from human simulation, motion capture, and VR systems, into accurate MTM analyses. This derivation or representation in the form of simulation analyses is a key element for the robust application of digital planning tools.

Simulation analyses describe and evaluate the digitally defined motion sequence (the individual operator method). In other words, "What you see (simulate, capture) is what you get (describe)!" Thus, a simulation analysis describes processes that do not occur in reality or the actual work process as captured or presented by digital tools. The link to human work performance is established for these work processes by describing and evaluating them in the form of an MTM analysis. This creates a connection to MTM standard performance and earns the "Approved by MTM ASSOCIATION" seal. Simulation analyses are converted into planning or production analyses through a formalized approval process by MTM or IE experts. This transforms the simulated motion sequence or the executed individual operator method into a consciously established, standardized work method. It's important to note that this transition into coordinated (!) planning analyses must be done intentionally. [49]

---

[47] cf. Benter & Neumann, 2023; Spitzhirn et al., 2022
[48] cf. Kuhlang, 2019a
[49] cf. Kuhlang, 2019, pp. 9-10; Kuhlang et al., 2020, p. 12

The following is an explanation of basic aspects regarding the processing of motion data with MTMmotion®. Subsequently, a specific application example is provided to illustrate the use of MTMmotion® interface data. The core of this chapter consists of the translation of interface data into valid MTM-UAS® and MTM-HWD® analyses.[50]

3.2 Technologies for processing motion data with MTMmotion®

Digital technologies are increasingly making their way into all aspects of the working world. In the field of work design, this includes technologies that generate or capture human movement data and subsequently process it. These technologies include, among others, human simulation[51], virtual reality[52] and motion capture[53]. These technologies are particularly useful for purposefully designing human work when the observed work processes are systematically evaluated in terms of time and ergonomics. Classic methods of work design like MTM and EAWS® are well-suited for this purpose.

For instance, the software manufacturer imk Industrial Competence has developed a solution to derive MTM-HWD® analyses from the simulation tool ema Work Designer and evaluated it in collaboration with the MTM ASSOCIATION e. V.[54] However, other technology manufacturers are also interested in solutions to derive established methods of work design. To ensure that these solutions provide valid, rule-compliant MTM analyses ("approved by MTM ASSOCIATION") and that all technologies have equal access to the MTM process building block systems, MTMmotion® was developed. Figure 15 illustrates this approach.

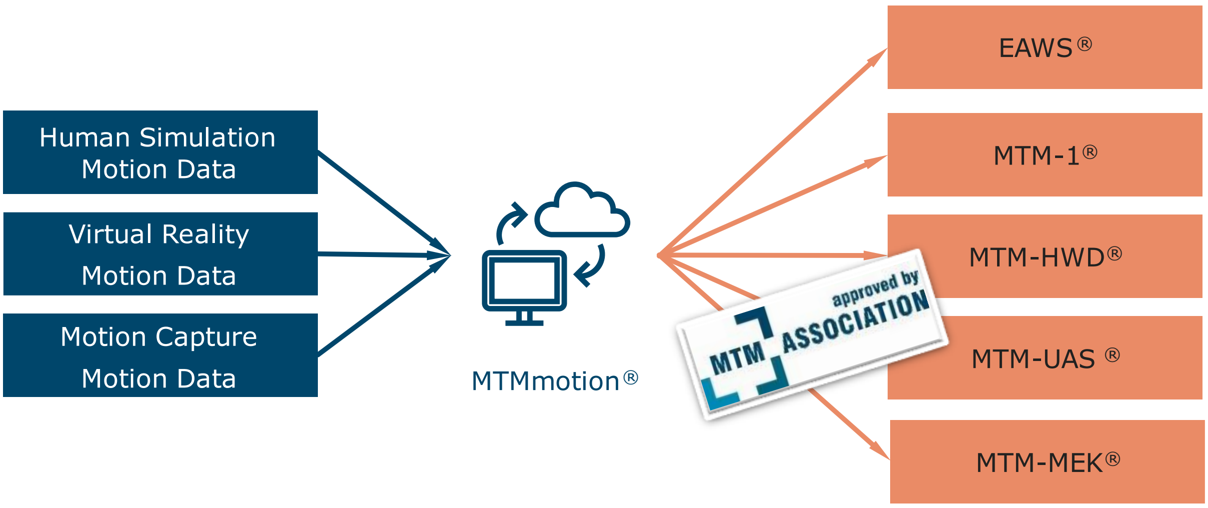


Figure 15: MTMmotion® - technology-independent translation to MTM analysis

[50] cf. Kuhlang et al., 2023
[51] e.g.: ema Work Designer: cf. imk, 2023; Fritzsche et al., 2019
[52] cf. LIVINGSOLIDS, 2023; halocline, 2023
[53] e.g.: XSens: cf. Movella, 2023
[54] cf. imk, 2023; Benter & Kuhlang, 2021

MTMmotion® was developed with the goal of serving as an interface (for all technologies) through which human movement data is translated into accurate MTM analyses. By incorporating the MTM method in this way, technology users can systematically analyze and design human workstations. It also contributes to the dissemination of MTM methods and ensures their correct application, thereby fulfilling the statutory mission of the MTM ASSOCIATION e. V..

3.3 Application Example

To explain the data in the interface and the translation into MTM analyses, the following example workstation is used. In this example, a person assembles a washing machine module, which consists of a component carrier, two pumps, several hoses and screws, and other small parts. The assembly time for the entire workflow is approx. two minutes. This article focuses on the final part, which is the attachment of the pumps with screws.[55]

The complete workstation, including all the necessary process steps, was modeled in the virtual reality (VR) software by the company LIVINGSOLIDS[56]. This VR solution utilizes a VR headset and handheld controllers. To record body motions, it also employs marker-based cameras for motion capture.

Figure 16 shows several views of the software that where captured during its use. On the bottom left is the test person with the VR components. Above this is the top view of the workstation, while the right side shows the view of the test person. At the time shown, a screw is being assembled using an electric rod screwdriver (see Figure 16, right image).

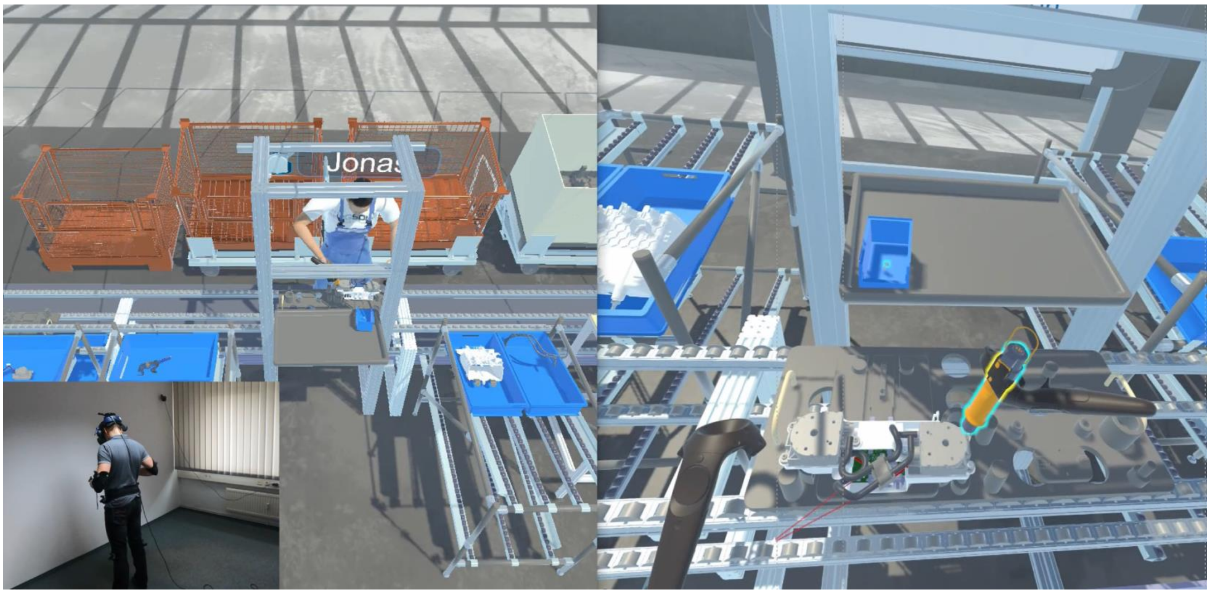


Figure 16: Views in the virtual reality tool of LIVINGSOLIDS

[55] cf. Benter & Neumann, 2023
[56] cf. LIVINGSOLIDS, 2023

3.4 Use of the MTMmotion® interface for the translation of VR motion data

To translate the data generated by the VR software, the MTMmotion® interface is used. Essentially, it can be described as a kind of digital language for describing human work processes. When valid data is supplied from the VR software to this interface, it can then be translated into rule-compliant MTM analysis by the MTMmotion® algorithms (see chapter 3.6). The structure of the interface is shown in Figure 17.

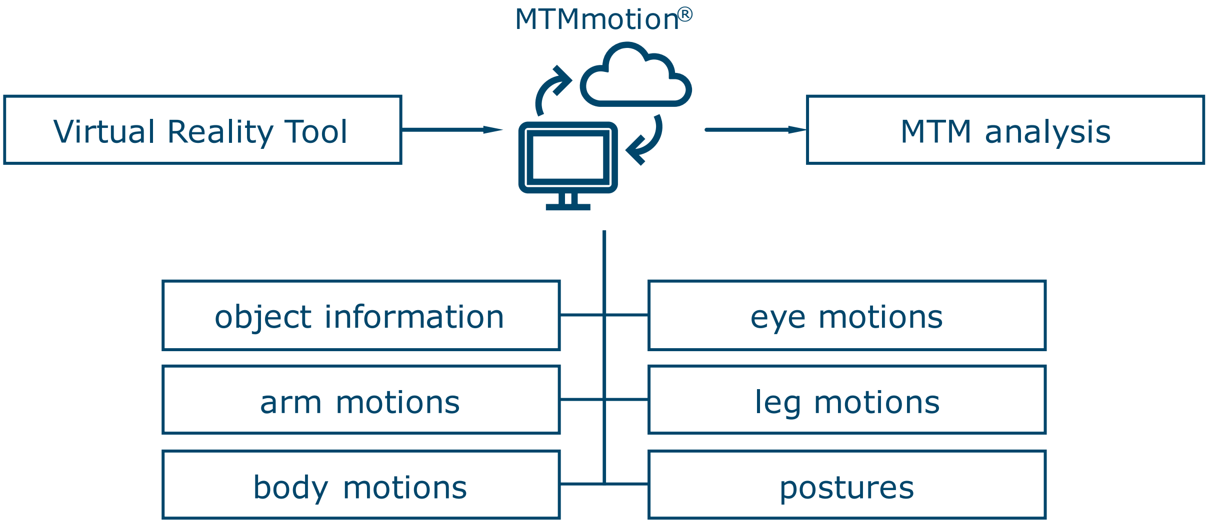


Figure 17: Derivation of MTM analyses via MTMmotion®

The interface describes digital motion data in such a way that it is possible for digital tools such as the VR solution from LIVINGSOLIDS to derive this data from their own data structure. It also contains all the information required to create valid MTM analyses. The data structure is explained in chapter 3.5.The derivation of interface data varies between technologies because they use different data architectures. In the application example, the algorithms for populating the interface were developed by LIVINGSOLIDS and validated in collaboration with the MTM ASSOCIATION e. V..

Chapter 3.6 and 3.7 then explain the steps MTMmotion® performs in deriving an MTM-UAS® and MTM-HWD® analysis. In addition, the analyses generated by the translation algorithms are also presented.

3.5 MTMmotion® interface data

The interface consists of an object list and six motion channels that describe human work processes. They are filled with all the necessary information to map the motions and postures of the person during the execution of tasks and the objects to be handled. The interface is structured as follows:[57]

1. Object List

[57] cf. Benter & Neumann, 2023

2. Channel Body Motions
3. Channel Arm Motions
4. Channel Leg Motions
5. Channel Eye Motions
6. Channel Body Postures
7. Channel Arm Postures

The object list enumerates the objects interacted with during the work task, along with relevant properties such as weight and dimensions to provide a more detailed description of the objects. Channels two to five (body, arm, leg, eyes) describe all of the motions of the person. The other two channels capture the posture of the person during the work process. The two channels Object List and Arm Motions are the most relevant, as they contain the key information about the manual work tasks. For the example workplace, the object list consists of the objects screw and cordless screwdriver.

Table 8: MTMmotion® data: Object list

object ID	object type	weight [kg]	dimensions [mm]	flexible
1	screw	0.02	5 x 12 x 12	no
2	screwdriver	1.2	150 x 50 x 80	no
3	hose	0.2	10 x 10 x 100	yes

To derive an MTM analysis, various object information is required (see Table 8). Various values, such as the physical properties of *weight*, *height*, *length*, and *width*, can be specified for these objects. In general, the larger or heavier an object, the more challenging it is to handle, and therefore, the MTM standard time is higher. *Flexibility* is another physical property that can complicate object handling. The table presents the three objects used in the steps of the process described: screws, hoses, and a screwdriver for assembling the screws and hoses, along with a selection of key object information.

Table 9 shows the necessary information for the Arm Motions channel. An essential aspect of these Arm Motions is the type of movement (motion) with which the employee performs their tasks. They can be distinguished by whether an object is obtained, moved, used, or held or placed aside. Additionally, the motion type UseObject can be differentiated further by the Usage Type, because for most objects there are different ways to use the object. A screw for example could – at its point of use – be screwed in or inserted or just placed on a screwdriver tip.

Table 9: MTMmotion® data: Arm Motions

time start	time end	object ID	side	arm motion	supply	usage type
51.0	51.5	2	right	ObtainObject	separated	-
51.5	52.5	2	right	MoveObjectTo OtherPosition	-	-
52.5	56.8	2	right	HoldObject	-	-
52.6	53.6	1	left	ObtainObject	clustered	-
53.6	54.4	1	left	MoveObjectTo PointOfUse	-	-
54.4	56.8	1	left	UseObject	-	place
56.8	57.8	2	right	MoveObjectTo PointOfUse	-	-
57.8	61.7	2	right	UseObject	-	screw in

At the example workstation, the test person first gets the separately hanging screwdriver with his right hand and guides it into the main work area. The screwdriver is held while a screw is removed from a container full of screws with the left hand. The screw is then moved to the screwdriver (point of use) and placed on the screwdriver. Finally, the screwdriver (with screw) is moved to its point of use (the pump) and the screw is screwed in.

The Arm Motions are further specified by various additional influencing factors to describe the isolated movement in detail. For example, it is relevant which arm (side) performs a motion. The start and end times of a movement are also important. This helps to follow the chronological sequence of operations as well as to determine if arm motions are simultaneously performed with movements of other body parts. In addition to the influencing factors that are important for all Arm Motions, there is also motion specific information, which is shown in Table 10. This article focuses on the main interface data.

Table 10: MTMmotion® data: Factors Influencing Arm Motions

	Distance	GraspType	Supply	Tolerance	Symmetry	Force	Process Time
Type	numeric	selection	selection	selection	selection	numeric	numeric
Unit	cm	-	-	mm	-	Newton	seconds
decimal points	1	-	-	-	-	1	2
required / optional	optional	optional	optional	optional	optional	optional	optional

The *Distance* represents the actual motion path traveled, which is usually curved, measured in centimeters. For hand movements, the measurement point for determining distance is typically the base knuckle of the index finger. For finger movements, the fingertip is used as the measurement point. The *GraspType* describes the hand's posture when it takes or releases control of an object. The *Supply* refers to the arrangement or position of the object before it is picked up. The Supply differs in how an object is provided: at a fixed location (e.g., a button), at a changing location for each work operation (e.g., tools), or together with other objects of the same kind (e.g., screws).

The *tolerance* describes the maximum ± deviation from the initial engagement point and is used to specify the required placement accuracy. There are five different tolerance ranges available, specified in millimeters. The *Symmetry* refers to the symmetry conditions of the positioning process. There are two options of symmetry given to the user: either the object does not need orientation for the positioning process (e.g.: placing a nail on a wooden board) or it does need orientation (e.g., placing a screwdriver on a screw).

The *Force* describes the required effort to move or position one object. It represents the physical force exerted by the body on the object to be moved or positioned. It is measured in Newtons and can be entered by the user. The *Process Time* is the time of a specific process that can be calculated through estimation, time study, or the use of self-activated data collecting tools (e.g., time recording devices). It can represent the operating time of a tool or a machine, such as the screwing process of a screwdriver or the pressing time of a press. Process time is measured in seconds and is also an optional influencing factor.

3.6 Derivation of an MTM-UAS® analysis

The translation of the interface data into a valid MTM analysis is the second aspect of MTMmotion®, following the actual data. The translation follows the steps outlined below: following procedure:[58]

1. Validation of the input data
2. Completion of the input data
3. Translation into MTM process building blocks
4. Combination of different body parts

3.6.1 Validation of input data

In the first step, the input data provided by the VR software is validated. This involves checking whether the data makes sense or if it contains logical errors. For instance, the algorithm checks if the handling of objects follows a logically possible sequence. Figure 18 shows a part of the validation algorithm. The algorithm, for example, identifies an error if objects are being moved that were not picked up earlier. In such cases, the object section that contains all movements with the same object in a specific order is deleted.

[58] cf. Benter & Neumann, 2023

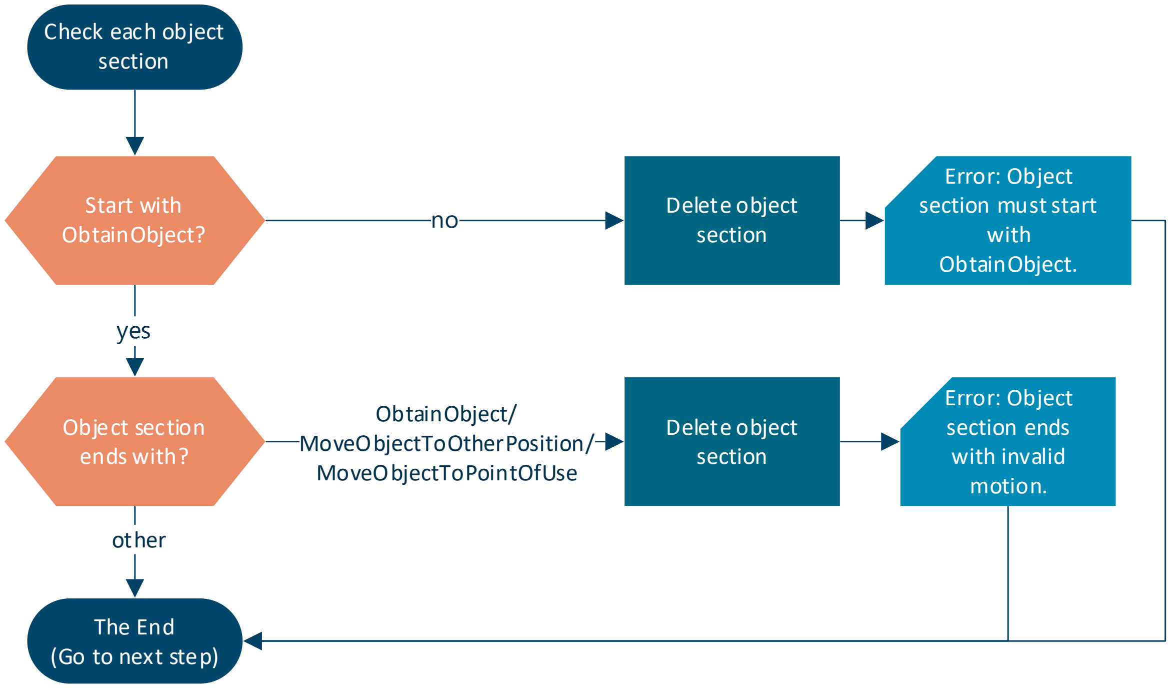


Figure 18: Validation of object sections

Furthermore, it is ensured that handling an object does not end with an unauthorized motion such as *ObtainObject* or *MoveObjectToPointOfUse*. These motions are only part of a meaningful object handling when they are followed by other motions like *UseObject*. If these motions are missing, the object section is deleted, and an error is reported. This can be explained based on the Arm Motions in Table 9. If the fourth row were missing there (time start: 52.6), the resulting sequence (cf. Table 11), the arm movement *ObtainObject* would be missing during the handling of the screw (objectID 1). This leaves uncertainty about how the screw was handled before the *MoveObjectToPointOfUse* motion (row 5, time start: 53.6) because a meaningful sequence cannot begin with this motion. Therefore, the remaining rows of object handling (lines 5-6) are deleted and not used for translation. Additionally, this deletion process is also logged.

Table 11: Missing Arm Motion for Screwdriver (objectID 1)

time start	time end	object ID	side	arm motion
51.0	51.5	2	right	ObtainObject
51.5	52.5	2	right	MoveObjectTo OtherPosition
52.5	56.8	2	right	HoldObject
53.6	54.4	1	left	MoveObjectTo PointOfUse
54.4	56.8	1	left	UseObject

There are additional queries by which the algorithm checks if the user-provided data is consistent. However, this contribution is not intended to explain the entire algorithm but rather focuses on a few examples to demonstrate how the translation works in general.

3.6.2 Completion of the input data

In the second step, the completion process, the input data is first checked for completeness (see Figure 19). Although the interface can capture all the information relevant for valid MTM analyses, it is not always necessary to fill in all the details. The interface distinguishes between required and optional influencing factors. Without the required data, the algorithm is unable to create a rule-compliant MTM analysis. Optional influencing factors are used to describe the processes in as much detail as possible. The algorithm first checks the object list. If an object is listed, that does not exist in the MTMmotion® object catalog, it is replaced with a default object since the system cannot process object data it is not familiar with. After that, missing information in all parts of the interface is filled with default values. For example, the algorithm would add a predefined screw weight if it was not provided by the VR tool. This step applies not only to object data but also to all movements and postures in the interface. For all arm and leg movements except *UseObject*, the default distance is set to 40 centimeters, for instance. The standard distance for *UseObject* is filled individually for each usage Type.

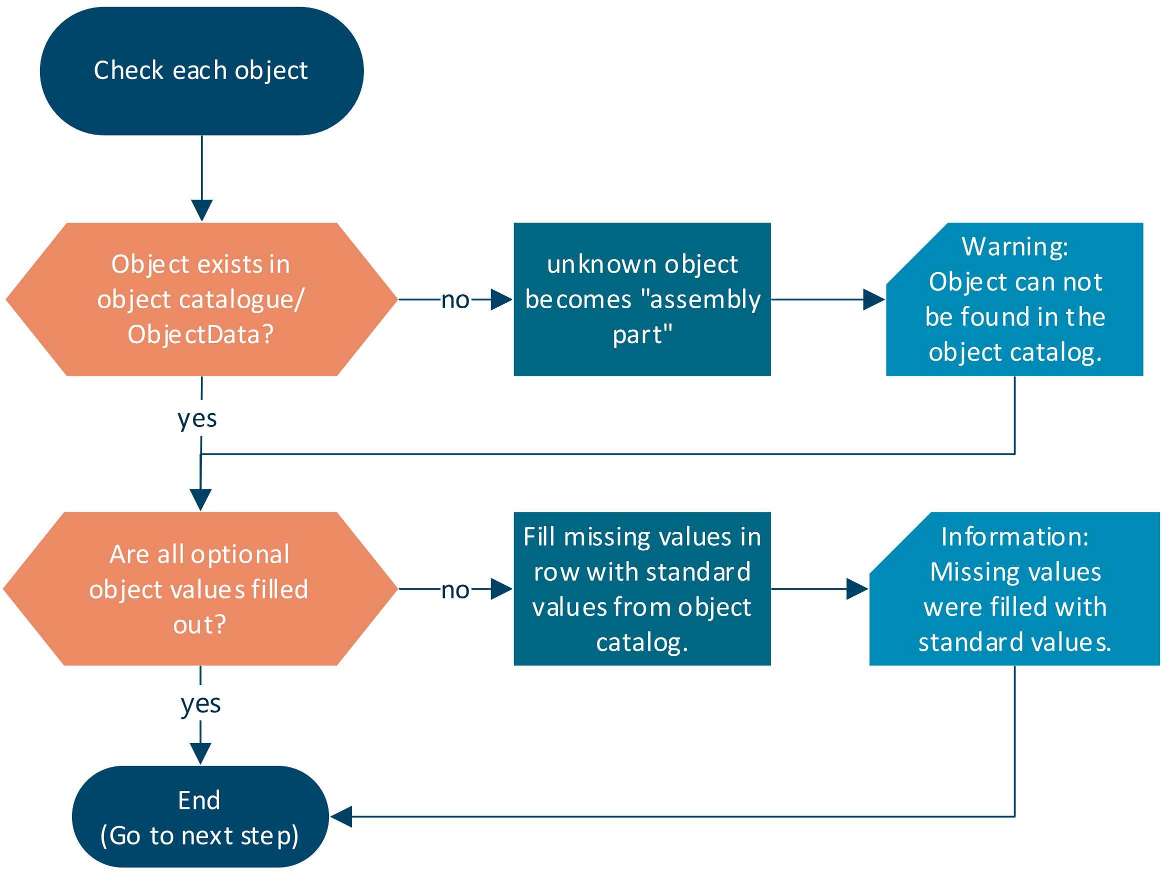


Figure 19: Validation of object information

3.6.3 Translation into MTM process building blocks

In the third step, the various motions are translated into MTM process building blocks. In the case of MTM-UAS®, it is necessary to combine certain motions into basic operations. However, each of these combined motions provides relevant data that is used to determine the correct MTM-UAS® code.

Table 12: Translation of the Arm Motions into an intermediate result with basic operations

time start	time end	object ID	side	arm motion
51.0	51.5	2	right	ObtainObject
51.5	52.5	2	right	MoveObjectTo OtherPosition
52.5	56.8	2	right	HoldObject
53.6	54.4	1	left	MoveObjectTo PointOfUse
54.4	56.8	1	left	UseObject

Therefore, the first step in translating to MTM-UAS® is to determine which motions correspond to a basic operation. Table 12 shows the Arm Motions and the corresponding basic operations (column 4).

Next, the influencing factors of the basic operations are derived from the input data. For MTM-UAS®, the *CaseOfGet* and the *CaseOfPlace* are central factors. The *CaseOfGet* value describes how an object is obtained. This can range from simply picking up an easy object like a screwdriver to the more challenging task of picking up of a heavy 10 kg box. These factors are calculated based on the entries int the object list and arm movement data. The influencing factors *CaseOfGet* and *CaseOfPlace* for the application example are shown in Table 12.

Finally, the influencing factors are used to derive the correct MTM-UAS® coding. A part of the algorithm to achieve this step is depicted in Figure 20. Using the given influencing factors for Get and Place the screw (Table 12, lines 4-6; *CaseOfGet* ≤ 1 kg, difficult, and *CaseOfPlace* is loose), the MTM-UAS® code AE* is derived.

3.6.4 Combination of different body parts

In the final step of the algorithm, the individual channels are compared to determine whether they influence each other or whether motions can be performed simultaneously. This can be explained well with the following example: If an Arm Motion immediately follows a Body Motion, an MTM rule comes into play, stating that part of the Arm Motion can be executed during the Body Motion, leaving a remaining motion length of the arm of

10 cm. The algorithm also checks the simultaneous executability of motions. In the application example, it is checked whether the screw can be picked up and placed while the other hand holds the cordless screwdriver. In this case, there is no conflict. However, if the person were to screw in two screws simultaneously with both hands, the algorithm would detect that certain MTM rules apply, and it would adjust the resulting analysis accordingly.

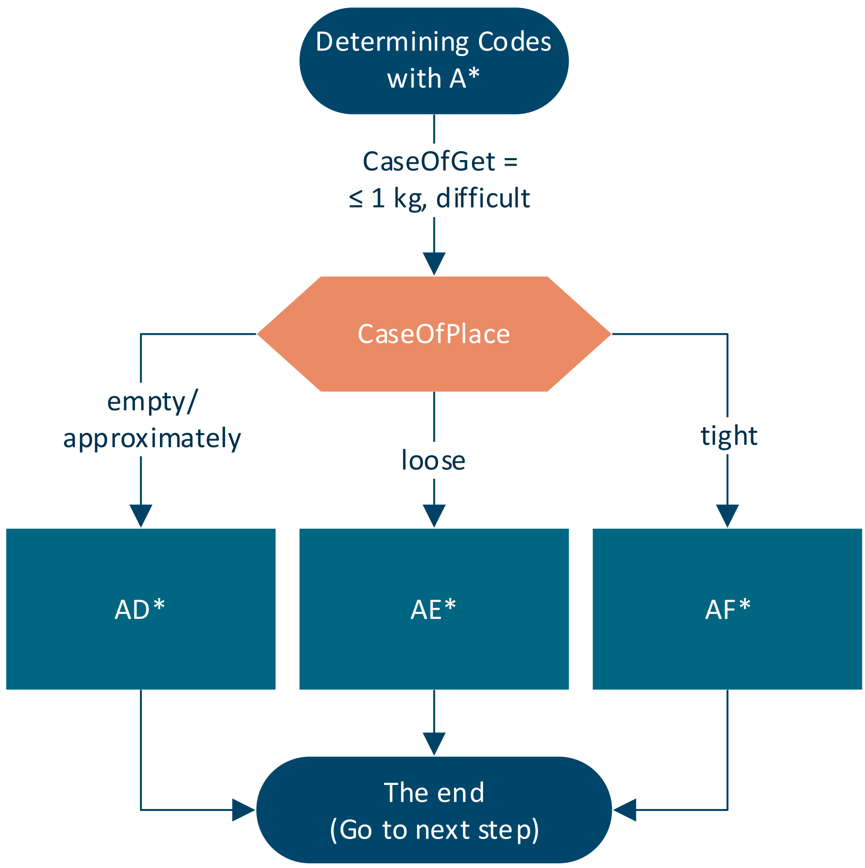


Figure 20: Extract from the translation of Get and Place

3.6.5 The resulting MTM-UAS® analysis

The result of these steps is a rule-compliant MTM-UAS® analysis that corresponds to the data provided by the VR tool. In Table 13, the result for the example workstation can be viewed. The analysis describes the assembly of the first two screws, resulting in a total time of 275 TMU (approx. 10 seconds) for this specific work section.[59]

To validate the results, a manual analysis based on the video, the objects used, and distances was conducted by an individual with extensive MTM knowledge. The comparison demonstrated that the automatically generated analysis from the VR input data aligns with the manually created analysis.

[59] cf. Benter & Neumann, 2023

Table 13: Automatically generated MTM-UAS® analysis

Description	Code	Q x F	TMU
Screwdriver into workspace	HA2	1 x 1	45
Place screw	AE2	1 x 1	55
Place screwdriver	PC1	1 x 1	30
Process time screwdriver	PTTMU	1 x 30	30
Place screw	AE2	1 x 1	55
Place screwdriver	PC1	1 x 1	30
Process time screwdriver	PTTMU	1 x 30	30
Sum	**-**	**-**	**275**

3.7 Derivation of an MTM-HWD® analysis

The MTMmotion® interface and its algorithms can be utilized to translate motion data into various MTM analyses for different application areas. While MTM-UAS® is traditionally used in serial production, MTM systems such as MTM-HWD® should be employed for work systems with shorter cycle times (e.g. mass production).[60] The use of MTMmotion® to create valid MTM-HWD® analyses follows the same process steps as with MTM-UAS®. This means that technology providers such as LIVINGSOLIDS can use the interface in the same way. Furthermore, the translation algorithm also follows the same procedure (see chapter 3.6). The first two steps are identical to those of MTM-UAS®, with the data being validated and checked in the same manner. Steps three (see chapter 3.6.3) and four (see chapter 3.6.4) are adjusted to MTM-HWD® to implement the system process modules and system-specific rules.

3.7.1 Translation into basic actions

Unlike MTM-UAS®, the MTM-HWD® algorithm does not consolidate the input movements into basic operations. Instead, they are translated into HWD actions (see Table 14). The removal of the screw and its placement on the screwdriver (Table 14, lines 4-6) are translated into the basic operations "Get" and "Place".

Table 14: Translation of the Arm Motions into an intermediate result with basic operations

[60] cf. MTMA, 2019a; MTMA, 2019b

object ID	side	arm motion	Basic Action	GraspMotion	CaseOfDeposit
2	right	ObtainObject	Obtain	Grasp	-
2	right	MoveObjectTo OtherPosition	Deposit	-	approximately B
2	right	HoldObject	no translation	-	-
1	left	ObtainObject	Obtain	Separate	-
1	left	MoveObjectTo PointOfUse	Deposit	-	close
1	left	UseObject			
2	right	MoveObjectTo PointOfUse	Deposit	-	loose
2	right	UseObject	Hold	-	-

Since MTM-HWD® is a more detailed MTM process building block system than MTM-UAS®, the algorithm processes more influencing factors. Most of them (e.g.: *TypeOfGrasp*) are read directly from the interface data and translated accordingly. Only a few of them are used subsequently to determine specific MTM-HWD® influencing factors, such as *GraspMotion* or *CaseOfDeposit*. *GraspMotion*, for example is the equivalent of *CaseOfGet* in the MTM-UAS® algorithm. It describes how the hand or fingers gain control over an object before further moving it. *GraspMotion* is calculated based on object data, *TypeOfGrasp* and *Supply* that were specified for the Arm Motion.

3.7.2 Combination of different body parts

The rules for combining different body parts in MTM-HWD® correspond to those used for MTM-UAS®. As explained in point 3.6.4, the algorithm compares the channels with movements to each other and checks if they influence each other. For instance, the MTM rule fort the motion length of an Arm Motion to consider after a Body Motion is shown in Figure 21.

To determine the actual distance for an MTM-HWD® Process building block, the algorithm checks each basic motion (originating in channel 2 or 3) for the existence of a Body Motion (channel 1) directly preceding it. If this case occurs, the distance class for the MTM-HWD® process building block is set to *UpTo10* (corresponds to up to 10 cm). Otherwise, the distance of the basic motion is to determine the distance range for each MTM-HWD®action, as shown in Figure 21.

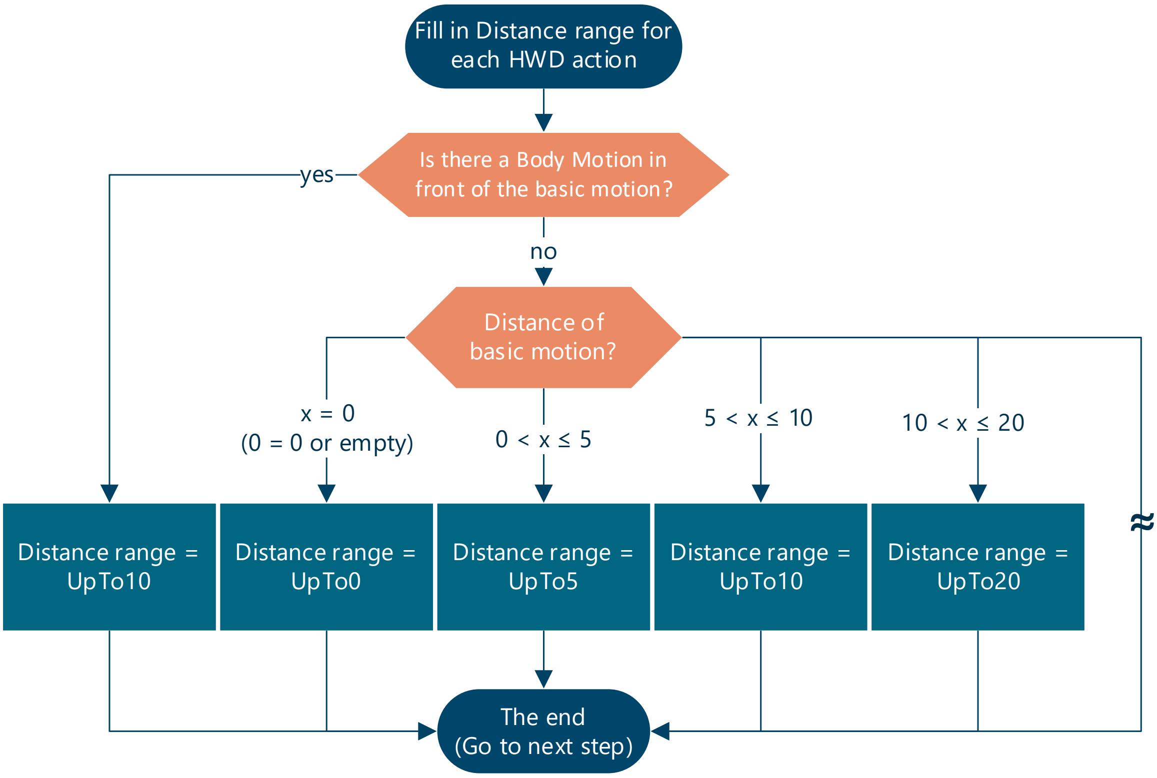
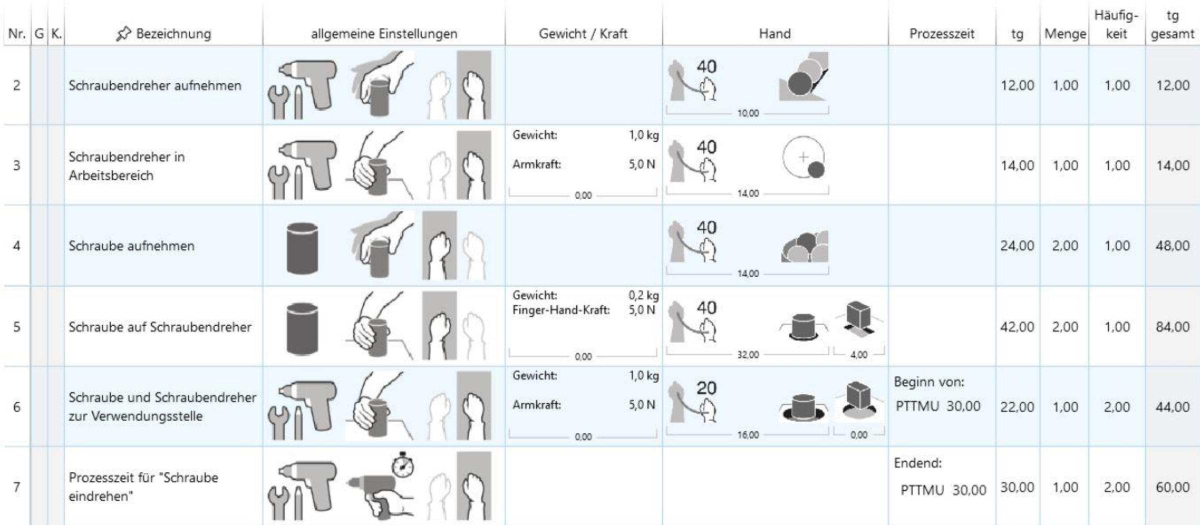


Figure 21: Determination of the distance class by considering body motions

3.7.3 The generated MTM-HWD® analysis

The automatically generated MTM-HWD® analysis also aligns with the input data. The cordless screwdriver is first brought into the work area, then the first screw is placed on the cordless screwdriver and subsequently screwed in. This is repeated for the second screw. The entire process can be traced in Figure 22 using the "Description" column. The pictograms support easy understanding of the analysis. For example, the "general settings" column describes the object, the type of HWD action being performed, and which hand handles the object. In the second row, it is shown, that the cordless screwdriver (a tool) is picked up with the right hand. Additionally, the weight of the object and additional forces can be captured in the MTM-HWD® analysis.

The influencing factors of the hand are listed in the "Hand" column, for example. Line 5 describes the placement motion of the screw onto the cordless screwdriver. This process occurs over a distance of 40 cm, where the screw needs to be aligned before being placed tightly onto the cordless screwdriver and then tightly secured in place. The process time for the cordless screwdriver is found in row 6 in the "Process Time" column. Other important factors are "Quantity" and "Frequency" which can be used to map the screwdriving of the second screw without creating additional analysis lines. Due to the repetition of placing and screwing in a second screw onto the screwdriver, the quantity in line 4 and 5 is set to 2, and the frequency in line 6 and 7 is also set to 2. The MTM-HWD® analysis includes additional influencing factors (e.g., lower extremities, trunk, or head) not shown in Figure 22. The total time of the translated MTM-HWD® analysis is 262 TMU (approx. 9.5 seconds).



Nr.	G	K.	Bezeichnung	allgemeine Einstellungen	Gewicht / Kraft	Hand	Prozesszeit	tg	Menge	Häufig-keit	tg gesamt
2			Schraubendreher aufnehmen			40 10,00		12,00	1,00	1,00	12,00
3			Schraubendreher in Arbeitsbereich		Gewicht: 1,0 kg Armkraft: 5,0 N 0,00	40 14,00		14,00	1,00	1,00	14,00
4			Schraube aufnehmen			40 14,00		24,00	2,00	1,00	48,00
5			Schraube auf Schraubendreher		Gewicht: 0,2 kg Finger-Hand-Kraft: 5,0 N 0,00	40 32,00 4,00		42,00	2,00	1,00	84,00
6			Schraube und Schraubendreher zur Verwendungsstelle		Gewicht: 1,0 kg Armkraft: 5,0 N 0,00	20 16,00 0,00	Beginn von: PTTMU 30,00	22,00	1,00	2,00	44,00
7			Prozesszeit für "Schraube eindrehen"				Endend: PTTMU 30,00	30,00	1,00	2,00	60,00

Figure 22: Automatically generated MTM-HWD® analysis

Digital work design using MTMmotion® simplifies the analysis and planning of work processes in labor management. The MTMmotion® interface acts as a link to translate human movement data into valid MTM analyses. Technologies such as human simulation, virtual reality and motion capture enable the targeted design of human work. The MTMmotion® translation algorithm validates, completes and translates the data into MTM process building blocks. These building blocks enable the generation of compliant MTM-1®, MTM-HWD®, MTM-UAS® and MTM-MEK® analyses for various application areas. The analyses generated automatically are consistent with those created manually and can serve as simulation analyses in the field of industrial engineering, particularly within the manufacturing industry.

Especially with regard to the increasing internationalization of industrial production, easy access to a common language for the analysis and design of work systems is crucial.

4 Current research projects

In addition to workflow planning, modern digital technologies are also making their way into the analysis and optimization of existing workflows. For example, motion capture technologies can be used to examine real workflows in order to identify weaknesses, including insufficient capacities or ergonomic risks. Both factors contribute to increased employee burden. Currently, the MTM ASSOCIATION e. V. is involved in two projects that explore the use of motion capture technologies and their integration with the MTM methodology.

4.1 Last Mile - Connecting Motion Capture with MTM

Currently, work in the service sector, particularly the parcel delivery and courier services are undergoing a significant transformation. During the COVID-19 pandemic, the volume of deliveries has increased significantly while the number of employees has remained relatively stable. This has placed a high burden on delivery personnel, potentially leading to overloads. Therefore, it is crucial to establish a scientific foundation for occupational health and safety in this sector. MotionMiners GmbH and the MTM ASSOCIATION e. V. are conducting a preliminary study, commissioned by the Federal Ministry of Labor and Social Affairs (BMAS), to determine internal performance standards and load limits for employees in this industry.

The BMAS preliminary study focuses on the final chapter of the supply chain, known as the "last mile," where items, including packages weighing over 30 kg, are loaded into delivery vehicles and delivered to end customers. In the preliminary study, the requirements of typical activities or process elements in parcel and composite delivery are identified and evaluated. The goal is to publish insights and data on service sector performance, establish objectively justifiable performance parameters from an occupational health and safety perspective, and thus facilitate sustainable improvements in delivery and courier service processes.

For this purpose, real-time data is collected using motion sensors and subsequently evaluated with machine learning. These results are then linked or combined with MTM standard performance. The modeling of target processes is based on the MTM analysis using MTM process building block systems like MTM-UAS® and MTM-LOG®. The evaluation of ergonomic risk in delivery and courier service workflows is carried out using established methods like EAWS® and LMM/KIM (Leitmerkmalmethode/Key Indicator Methode)

The developed integration of motion capture with MTM standard performance aims to facilitate the cost-effective analysis of current processes in logistics operations and other basic work domains. This approach allows for systematic comparisons with target processes and the identification of weaknesses to ensure ergonomic work design.

4.2 AI and MTM: HAawAI research project

We are considering the connection between AI, specifically Machine Learning, and MTM in the research projects such as *Human-Centered Production Analysis of Manual Motion Sequences using Motion Capturing and Artificial Intelligence* (HAawAI).

The project aims to automatically generate MTM-HWD® analyses from motion capture data (see Figure 23). This will be achieved by processing this data through the MTMmotion® interface and then outputting the derived MTM-HWD® analysis. An essential part of the solution is the extraction of necessary information from the motion capture raw data using machine learning (ML) methods.

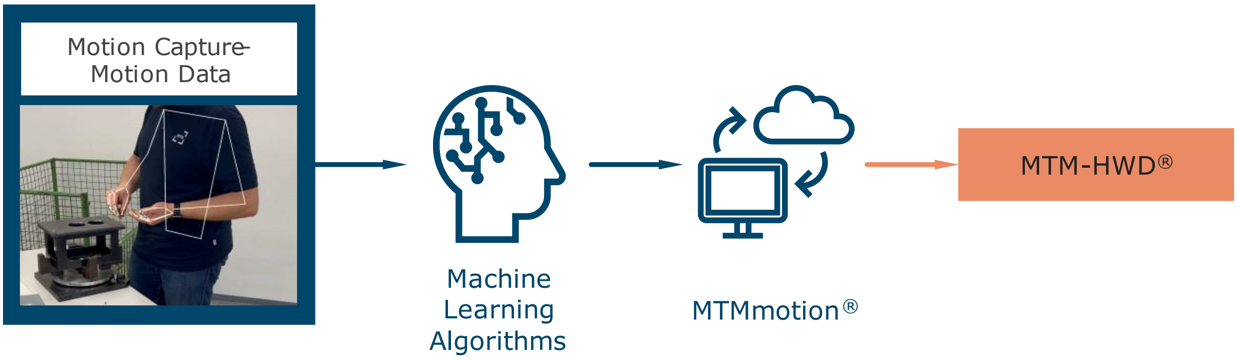


Figure 23: Approach in the research project HAawAI

By combining ML algorithms with MTMmotion®, the quality of Motion Capture analyses is expected to be significantly improved, making it possible for the first time to automatically derive valid MTM analyses from such data.

5 Classification and outlook

This publication concludes with an evaluation of our considerations and efforts regarding the automated application of MTM within a broader, future-oriented context.

5.1 Work design and digitalization

"Time" has always been and remains a central control factor for businesses, as targeted work design requires a temporal evaluation of processes. This fact can be traced back to the beginnings of industrial engineering. Industrial engineers have been determining times and using them as reference, evaluation, and planning metrics, both in the past and today.

An essential, current, and ongoing development or trend is the digitization of the work environment. The significance of time continues to grow in this context and will remain significant in the future. Consequently, there is an increasing demand for accurately and understandably determined (basic) time, particularly in digitally planned processes. This demand for digitally planned work processes can arise for various reasons. Firstly, digitally depicted human motion sequences no longer occur in their original form. This may be due to the use of a motion capture suit or a VR headset during data capture, or the movements being generated by computer algorithms (see Figure 24). As a result, typical necessary operations, such as screwing operations, are not or only rudimentarily carried out in digital planning. They are, if included at all, merely indicated and are therefore only conditionally comparable to real work processes. Secondly, digital work processes are no longer experienced in a real way. For example, the sense of strain is lost because forces are non-existent, and the weights of parts are not perceived when handling them.

These factors, coupled with the fact that no level of routine is established in the execution of digital processes, make it difficult to assess performance when using digital planning technologies. As a result, time standards such as MTM, which are based on a consistent reference performance, become increasingly important and relevant for digital tools.

5.2 Development of MTMmotion®

The MTM ASSOCIATION e. V. provides tool/software developers and interested MTM users with MTMmotion®, a tool, that allows them to incorporate MTM time standards into their software tools and applications.

One of the key reasons behind the development of MTMmotion® was that the implementation and quality of MTM analyses, whether manually entered or automatically generated, did not meet the quality standards in various software tools in numerous cases. This had a negative impact on the proper dissemination and the image of the MTM methodology.

This led to the necessity for us to provide accurate MTM analyses (compliant analyses in the various MTM process building block systems) and to enable as many users as possible to utilize the MTM analysis and its (basic) time. This includes, in particular, the field of AI-driven applications. Furthermore, the compliant and hence high-quality integration of MTM into different tools promotes the dissemination of MTM.

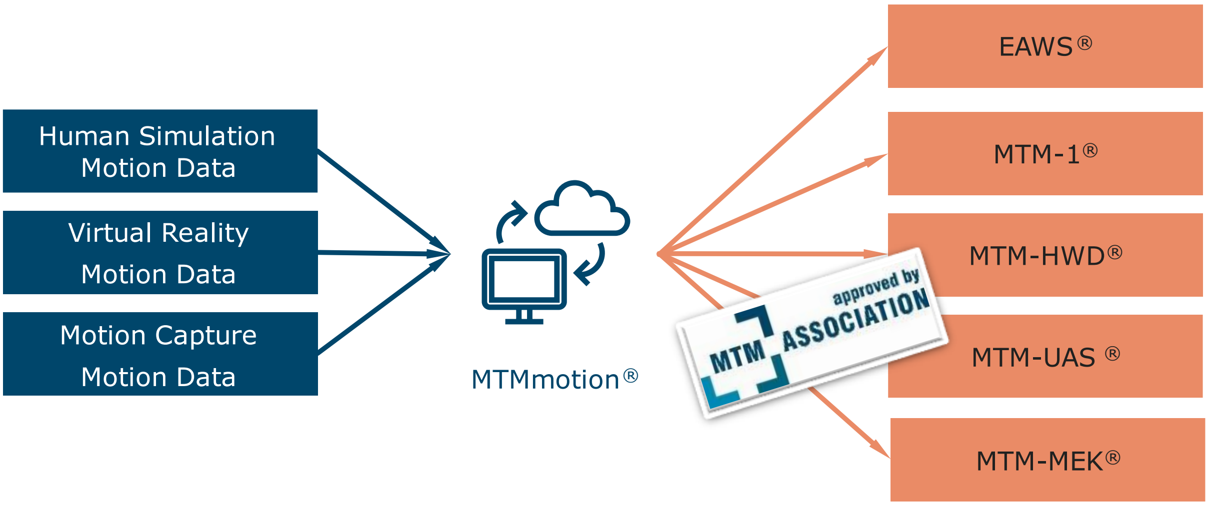


Figure 24: MTMmotion® motion data sources

5.3 Further development and future of MTMmotion®

In addition to integrating the MTM methodology into tools that capture or process human movement data, the concept and structure of MTMmotion® offer further possibilities, some of which are currently in progress and are outlined below.

One promising approach is to use the MTM language much earlier, even before the actual execution of the movement. An example of this is the use of data from ERP systems or design data to obtain comparable assessments for eHpU[61] or PROKON[62]. By processing

[61] Engineered Hours per Unit
[62] Production-Oriented Design

information about components, assemblies, or tools, the MTM process language can be integrated at an early stage.

Furthermore, it is possible to extract information from manufacturing documents such as work plans or work instructions through machine learning, which can be further processed with MTMmotion® and assigned to MTM analyses (see Figure 25).

Consistently thought through, the goal of digitally applying MTM should be to immediately - in real time - show a designer the impact of changes on the workflow and thus on time and ergonomics at every step of the design process, and to show a work planner the impact of changes at every step of the process.

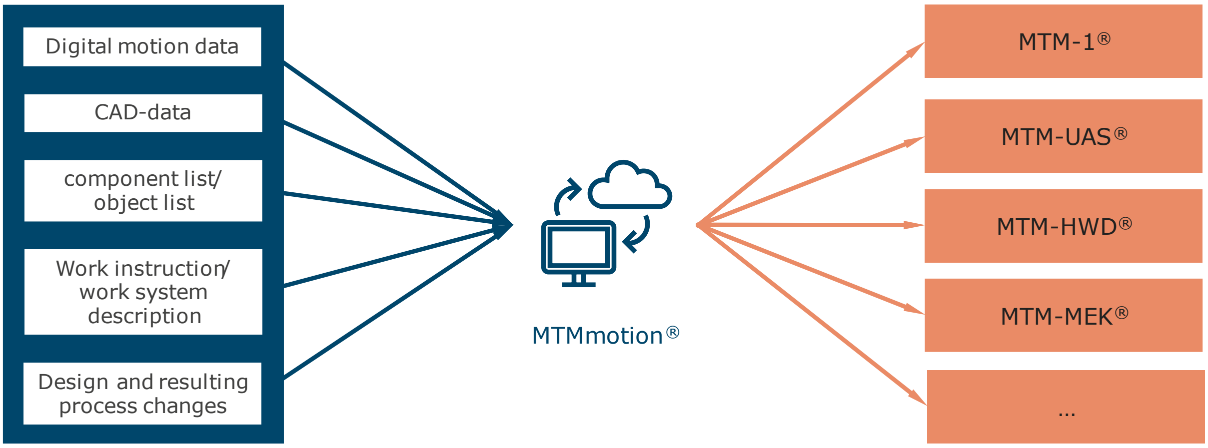


Figure 25: MTMmotion® - possible additional data sources

5.4 View on Future Demand for MTM Training and Consultation

In the MTM community, it is understandable that there is an opinion that the considerations outlined in MTMmotion® may create competition for our own business, especially in MTM consulting. However, we, the MTM ASSOCIATION e. V. and the Deutsche MTM-Gesellschaft mbH, have a different, modern, and forward-looking perspective on this matter.

We believe that the dissemination through digital tools will result in more MTM users and practitioners, leading to an increased demand for the competencies of the MTM organization, ranging from research and education to software and consulting – especially in the international market. Of course, the nature of the demand may change. The type and extent of MTM training may be affected, as well as the demand for "typical" analysis services. On the other hand, this could lead to an increased need for design and improvement workshops.

Overall, we believe that our work, like that of all industrial engineers, will undergo fundamental changes due to digitization. We view this development for MTM primarily as an opportunity and not as a risk.

5.5 Contribution to the Future Vision of Industrial Engineering

This way, MTM contributes to the future understanding of the work of our discipline. Digitalization is intended to and will significantly influence the work of industrial engineers and bring about a paradigm shift.

Intelligent and creative work design will take center stage. More efforts will be put into exploring possible solutions, evaluating various alternatives digitally at an early stage, and generating new ideas. The administrative aspects of the industrial engineer's work, such as data management, as well as the "writing of MTM analyses," will be supported and automated by technology, thereby taking a backseat.

We will continue to support this understanding of current and future developments with our expertise, our own developments and products, as well as matching services – always in the spirit of worldwide, uniform, and correct dissemination of MTM.

6 Literature

Antis, W.; Honeycutt, JM; Koch EN.:
Die MTM-Grundbewegungen. Maynard, Düsseldorf, 1969.

Benter, M.; Kuhlang P.:
Derivation of MTM-HWD® analyses from digital human motion data Scientific Track: Ergonomics in Manufacturing. In: Nancy L. Black, W. Patrick Neumann, Ian Noy [Eds.], Proceedings of the 21st Congress of the International Ergonomics Association (IEA 2021), Volume III: Sector Based Ergonomics, IEA 2021, LNNS 221, pp. 363-370, 2021.

Benter, M.; Neumann, M.:
Digitale Arbeitsgestaltung mit MTMmotion®. In: Gesellschaft für Arbeitswissenschaft e. V. (Ed.): Tagungsband zum Frühjahrskongress 2023 "Nachhaltig Arbeiten und Lernen - Analyse und Gestaltung lernörderlicher und nachhaltiger Arbeitssysteme und Arbeits- und Lernprozesse", 1.3.-3.2023, Hannover, 2023.

Benter, M., Neumann, M., Kuhlang, P.:
Ableitung von MTM-UAS®-Analysen unter Verwendung von Virtual Reality und MTMmotion®. In: Tagungsband Fachtagung „Smarte IKT und AR im Arbeitskontext“, 19. September 2023, Bundesanstalt für Arbeitsschutz und Arbeitsmedizin (BAuA), Dortmund, 2023.

Bokranz, R.; Landau, K.:
Handbuch Industrial Engineering. 2. Edition. Stuttgart: Schäffer-Poeschel, 2012.

Bovenschulte, M.; Peters, R; Burmeister, K.:
Basisarbeit - Stützen der (Arbeits-) Gesellschaft. Berlin: Bundesministerium für Arbeit und Soziales, 2021.

DMTMV:
Deutsche MTM-Vereinigung e. V. - Course material – EAWS practitioner. Hamburg: Self-publishing, 2014.

Finsterbusch, T.:
Modellierung menschlicher Arbeit – Das Bausteinsystem MTM-HWD®. In: Kuhlang, P. (Ed.) Modellierung menschlicher Arbeit im Industrial Engineering – Grundlagen, Praxiserfahrungen und Perspektiven. Ergonomia Verlag, Stuttgart, 2015.

Finsterbusch, T.:
Entwicklung einer Methodik zur Bildung von Bausteinsystemen für die Gestaltung menschlicher Arbeit. Dresden, Techn. Univ., PhD thesis, 2016.

Finsterbusch, T.; Kuhlang, P.:
Verfeinerung und Erweiterung des Arbeitssystemmodells zur Gestaltung human-orientierter Arbeit für Mensch-Mensch-Interaktion. In: GfA (ed.) Tagungsband zur GfA-Frühjahrskonferenz 2017 „Soziotechnische Gestaltung des digitalen Wandels“. Brugg/Zürich, Switzerland, 2017.

Fischer, H.; Kuhlang, P.:
Lingua Latina Industriae. In: Kuhlang P. (ed.) Modellierung menschlicher Arbeit im Industrial Engineering - Grundlagen, Praxiserfahrungen und Perspektiven. Ergonomia Verlag, Stuttgart, 2015.

Fritzsche, L.; Ullmann, S.; Bauer, S.; Sylaja, VJ.:
Task-based digital human simulation with Editor for Manual work Activities - industrial applications in product design and production planning. In: DHM and Posturography, Academic Press 2019.

Graute, R.:
MTM-HWD® besteht Praxistest bei Miele – Rollout ist geplant. MTM-Newsletter 2016. https://www.dmtm.com/newsmedien/presse/ presseartikelde-tails/de-tails/mtm-hwdsupsup-besteht-praxistest-bei-miele/?inlink=1&inlink=1. Zugegriffen: 7. April 2017.

halocline:
https://halocline.io. Last accessed 10.06.2023.

imk:
https://imk-ema.com/ema-workdesigner.html. Last accessed 10.06.2023.

Kuhlang, P.; Finsterbusch, T.; Rast, S.; Härtel, J.; Neumann, M.; Ostermeier, M.; Schumann, H.; Mühlbradt, T.; Jasker, K.; Laier, M.: Internationale Standards zur Gestaltung produktiver und ergonomiegerechter Arbeit. In: Dombrowski U., Kuhlang P. (Eds.): Mensch-Organisation-Technik im Lean Enterprise 4.0. Shaker Verlag, Aachen, 91-154, 2017.

Kuhlang, P.:
Produktive und ergonomiegerechte Arbeit – Von der Prozessprache MTM über die Ergonomiebewertung zu Human Work Design (MTM-HWD®). In: ifaa (ed.), Leistung und Entgelt. Joh. Heider Verlag, Düsseldorf, Ausgabe 2/2018, 6-46.

Kuhlang, P.:
Digitalisierung in Planung und Produktion – Woher wissen wir, dass wir den Ergebnissen trauen können? In: UdZPraxis –Magazin für Betriebsorganisation in der digital vernetzten Wirtschaft, ISSN 2509-7350, FIR e. V. an der RWTH Aachen, 02-2019a, 61-63.

Kuhlang, P.:
Positionen der Deutschen MTM-Vereinigung e. V. zu Assistenzsystemen und zur Verarbeitung von digitalen Bewegungsdaten. In: Kuhlang P. (Ed.), MTM-Schriftenreihe Industrial Engineering, Ausgabe 12. Hamburg: Eigenverlag Deutsche MTM-Vereinigung e.V., 2019b.

Kuhlang, P.; Benter, M.; Ostermeier, M.; Finsterbusch, Th.; Härtel, J.; Jasker, K.:
Position der MTM ASSOCIATION e. V. zum Wandel des Einsatzes und der Anwendung von MTM-Prozessbausteinsystemen. MTM-Schriftenreihe Industrial Engineering, Issue 14. Hamburg: Self-publishing MTM ASSOCIATION e. V., 2020.

Kuhlang, P.; Benter, M.; Neumann, M.; Mühlbradt, Th.:
Digitalisierung und Internationalisierung der Arbeitswirtschaft für produktive und ergonomiegerechte Basisarbeit in Produktion und Logistik. In: Menschengerechte Arbeitsgestaltung – Basisarbeit und neue Arbeitsformen, Tagungsband der Herbstkonferenz 2023, Gesellschaft für Arbeitswissenschaft e.V. (Ed.), Sankt Augustin, Düsseldorf, 2023.

Kuhlang, P.; Benter, M.; Neumann, M.:
MTM in Motion - Perspectives to digital work design. Deriving MTM-analyses From Virtual Reality Tools. In: Deuse, J. [Ed.]: How can industrial management contribute to a brighter future? Schriftenreihe der Wissenschaftlichen Gesellschaft für Arbeits- und Betriebsorganisation (WGAB) e.V., GITO mbH Verlag Berlin, 2023.

Kuhlang, P.; Neumann, M.:
Zeitdaten – Wie aus Bausteinen Daten werden. In: Irgendwas mit Logistik (Ed.): Manuelle Prozesse - Handtastische Ergänzung zur Automatisierung, Report 08, Oktober 2023, Hamburg, 2023.

Lavatelli, I.; Schaub, K.; Caragnano, G.:
Correlations in between EAWS and OCRA Index concerning the repetitive loads of the upper limbs in automobile manufacturing industries, IOS Press, 2012.

LIVINGSOLIDS:
https://www.livingsolids.de. Last accessed 10.06.2023.

Maynard, H.B.; Stegemerten, G.J.; Schwab, J.L.:
Methods-Time Measurement. McGraw Hill, New York, 1948.

Movella:
https://www.movella.com/products/motion-capture. Last accessed 10.06.2023.

MTMA:
MTM ASSOCIATION e. V. - Manual MTM-1. Hamburg: Self-publishing, 2019a.

MTMA:
MTM ASSOCIATION e. V. - Manual MTM-UAS. Hamburg: Self-publishing, 2019b.

MTMA:
MTM ASSOCIATION e. V. - Manual MTM standard operations logistics. Hamburg: Self-publishing, 2019c.

MTMA:
MTM ASSOCIATION e. V. - Lean Base Award 2022 – Das Ganze und das Detail im Blick: So einfach war MTM noch nie!, Hamburg: Self-publishing, 2022.

Mühlbradt, T.; Hartmann, E.; Hacker, W.:
Arbeitsgestaltung für Industrie 4.0 – neue Herausforderungen für die Arbeitswissenschaft. In: Gesellschaft für Arbeitswissenschaft e. V. (Ed.): Tagungsband zum Frühjahrskongress 2018 „Arbeit(s).Wissen.schaf(f)t – Grundlage für Management & Kompetenzentwicklung“, 21.-23.02.2018, Frankfurt am Main, 2018.

Quick, JH.:
Das Work-Factor-System. Beuth, Berlin, 1960.

REFA:
Datenermittlung. Carl Hanser, Munich, 1997.

Schaub, K.; Caragnano, G.; Britzke, B.; Bruder, R.:
The European Assembly Worksheet. In: Theoretical Issues in Ergonomics Science. Volume 14 (Issue 6), pp. 616-639. London: Taylor & Francis, 2012.

Schlick, C.; Bruder, R.; Luczak, H.; Mayer, M.; Abendroth, B.:
Arbeitswissenschaft (3rd, completely revised and expanded edition). Berlin: Springer, 2010.

Schmauder, M.; Spanner-Ullmer, B.:
Ergonomie – Grundlagen zur Interaktion von Mensch, Technik und Organisation. In: REFA-Fachbuch-Reihe Arbeitsgestaltung. Carl Hanser Verlag, Darmstadt, 2014.

Schüppstuhl, T.; Tracht, K.; Raatz, A.:
Annals of Scientific Society for Assembly, Handling and Industrial Robotics 2021. With the collaboration of Thorsten Schüppstuhl, Kirsten Tracht and Annika Raatz. Cham: Springer International Publishing. Available online at https://library.oapen.org/handle/20.500.12657/52428, 2022.

Spitzhirn, M.; Benter, M.; Heindl, C.; Scheder, N.; Reisinger, G.; Strohmeier, F.; Behrendt, W.: Hybrid work systems platform-based work planning designing productive and human-centered work processes. Zeitschrift Für Arbeitswissenschaft, 76(4), 489-509, 2022.

Sunk, A.; Nemeth, T.; Edtmayr, T.; Kuhlang, P.; Sihn, W.:
Modellierung logistischer Prozesse als Grundlage systematischer Verbesserungsarbeit mit Zielzuständen. In: Logistische Modellierung. 2. Wissenschaftlicher Industrielogistik-Dialog Leoben. München: Rainer Hampp Verlag, 15 – 30, 2014

ISBN: 978-3-94563-527-8
9 783945 635278