COMPUTER AIDED WORK TIME STANDARDIZATION IN INTEGRATED DEVELOPMENT OF PRODUCT, PROCESS AND MANUFACTURING SYSTEM

Jan DUDA

Summary: One of the most important tasks during process and manufacturing systems design is the work time standardization. It is used to determine the duration of the planned or executed works using the measurement, calculation and comparative analytical methods. The paper presents the idea of integrated product, process and manufacturing system design. The development of applications for computer aided time standardization, being increasingly very often the part of MPM system for digital modelling of process and manufacturing systems is also presented. This idea was verified during process and manufacturing system design in PLM environment.

Keywords: standardization, work time, CE, MTM, MOST.

1. Introduction

Work time standardization is essential activity in integrated development of product, process and manufacturing system. In the paper the classification and description of software for the time measurement are presented. Software for work time standardization is used for the time measurement of existing processes with the use of measurement methods and process in the design stage with the use of calculation methods (MTM, MOST) for the mass production, or comparative methods for the low series production. The appropriate use of such software allows to analyse in details the contents of the work being normalized, which allow to improve and rationalize the work processes.

2. Concurrent development of products, processes and manufacturing systems

According to the new development strategies, the product development focuses on as much as possible parallel execution of all development related product life cycle phases, thus creating CE (Concurrent Engineering) environment. CE strategy assumes the development of resources and production facilities at the early product design phases to shorten the production start-up time. Features of modern development strategies indicate the need for product development phase integration.

Integration and parallel execution of activities were received through the separation of the conceptual design stages, allowing for the creation of the variant design solutions. Variants are then evaluated in the view of the requirements of the next development phase [2,3]. The selected variant fulfilling the established criteria is next further developed in the detail design stage (Fig. 1).

The advancements allowing for the execution of development strategies of processes and manufacturing systems described in point 2 suggest the necessity for the integration of product development phases (Fig .1). Integration in the area of design and technological product development indicates the extraction of the following phases:

– conceptual process planning (STAGE III A),
– detailed process planning (STAGE III B).

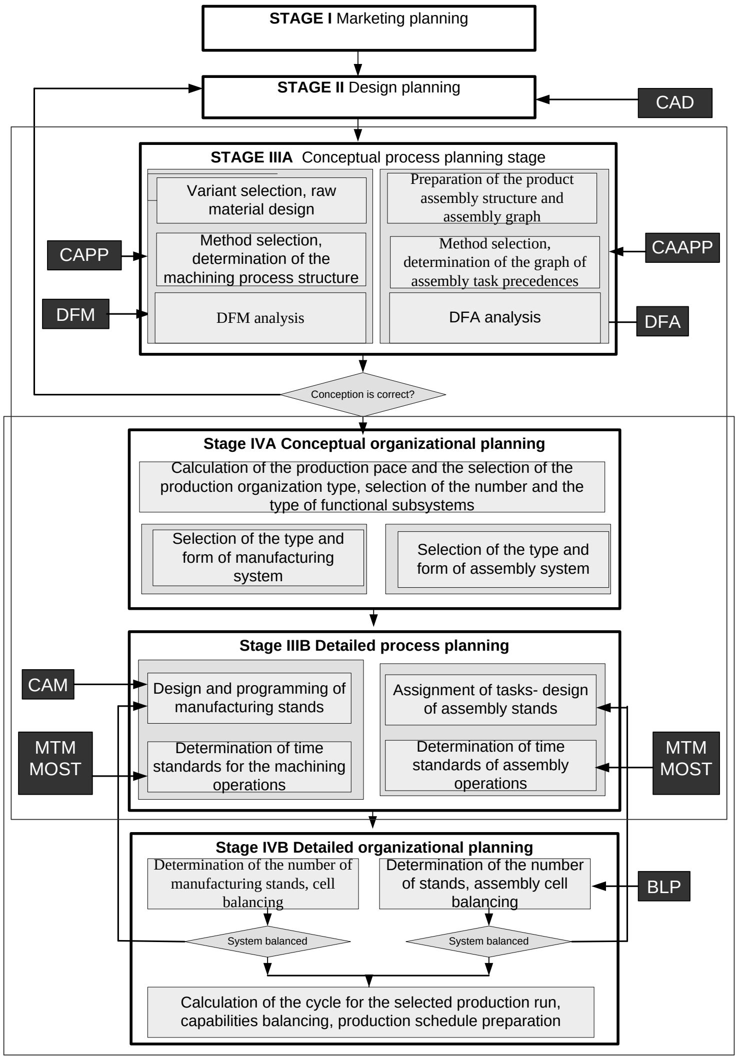

Fig. 1. Concurrent execution of the product development phase

The basic goal of the conceptual phase is the determination of the variants of manufacturing processes on the base of the design product features selected during the design planning stage. The multivariant nature of the process planning is due to the possibility to use different manufacturing methods and raw materials for the elements constituting the product. The multivariant nature of the assembly processes is due to the possibility to use several assembly sequences with the application of methods and manufacturing means and different automation levels. On the base of the defined variants of manufacturing/ assembly processes, the manufacturability analysis DFM and assemble ability analysis DFA are carried out. The results of the subsequent iterations are used to simplify the product design (by minimization of the number of parts and the integration of parts), thus decreasing the time and costs of the assembly and to estimate the times and costs for different manufacturing methods of constituent product elements. It should be noted that the DFA and DFM analysis should be applied together to check whether the simplification of the product structure and elimination of some parts does not lead to the higher manufacturing costs. The result of the analysis is the selection of the product design variant and the variant of the manufacturing and assembly plans for constituent product elements with the level of details allowing for the necessary organizational calculations. Integration in the area of technological and organization product development indicates the extraction of the following phases:

- conceptual organizational planning (STAGE IV A),
- detailed organizational planning (STAGE IV B).

The information from the previously executed product development stages describing the production task (production program of products and their design features, variants of manufacturing plans) are used as the base for the organizational planning. The main goal of the conceptual production organizational planning stage (Fig. 1) is the development of the production system concept. The planning activities cover:

- for the assumed planning data: required volume of production, allowable duration of production, calculated production pace
- selection of the production organizational variant by choosing the type and organizational form of the production,
- selection of the number and types of functional subsystems for transport, storage and quality checking.

The result of the above actions is the concept of the production system offering the possibility to execute the detailed manufacturing planning (STAGE IIIB) within the scope of developing the concept of the manufacturing stands, selection and design of the manufacturing assembly stands. The design activities on the detailed process planning stage cover the activities resulting in the preparation of the instruction sheets for the manufacturing/assembly.

The planning of the process plan operation covers:

- selection and design of the manufacturing machines, equipment and tooling,
- selection of the structure of the process plan, generation of set-ups, machining cycles and technological parameters,
- preparation of the control programs for the operations executed on the programmable devices,
- selection of the time-standard elements.

The planning of the assembly plan operation covers:

- selection and design of the manufacturing machines, equipment and tooling,
- selection of the structure of assembly operation, and the assembly activities,
- preparation of the control programs for the assembly devices, robots and manipulators,
- estimation of the assembly operation times.

The results are the base for the selection of the organizational variant of the manufacturing stands and the base for the detailed organizational planning stage (STAGE IVB) covering:

- calculation of the production pace, selection of the production type (serial, parallel

or serial-parallel),
- synchronization of the isolated functional subsystems of manufacturing cells by calculating the number of stands and line balancing,
- preparation of the production schedule, balancing of the throughput for the designed manufacturing systems.

The presented process of integrated product development is executed iteratively. The subsequent versions of product, process and manufacturing systems are created using digital techniques which allows for the complete analysis of the generated solutions.

3. Applications of work time standardization

The work time standardization i.e. the determination of the duration of activities using the analytical, empirical, calculation or comparative method is the base for the improvement of the process and production organization.
In the production practice are using following systems:
- Simple support programs built mostly on the basis of an Excel spreadsheet,
- Specialized software tools dedicated to the work time standardization with using of the specified method. There are modules integrated with the database of larger applications supporting the organizational improvement of work processes,
- Modules MPM-class applications that are components of PLM supporting the work time standardization in digital modeling of manufacturing processes and systems.

The following describes the sample applications.

3.1. Applications based on the timing methods

Timing is the most frequently used method in the industry, belonging to the analytical and measurement methods. The execution times of activities are measured several times depending on the required accuracy and the assumed measurement error. Because this is very time and labour consuming processes, the software for the measurement, storage, calculation and report generation is used. These can be simple application based on the Excel spreadsheet or more complex software packages with the functions for the other tasks within the area of production organization preparation.

The example of such solution is Timer pro Professional [8] – the advanced tool for the work time standardization, development of the new processes and the improvement of the existing ones. The available functions include:
- the time measurement using video record,
- access to the library of the work time standards,
- balancing of the production lines using the video record,
- Lean, Kaizen, SMED, 5S analysis,
- time measurement using palmtop devices,
- export of data to the Microsoft Excel files, automatic generation of reports.

Timer Pro Professional has also simple functions for the work time recording during the observation of the process execution. This allows for the timing analysis. As opposite to the traditional timing methods, the data registration is done not with the chronograph but with the personal computer (Palmtop, Pocket PC) running the Time pro application developed especially for such devices. The person making the measurement registers the times for the particular activities, thus creating the database, which can be used for further analysis. Such timing methods has several advantages over the conventional approaches. All data are stored on the electronic means which eliminates the needs of using the paper documentation and thus shortens the observation times. The data can be also moved to the personal computer running Timer Pro and further processed (analyzed). This is possible, because these two systems are fully compatible. The data can be also used for the creation of the work time standards, which can be used later during the analysis of the next processes. The coherence and compatibility of the various functions is a very important feature of the system. The analysis using the video record (Fig. 2) is a very helpful solution, which can be applicable in many tasks (line balancing, Lean and Kaizen analysis, standard development).

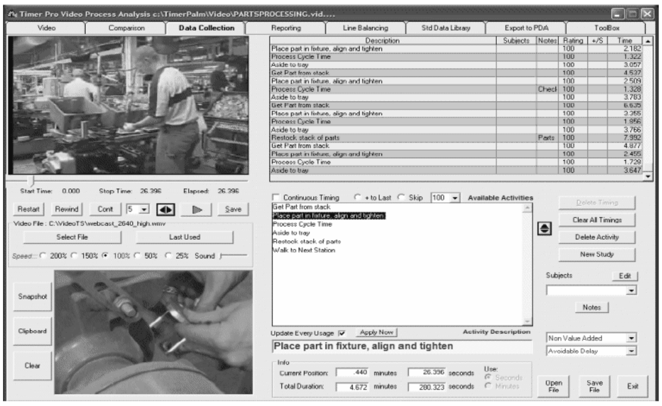

Fig. 2. Screenshot of the analysis of video record

Quick Times (Fig. 3) is a module of Timer Pro Professional for the process design using the previously developed work time standards.

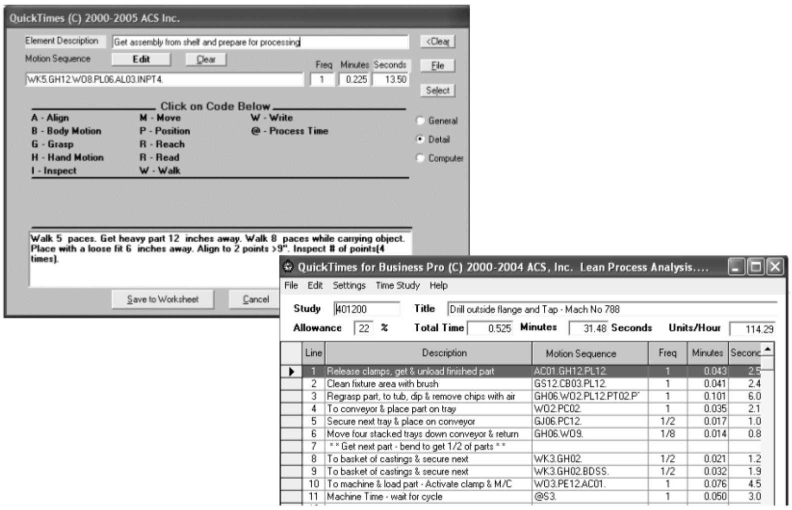

Fig. 3. Generation of the descriptive sentences for the activity, standardization sheet in the Quick Times mode

It has a large database. This function is especially useful when the user has no direct access to the process or the process is on the design stage.

To simplify the use of Quick Times, the movements are divided into several categories (for example reaching, walking, writing – Fig. 3), each of them includes several variants with the associated execution times. Using such standards, the person making the analysis is capable of creating the activities of the whole process. Quick Times allows also for the analysis of the existing processes to check them in the view of its optimization. In case of finding any abnormality, the user can implement appropriate changes using the standards to improve the process and its capacity. The Quick Times database was developed using the timing standards MTM1, described in the section 3.2.

One of the function of Timer Pro Professional is the production line balancing. It allows to analyse the process. The following task can be executed:

– when the number of manufacturing stands is fixed, the PLB (Production Line Balancing) allow to re-group the manufacturing activities to increase the number of final products – i.e. to minimize the production cycle time.
– when the number of production stands is on the design stage, the goals of PLB is to determine the minimal number of machines to receive the required number of final products and to minimize the work area of production facilitates.

The results of the production line balancing are presented in the bar charts illustrating the assignment of the activities to the production stands. Application can also present the results in the form of Microsoft Excel report. The data required for the analysis can be received through the module for the video record analysis, which further simplifies and shortens the labour time.

3.2. Application based on the analytical and calculation methods

The analytical and calculation methods, based on the previously developed time standard, play a very important role in work time standardization. The special place have the PMTS (*Predetermined Motion Time System)* systems using the elementary movement methods. The basic ideas use the fact that every action of the man can be decomposed into the singular movement of limbs and body. The sum of such elementary movements gives the time necessary for the realization of the particular action. This method is used for the man work analysis. Because the elementary movement can be considered as independent, the standards including the movement descriptions and their execution times could be developed. All time values were received through the detailed measurements, and the values are available to everyone. The basic elementary movements includes such actions like: reaching, gripping, moving, placing, etc. Additionally, the movements describing the work of the legs (foot movements, leg movement) and the eye work (move the sight, look at sth.) are distinguished.

The use of elementary movement method covers [5] for example:

– the analysis and the improvement of the work,
– design of the work procedures and the organization of the work stands,
– analysis of the design solutions of machines and devices in the view of the production and operation,
– development of the work time standards,
– the development of the objective means for measuring the capacity on the stands.

The main system using the elementary movement standardization is MTM (*Method Time Measurement*) system. MTM is a procedure for the analysis of the manual operations or procedures in view of the movements necessary for the execution. It assign the standard duration time to each movement based on the movement characteristics and the surrounding conditions. MTM methods allows to design and optimize non-existing manufacturing processes. It allows to eliminate the unnecessary costs introduced by the technical and organizational errors. MTM methods:

– single methodology for the work time measurement,
– simple structure, high accuracy and the uniform time standards,
– eliminate the burdensome estimation of the work pace and reduce the time consumption of the analysis in comparison to the timing methods,
– helps to rationalize the working procedures, work organization and design of the tools and products.

Many varieties of MTM methods evolved along the time and some of them are presented in the Table below [5]:

Form of method	The detail level	The duration time	Type of production
MTM1	movements	Up to 0.5 min.	mass production
MTM2,BMP, TMC	movement sequences	0.5-5 min	
MTM3,AMP, UMP	actions	5-30 min	
MTM4	operations	0.5-30h	
MTM5	process	0.5-30h	small batch production

MTM method uses the alphanumeric coding of the movements and their characteristics. The time unit of 1/100000 of the hour, so called TMU ((Time Measurement Unit) is used to simplify the storage of the short movement measured using the number of video frames.
The relations between TMU and the standard time units are as follows:

$$1 \text{ TMU} = 0{,}00001 \text{ h} = 0{,}0006 \text{ min} = 0{,}036 \text{ s}$$

TiCon3 [7] can be given as example of such applications. The program has modular structure, which can be easily modified to suit the need of the company. The backbone of the system is so called „TiCon-base" offering the basic functions for the integrated methods and time planning. It can be extended by adding the following modules:

– CIP – statistical simulation module,
– MSA – graphic module for the work division simulation,
– Web-Client – internet database,
– MTM – Ergo – analysis of the workplace ergonomy,
– Balancing – balancing of the manufacturing lines,
– Production Planning – production planning,
– PROKON – The tool for the assembly process planning.

It has a simple user interface based on the Windows.

To simplify and reduce the time consumption of the MTM methods, the simplified analytical methods was developed based on the working motions MOST – (*Maynard Operation sequence technique)*, using the following observations:

– use of the MTM standards,

- the manual activities are executed in the established sequences - five types of such sequences can be distinguished,
- most of the working tasks covers only the manipulations on the workpiece.

Three types of this method can be distinguished:

- MiniMOST – used for the analysis of the activities repeated more than 1500 times per week and with the duration time shorter than 1.6 minutes (in most cases it is 10 seconds or less). This method is suitable for the standardization of the works featuring short (cycle < 0.25 minutes), repetitive working cycles, without the differences in the movement scheme (1TMU),
- BasicMOST – used for the analysis of the activities repeated usually from 150 to 1500 times per week and with the duration time from a few to 10 minutes. It includes the basic movement sequences (10TMU),
- MaxiMOST – used for the analysis of the activities repeated at lease 150 times per week and with the duration time from a 2 minutes to a few hours. It is suitable for the standardization of the works featuring long, no repetitive cycle times, non uniform assembly procedures in machine or ship building industry (100TMU).

The work time standardization in the MOST method includes the following steps:

- Selection of the variant of the movement sequence for the separated part of the work.
- Determination of the index values for the subsequent literal designations featuring the conditions and the complexity of the movements using the standardization table. for example:

$$\mathbf{A_1\ B_0\ G_1\ A_1\ B_0\ P_3\ A_0}$$

- The index values for the subsequent literal designations describe the conditions and complexity of the movements. The index values can be read from the appropriate auxiliary tables. The tables are created using the classifications. Each category represents the variation of the conditions, but has only one normative value. The category are sorted according to the geometry occurrences.
- Calculation of the index values

$$\mathbf{A_1+ B_0+ G_1+ A_1+ B_0+ P_3+ A_0=6}$$

- Calculation of the number of TMU units

6*10(for BasicMost)=60 TMU

The example software using the MOST method is the product offered by H.B Maynard – (*Standard Pro Work Measurement*) [6]. This is the tool designed for the creation, maintaining and the analysis of the work time standards for each type of works. It allows for the individual development of rational work units, which can describe the minor and often repeated activities, as well as non-repetitive activities with the long cycle time. Hierarchical structure of the data units can be used to create the standards, eventual production plans for the subsequent parts, components and products. To ensure the coherence of the application and its high accuracy, system was equipped with the large database having the efficient mechanism for data retrieval. It allows to create the different combinations of data in the form of reports. Program allows for the creation of the individual work units, so called sub-operations and to calculate the proper times required for their execution. The user can select one of the modes for the analysis:

- Direct MOST for the generation of the descriptive methods for the activities being standardized and the optional data received from the previous analysis,
- Quick MOST using the previously defined templates of activities.

The procedure for standardization in the „Direct" mode is given on Fig. 4.

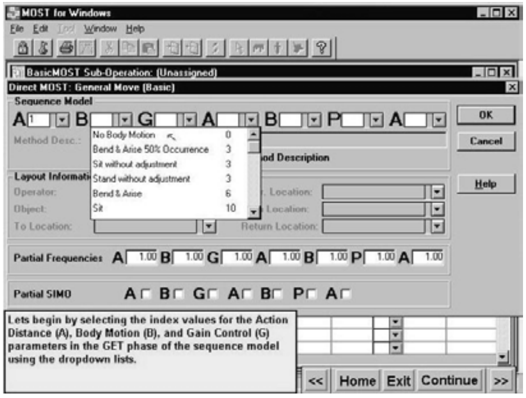

Fig. 4. Definition of activities in direct mode

Database of Standard Pro is created using the standardization times of MOST system. The program has user friendly and intuitive graphic interface offering:

- access to the history of changes implemented in the time standards,
- creation of the detail documentation for the processes being standardized,

sharing of the standardization databases through network for the workers engaged in the production preparation.

3.3. MPM applications for computer aided time standardization with digital modeling of processes and manufacturing

MPM (Manufacturing Process Management) module – the part of the PLM solutions offered by Dassault Systemes is an example of the integrated tool for computer aide standardization (Fig. 5). It is a database application, grouping all production preparation process elements, including the products, manufacturing processes and the manufacturing resources.

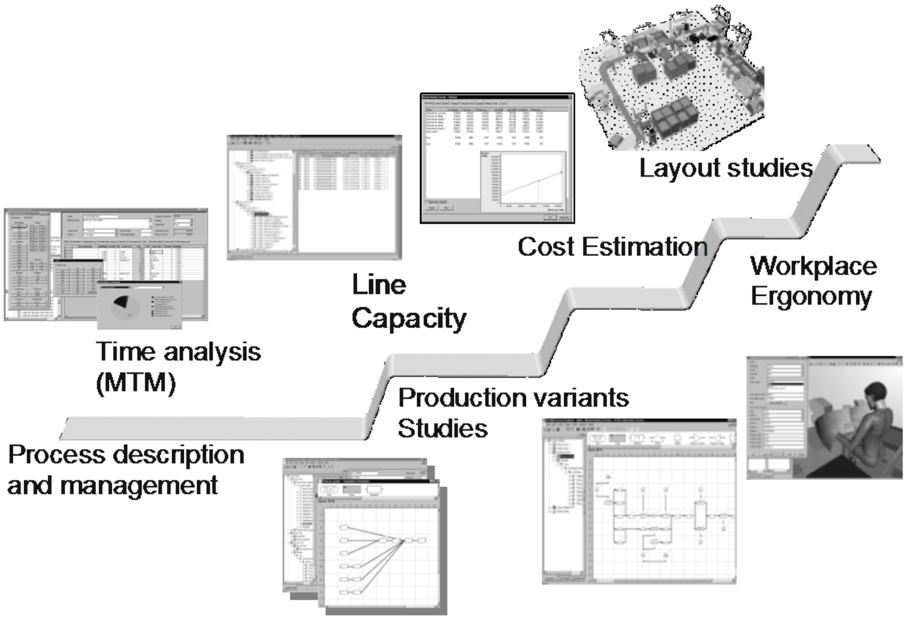

Fig. 5. Process Engineer functions

4. Verification concept in PLM environment

The verification presented in 2 point concept in area of assembly process planning was done with PLM solutions. These solutions include the following systems [3,4]:

- CAD/CAM CATIA for product, manufacturing process and resource design,
- PDM SMARTEAM and ENOVIA for the development process management,
- MPM DELMIA for process and manufacturing system design.

4.1. Conceptual process planning phase

The assembly process is created on the basis of the digital product model prepared with CATIA system. The process planning activities includes:

- the development of the product assembly structure – separation of the assembly units (assemblies, subassemblies and parts),
- development of the assembly process plan including the basic parts for separated assembly units , methods and hierarchical order of assembly of these units to receive the design features of the product,
- mounting of subassemblies, assembles and parts prepared with Part Design module in Assembly Design module based on the developed assembly plan.

The results of the above actions are necessary to make the assembleability analysis of the product and for iterative improvement of the design form in view of the assembly requirements. The product design resulting form the subsequent iterations and its assembly plan form the base for defining the graph of the assembly activities, representing the admissible variants of the execution of product assembly.

4.2. Conceptual production organization planning phase

The conceptual manufacturing organization stage is used to select the appropriate form of the production organization, production pace, and the initial calculation of the number and type of functional subsystems. On this stage, also the type and organizational form of assembly system is selected.

4.3. Detailed process planning phase

The selected type, organizational form of the assembly and the graphical product assembly plan verified with DMU Kinematics module of CATIA are the basis for the assembly process planning. The assembly process planning includes the selection of the operations and activities, selection of the assembly equipment, conceptual design of the assembly stations as well as the decisions on the concept and the selection or design of the transport system components. Based on the above process, the digital model of the assembly system and work places is created. The data required for the making the detailed production organization calculation and for the calculation of the duration of assembly activities are gathered from the components of the digital model of the system. The duration times of the assembly activities were determined using the MTM and MOST methods.

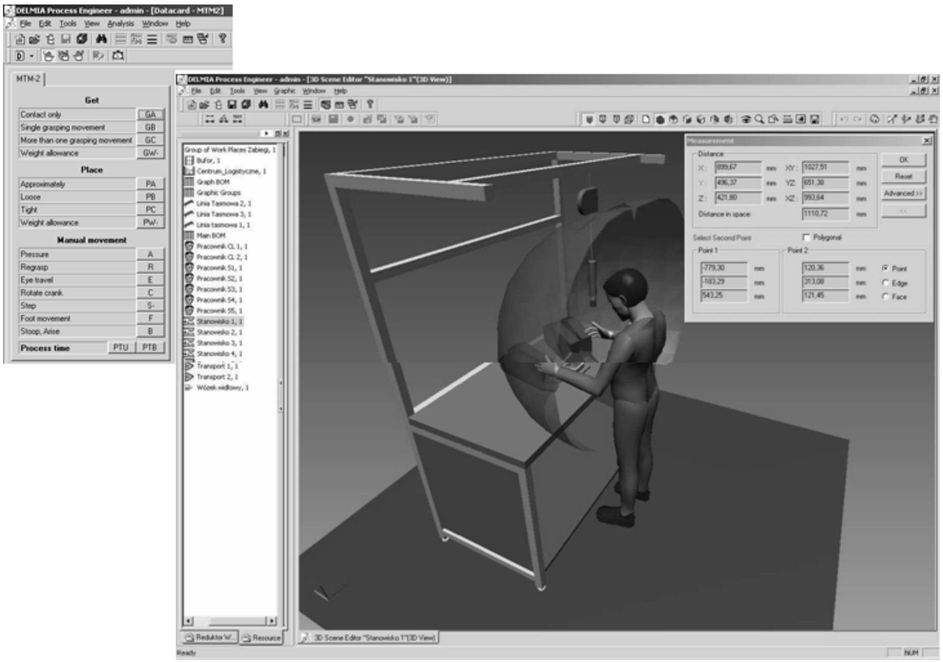

Fig. 5. STM – MTM2 time analysis

4.4. Detailed production organization planning phase

The selected structure of the assembly process and the determined duration times of assembly activities covered by the operations are the base for the synchronization within the isolated assembly subsystem. For analysed production organization forms, for example production lines, these steps include the calculation of the number of stands and line balancing. The activities for the selected organization forms (assembly stations) include ergonomic analysis. The outcome of the detailed production organization stage is the digital model of the manufacturing system linking all the components of the assembly system with assembly process plan stored in library and process schedule. The further test on simulation model are used to analyze and improve the system being developed.

5. Summary

The software for the work time standardization significantly shortens the time consumption. The appropriate use of such software allows to analyse in details the contents of the work being normalized, which allow to improve and rationalize the work processes. The timing methods allow to measure, automatic calculate and register the results using the video record of the works. The method of elementary movement allows to analyse the alternative solutions. It can be used on the stage of the design of new products. Because of this, its use in the enterprises should be popularized. The proposed methodology of concurrent development of products, processes and manufacturing systems using such PLM tools like CATIA and DELMIA increases the integration of the technical production preparation phases and covers various planning actions, including the ones executed with the computer systems like Design For Manufacturing (DFM) analysis, Design for Assembly (DFA) analysis, Computer Aided Assembly Process Planning (CAAP), MTM time analysis, ergonomic analysis and line balancing.

References

1. Duda, J.: Zastosowanie Systemu Delmia w zintegrowanym projektowaniu procesów i systemów wytwarzania. [aut. książki] Knosala Ryszard. Komputerowo zintegrowane zarządzanie. Zakopane : PTZP, 2010, pp. 360-366.
2. Duda J.: Zintegrowane projektowanie procesów i systemów wytwarzania. *Archiwum Technologii Maszyn i Automatyzacji.* 2010, Tom vol. 28.
3. Duda J, Pobożniak J.: New Word Situation: New Directions in Concurrent Engineering. [book auth.] Jerzy Pokojski , Fukuda Shuishi and Jerzy Salwiński. New Word situation: New Direction in Concurrent Engineering. London : Springer-Verlag, 2010, pp. 37-44.
4. Duda J.: Modelling of concurrent development of the products, processes and manufacturing systems in product lifecycle context. New Trends in Technologies: Devices, Computer, Communication and Industrial Systems,. Wiedeń : SCIYO ISBN 978-953-307-212-8., 2010.
5. Strzelecki T.J., Wołk R.: Badanie metod i normowanie pracy. Wydawnictwo Politechniki Warszawskiej 1993.
6. www.hbmaynard.com.
7. www.mtm.org/TiCon.htm.
8. www.acsco.com.

Dr hab. inż. Jan DUDA Prof. PK
Instytut Technologii Maszyn i Automatyzacji Produkcji
Politechnika Krakowska
31-864 Kraków, Al. Jana Pawła II 37
tel.: 012 628-32-84, 012 628-32-50
tel. kom.: 515 105 689
fax.: 0-12 628-20-1
email: duda@mech.pk.edu.pl