MOST AND MTM FOR WORK METHODS OPTIMIZATION: A REAL CASE STUDY BASED ON MODELING & SIMULATION

Antonio Cimino[(a)], Francesco Longo[(b)], Giovanni Mirabelli[(c)], Enrico Papoff[(d)]

[(a) (b) (c) (d)] Modeling & Simulation Center - Laboratory of Enterprise Solutions (MSC-LES)
Mechanical Department, University of Calabria, 87036 Rende (CS), Italy

[(a)]acimino@unical.it, [(b)]f.longo@unical.it, [(c)]g.mirabelli@unical.it [(d)]e.papoff@unical.it

ABSTRACT
The starting point of the research work is the actual configuration of a workstation (Pressure test workstation) belonging to a manufacturing system operating in the field of idraulic hoses production. The objective of the paper is twofold. From one side it aims at comparing four different work methods for optimizing the workstation productivity. Note that the comparison is accomplished according to the work methods process time. From the other side the authors aim at comparing two different work measurement methods trying to establish the more efficient one. Note that the work measurement methods are used for calculating the work methods process time. Moreover, the authors adopt a Modeling & Simulation (M&S) based approach for implementing a three dimensional environnment capable of recreating the Pressure test workstation with satisfactory accuracy. It allows the researchers to conduct the simulation study without disturbing the real system.

Keywords: Manufacturing system, time measurement & work method, MOST, MTM, Simulation

1. INTRODUCTION

Today manufacturing systems are forced to continually increase their efficiency and productivity in order to ensure their competitiveness and survival. There are many alternatives available for improving productivity. Clearly the effective design of work methods is one of the most important aspects of increased productive output. In this regards, Methods Engineering is a systematic technique for the design and the improvement of work methods, for the introduction of those methods into the workplace, and for ensuring their solid adoption (Zandin 2001). Motion and time study is at the heart of methods engineering (Ben-Gal and Bukchin 2002). As reported in Lawrence (2000) the motion study is determining the best way to perform a job and the time study is measuring the time required for a job to be completed using the best method.

Current research, which is related to methods engineering and workstation design, concerns the development of methodology set to apply the emerging technologies in design applications.

Several attempts have been made to apply computer technology to methods engineering and workstation design.

Braun et al. (1996) present an example of computer aided planning of a manual assembly workstation using a system called EMMA. The system is based on AutoCad and consists of a database of workstation elements and anthropometric data combined with an MTM analysis module.

Arzi (1997) suggests the integration of more advanced technology in the design process. Technology capable of effectively simulating human movement and rapid generating workstation prototypes. In this regards the author presents a framework for Rapid Prototyping (RP) based system.

Gilad and Karny (1999) present a considerably different approach. In effect, they develop an expert system suited for professional ergonomists as well as novices. The system, called ERGOEX, receives various data about the worker and the working environment, and generates quantitative and qualitative recommendations based on ergonomic knowledge bases.

The main contribution of this paper to the state of the art is to present an integration between M&S and work measurement tools for optimizing work methods. In particular Rhinoceros and eMWorkplace have been used for recreating in the virtual environment the system under consideration. MTM and MOST methods have been applied for the work measurement. Moreover, note that the research work allows to compare the work measurement tools trying to establish the more efficient one.

Before getting into details of the study let us give a brief overview of each section of the paper. Section 2 describes the manufacturing process and the pressure test workstation. Section 3 provides a brief description of the MTM and MOST methods. Section 4 gives specific details on the simulation model implementation. Section 5 presents a detailed analysis of the simulation results and shows the optimal work method. The last section reports the conclusions that summarize the scientific contribution of the work.

2. THE MANUFACTURING PROCESS AND THE PRESSURE TEST WORKSTATION

The Pressure test workstation belongs to a manufacturing system devoted to produce high pressure hydraulic hoses. The manufacturing plant, AlfaTechnology s.r.l., is located in the South of Italy (Calabria) and covers a surface of about 13.000 square meters. The plant layout is subdivided in two different operative areas. The first one, the Mechanical area, produces fittings and ring-nuts (and some other components usually used for hydraulic hoses assembly). The second one, the Assembly area, assembles rubber hoses with fittings and ring-nuts in order to obtain the final product. The Assembly area consists of 8 different workstations each one performing a specific operation of the hydraulic hoses assembly process. The operations performed in each workstation are described as follows.

1) *Preparation workstation*: according to the S.Os information, the operator takes the main components from the raw materials warehouse shelves and defines the length of the rubber hose;
2) *Seal Press workstation*: the operator prints on ring-nuts and fittings the quality and traceability identifying numbers by using the seal press machine and places the components inside apposite boxes;
3) *Cutting workstation*: the operators take rubber hose rolls from the raw materials warehouse shelves and cut the rolls according to the S.Os requirements (by using an automated or manual machine);
4) *Skinning workstation*: the operators eliminate a part of rubber at the ends of each hose in order to guarantee a good junction with the fittings;
5) *Assembly workstation*: the operators manually assemble the rubber hoses with fittings and ring-nuts;
6) *Stapling workstation*: the operators tighten the ring-nuts on the hoses by using the stapling machine;
7) *Pressure Test workstation*: the operators test the hydraulic hoses by using a pressure machine (setting a pressure value higher than the nominal value);
8) *Check and packaging workstation*: the operators compare the S.Os requirements and the hoses characteristics (quality controls), put the hydraulic hoses in the shipping cases.

Consider now the Pressure test workstation. The operations performed in this workstation have been subdivided in 6 different groups (each group has to be regarded as a macro-activity), described as follows.

- *Macro-activity 1* – the operator sets the workstation for starting the testing operations;
- *Macro-activity 2* – the operator prepares the hydraulic hoses to be tested;
- *Macro-activity 3* – the operator moves the hoses from the work table to the testing machine;
- *Macro-activity 4* – the operator connects the hydraulic hoses to the testing machines, performs the security procedures and starts the testing phase;
- *Macro-activity 5* – the operator puts away from the machine the hydraulic hoses, performs the visual checks and moves the hoses on the work table;
- *Macro-activity 6* – the operator completes the Shop Order.

Let us introduce the four different work methods. The authors focalize on operator's work methods in terms of hydraulic hoses simultaneously tested in the pressure machine: one single hydraulic hose (work method 1) two hydraulic hoses (work method 2), three hydraulic hoses (work method 3) and four hydraulic hoses (work method 4). Obviously the work method affects the workstation productivity in terms of Shop Orders completion. In fact, the higher is the number of hydraulic hoses to be simultaneously tested, the higher is the time for connecting the hydraulic hoses to the tesintg machines as well as the time required for their test and the lower is the operations frequency (i.e. the number of tests to be accomplished for a Shop Order completion).

On the other hand, the lower is the number of hydraulic hoses to be simultaneously tested, the lower is the time for connecting the hydraulic hoses to the testing machine as well as the time for their test and the higher is the operations frequency.

In this regards, the authors calculate the process time related to each work method applying the work measurements methodology (MTM and MOST) by means of simulation model (the simulation model is reported in the section 4) capable of reproducing with satisfactory accuracy the Pressure test workstation. Note that, this research approach allows to not disturb the real system until the simulation study is completed.

3. WORK MEASUREMENTS METHODOLOGIES

In this paragraph the Method Time Measurement (MTM) and the Maynard Operation Sequence Technique (MOST) are presented. MTM and MOST are predetermined time systems and provide information about manual work cycles in terms of basic human motions and time to them related. Sections 3.1 and 3.2 provide a brief description of such methodologies.

3.1. MTM

The Method Time Measurement is the most widely used system of predetermined times (Rice 1977).

The MTM is a procedure for analyzing any manual operation or method by breaking out the basic motions required to perform it and assigning to each a predetermined standard time based on its nature and the conditions under which it is made (Karger and Bayh 1987). The total time for the manual operation is then calculated as sum of the time of each basic motion it is made by. Reach is the most common or basic MTM motion. Other motions include the following:

- *Move*: the predominant purpose is to transport an object to a destination;
- *Turn*: the hand is turned or rotated about the long axis of the forearm;
- *Position*: motion is employed to align, orient, and/or engage one object with another;
- *Grasp*: the main purpose is to secure sufficient control of one or more objects with the fingers or the hand;
- *Release*: the operator relinquishes control of an object;
- *Disengage*: contact between two objects is broken;
- *Eye times*: the eyes direct hand or body motions;
- *Body motions*: motions are made by the entire body, not just the hands, fingers or arms.

3.2. MOST

MOST concentrates on the movement of objects (Zandin and Kjell 1990). The primary work units are no longer basic motions, but fundamental activities (collection of basic motions) dealing with moving objects. These activities are described in terms of sub activities fixed in sequence. In other words, to move an object, a standard sequence of events occurs.

Objects can be moved in only one of two ways: either they are picked up and moved freely through space or they are moved and maintain contact with another surface. The use of tools is analyzed through a separate activity sequence model.

Consequently, only three activity sequences are needed for describing manual work. Summarizing the MOST technique is made up of the following basic sequence models:

- The *general move sequence* for the spatial movement of an object freely through the air. The activity sequence is made up of four different sub activities: action distance (A), body motion (B), gain control (G) and place (P);
- The *controlled move sequence* for the movement of an object when it remains in contact with a surface or is following a controlled path during the movement. In addition to the A, B and G parameters from the general move sequence, the sequence model for controlled move contains the following sub activities: moved controlled (M), process time (X), align (I);
- The *tool use sequence* for the use of common hand tools. The tools use sequence model is a combination of general move and controlled move activities.

4. SIMULATION MODEL DEVELOPMENT VALIDATION PROCESS

As before mentioned, a simulation model has been used to compare four different work methods for optimizing the workstation productivity. The simulation model has been developed by means of the CAD software Rhinoceros and the simulation software EMWorkplace.

The CAD software has been used to model workstation equipments and final product components

The simulation software has been used for recreating in the virtual environment the Pressure test workstation. In fact, all the objects modeled by means of Rhinoceros have been imported and located in the right position (the same position the real objects take place in the real workstation) in the virtual environment provided by EMWorkplace.

The modeling phase has required a specific input data collection in order to recreate three dimensional objects with high level of detail. In this regards data about dimensions (length, width and height) and weights of all the objects being modeled were collected. Table 1 reports data for the geometric model implementation.

Table 1: data collection for geometric models implementation

Object Description	Object Type	Weight (Kg)	Dimensions (cm) L x W x H
Ring	Component	0.168	Depending on S.O.
Fitting	Component	0.336	Depending on S.O.
Marking die	Component	1.800	Depending on S.O.
Workstation stamp	Component	0.100	Depending on S.O.
Scanner	Component	0.400	12 x 7 x 18
Empty bin	Component	0.300	30 x 20 x 15
Rubber hose	Component	1.020	Depending on S.O.
Manual operated Dolly	Equipment	35.300	100 x 120 x 76
Rings bin	Equipment	0.300	30 x 20 x 15
Work table	Equipment	100.800	240 x 220 x 95
Pressure test machine	Machine	1020.040	368 x 90 x 150

Figure 1 and figure 2 shows respectively the work table and the pressure test machine three dimensional models. Finally figure 3 shows a panoramic view of the virtual layout of the Pressure test workstation.

After workstation layout recreation, next step was to insert and to train human models capable of reproducing in the virtual environment the real work methods. Human models have been selected from eM-Workplace libraries.

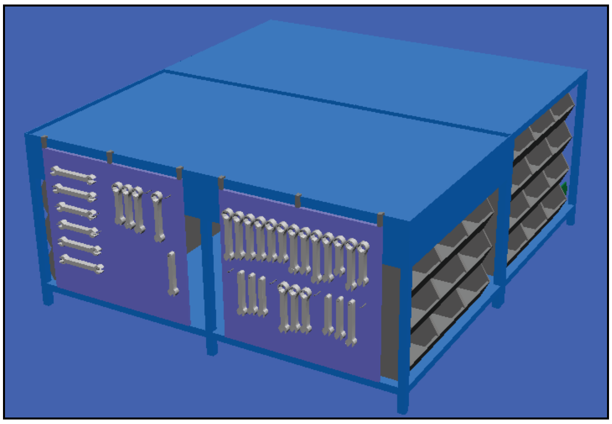

Figure 1: Work table three dimensional model.

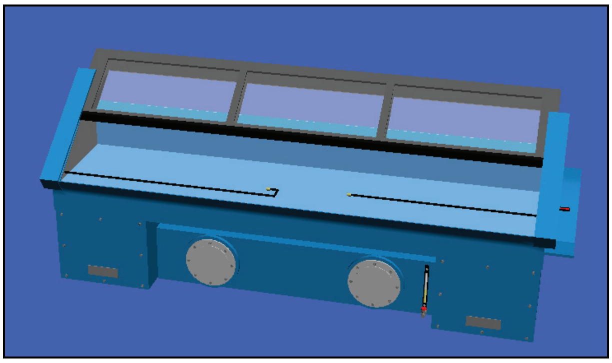

Figure 2: Pressure test machine three dimensional model.

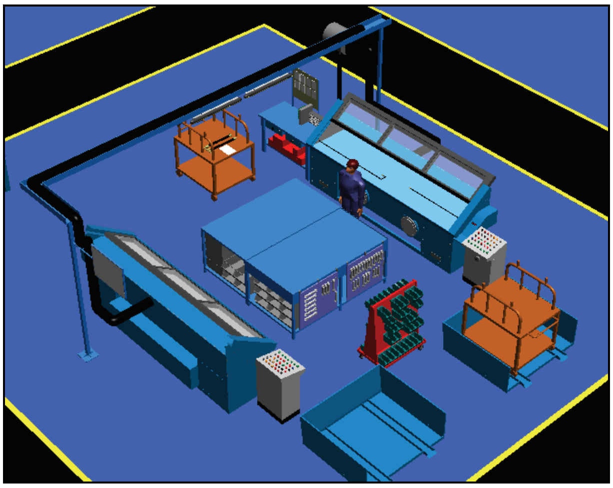

Figure 3: Panoramic view of the virtual layout of the Pressure test workstation.

The selection process has been carried out taking into account the characteristics of the real operators (age, gender, height, weight and physical condition) with the aim of importing in the virtual environment human models as much as similar to the real workers. Naturally each human model needs to be trained in order to perform the manufacturing operations. To this end, eM-Workplace provides the user with a programming language for teaching the basic motions of each operation. Figure 4 shows several programming code lines written for teaching the human model.

```
R 3
%VIEW      734.53     114.66   -1080.08      61.18
WALK vaicarrello1>vaicarrello2 (ARMFIX BODYFIX 850
%VIEW     1387.70   -1431.71    1055.31      43.56
CP RHAND    79.42     0.02  -12.75  0.00 -0.00 90.00
GET DXFIMPORT_0094 /POSE=afferrafoglio  /RHAND=affe
CP RHAND    79.42     0.02  -12.75  0.00  0.00 90.00
MV  /POSE=alzafoglio  /RHAND=alzafoglio /AMR=0 /MTM
MV  /POSE=avvicinafoglio /MTM1=(,,M)
%VIEW      -54.78   -1965.30    1168.56      52.18
WALK CURR>vaitavolocollaudo (ARMFIX BODYMOVE 850 W
PT 2.0 /D=0.07
MV  /POSE=GUARDAfolglio
D 2
```

Figure 4: An example of programming code lines

After the simulation model implementation, determining if the simulation model is an accurate representation of the real system under consideration is a mandatory step for considerably increasing the success of the simulation study. In this context the simulation model has been analyzed and discussed with workers and employees of the manufacturing system. All the basic motions of the human models have been checked with workers' help and some errors concerning the work methods (wrong working postures, wrong motions or redundant motions) have been corrected. At the end of the validation, it was concluded that the simulation model is capable of recreating the real Pressure test workstation with satisfactory accuracy.

4. SIMULATION RESULTS

The different work methods previously described (see section 2) have been analyzed by means of a simulation model and using the Methods Time Measurement (MTM) and Maynard Operation Sequence Technique (MOST) for evaluating the time of each single macro-activity (see section 2). Note that, the authors take into consideration a typical Shop Order that requires the production of 12 medium section hydraulic hoses.

The macro activities 1 and 6 (workstation set-up and Shop Order completion) are made by preparation operations and so performed just once for the Shop Order completion. On the other hand the macro activities 3, 4 and 5 consist of cyclic operations and so cyclically performed for each hydraulic hoses. Obviously the frequency of such macro-activities depends on the work method performed by the operator (one, two, three, four hydraulic hoses to be simultaneously test by means of the pressure machine).

In addition, the macro-activity 2 is cyclically performed but the time of the macro-activity 2 affects the Shop Order total completion time just once (in other words it is cyclically repeated during the macro-activity 4).

Table 2 and table 3 reports respectively the MTM and MOST time values for each work method and for each macro activity as well as the total time for completing the Shop Order under consideration.

The work method 3 (three hydraulic hoses simultaneously tested) is characterized by the minimum Shop Order completion time according both the MTM and MOST methods.

Table 2: MTM results for the Pressure test workstation

	Macro-Activity 1 (sec.)	Macro-Activity 2 (sec.)	Macro-Activity 6 (sec.)	Total preparation time (sec.)
wm1	4.6	27.8	20.9	52.3
wm2	6.2	35.8	24.3	66.3
wm3	8	51.4	26.3	85.7
wm4	9.2	69	27.2	105.4
	Macro-Activity 3 (sec.)	**Macro-Activity 4 (sec.)**	**Macro-Activity 5 (sec.)**	**Total working time (sec.)**
wm1	189.3	349.6	373.6	912.5
wm2	87.6	235.3	274.1	597
wm3	54	219.1	243.4	516.5
wm4	44	224.5	243.6	512.1
	Total time for completing the Shop Order (sec.)			
wm1	965.8			
wm2	663.3			
wm3	602.2			
wm4	617.5			

Table 3: MOST results for the Pressure test workstation

	Macro-Activity 1 (sec.)	Macro-Activity 2 (sec.)	Macro-Activity 6 (sec.)	Total preparation time (sec.)
wm1	4.8	28.5	22.6	55.9
wm2	5.7	36.4	24.5	66.6
wm3	7.1	52.1	27.1	86.3
wm4	8.3	69.7	27.6	105.6
	Macro-Activity 3 (sec.)	**Macro-Activity 4 (sec.)**	**Macro-Activity 5 (sec.)**	**Total working time (sec.)**
wm1	192.5	342.1	376.9	911.5
wm2	90.4	230.3	276.2	595.9
wm3	55.1	217.1	245.6	517.2
wm4	45.1	221	246.6	512.7
	Total time for completing the Shop Order (sec.)			
wm1	967.4			
wm2	662.5			
wm3	604.1			
wm4	618.3			

Considering the MTM method, the total time is 602.2 seconds (about 10 minutes and 2 seconds). Note that the completion time improvement is about 38% respect to the first scenario, 9% respect to the second scenario and 2.5% respect to the fourth scenario.

Considering the MOST method, the total time is 604.1 seconds (about 10 minutes and 4 seconds). In this case the completion time improvement is about 37.5% respect to the first scenario, 9% respect to the second scenario and 2% respect to the fourth scenario.

Let us make a comparison between MTM and MOST methods. Such methodologies, for each work method, provide the user with very similar total time values. For instance, note that the MTM and MOST time values for the Shop Order completion, considering the work method 1, are respectively 965.8 and 967.4 seconds. Moreover 662.5 and 663.3 seconds are the time values the methods evaluate considering the work method 2. It can be concluded that MTM and MOST outputs differ one another of few percentage points. In this regards, they conduct the user to the same final considerations (in this research work the choice of the optimal work method). Consider now, for such methodologies, the procedure for calculating the operation time. As previously stated (see section 3), the MTM method breaks out the basic motions required to perform an operation and assign to each a predetermined standard time. The operation time is the sum of time of the basic motions it consists of. On the other hand the MOST considers fundamental activities (collection of basic motions) dealing with moving objects. These activities are described in terms of sub activities (parameters) fixed in sequence. An index value is assigned to each parameter. Finally the time calculation is performed as follows:

1. Add all index values for the parameters;
2. Convert the total to Time Measurement Unit (TMU) by multiplying by 10.

Note that 1 TMU is 0.036 seconds.

In order to better understand the methods differences let report an application example. Consider the following operation: the worker walks three steps to pick up the Shop Orders sheet, reads the information he/she needs and puts it back. Note that such operation represents the macro activity 1.

Let consider the MOST method. A fully indexed Sequence Model might appear as follows:

$A_6\, B_0\, G_1 \quad A_1\, B_0\, P_0 \quad T_3 \quad A_1\, B_0\, P_1 \quad A_0$

where,

A_6 = Walk three steps to object location;
B_0 = No body motion;
G_1 = Gain control of Shop Order Sheet;
A_1 = Bring part within reach;
B_0 = No body motion;
P_0 = No placement;
T_3 = Read the Shop Order information;
A_1 = Bring part within reach;
B_0 = No body Motion;
P_1 = Release the Shop Order sheet.

For instance consider the code A_6: the letter "A" represents the parameter and the number "6" is the index value. The sum of all the index values is:

$$6 + 0 + 1 + 1 + 0 + 0 + 3 + 1 + 0 + 1 + 0 = 13$$

Finally the operation time is calculated as follows:

$$13 \text{ x } 10 = 130 \text{ TMU} = 4.8 \text{ seconds}$$

Note that the parameters with index value "0" are here reported only for a clearer explanation of the method. In effect they do not add any time value to the final operation time (in the example under consideration only six parameters have to be considered).

Let consider the MTM method. Figure 4 reports the MTM analysis sheet.

The operation time is 135.80 TMU or rather 4.6 seconds considering the conversion factor (1 TMU is 0.036 seconds).

MTM Analysis Sheet

Status:
Project nr:
Product description:

Nr.	Description:	Code	L	TMU	R	Code	Description:
1			0,00	39,00	0,00	W3P	Walk three steps to object location
2			2,50	10,00	10,00	M49B0	Move the right hand a distance within reach
3			0,00	6,40	6,40	R50B	Reach the Shop Order sheet
4			0,00	2,00	2,00	G1A	Grasp the Shop Order sheet
5			0,00	10,00	10,00	M49B0	Move the Shop Order sheet in a distance within reach
6			0,00	40,00	55,60	PT55.6	Read the Shop Order information
7			0,00	10,00	10,00	M49B0	Move the Shop Order sheet in a distance within reach
8			0,00	6,4	6,4	P5B	Put the Shop Order sheet on the work table
9			0,00	2,00	2,00	RL1	Release the Shop Order sheet
10			0,00	10,00	10,00	M49B0	Move the right hand a distance within reach
				135,80			

Figure 4: MTM analysis sheet

It has been calculated as sum of the 10 basic motions the MTM method identified. In this regards a first difference between MTM and MOST methods is represented by the number of basic motions/parameters affecting the final operation time. Obviously the number of basic motions is higher than the number of parameters. In effects, as previously stated, a parameter represents a basic motions collection. Moreover, in addition to the MOST method, the MTM distinguishes between operations performed with the right hand and operations performed with the left hand. However, note that in the application example the operator does not use the left hand for performing basic motions.

Another relevant difference regards the methodologies codes. The MTM codes are more complex than the MOST codes. In effect the first ones are alphanumeric sequences (more letters and more numbers) longer than the second ones (one letter and one index).

After these brief considerations, we can conclude that the MTM method is a very exact system, but also very slow to apply. In effect basic motions distances must be accurately measured in inches or centimeters and correctly classified. Moreover, it can be used for conducting very detailed and accurate analysis. In this context, it provides the analysts with a complete list of basic motions; all of them can be checked and some errors concerning the work methods (wrong working postures, wrong motions or redundant motions) can be corrected. In conclusion the MTM can be also used as tool for analyzing and improving the work methods.

As concerns the MOST method is a simpler system, but still able to provide high level of accuracy and consistency (in effect, in this research work MOST and MTM time values are very similar). On the other hand, it can be used for conducting studies that do not require a high level of details in terms of basic motions analysis.

5. CONCLUSIONS

The starting point of the research work is the actual configuration of a workstation belonging to a manufacturing system operating in the field of idraulic hoses production. The main objective of the paper is to compare both four different work methods for optimizing the workstation productivity and two different work measurement methods (MTM and MOST) trying to establish the more efficient one. The work methods have been compared in terms of process time. The process time has been calculated by the MTM and MOST methods.

An approach based on Modeling & Simulation has been adopted.

The authors started the research work by modeling the actual configuration of Pressure test workstation. The simulation model has been developed by using the CAD software Rhinoceros and the simulation software eM-Workplace. By means of the simulation model and of the work measurement methods the different work methods have been analyzed compared.

The best work method in terms of hydraulic hoses to be simultaneously tested has been selected.

Moreover the MTM and MOST main differences have been identified and several considerations about the methods applications have been accomplished.

Further researches are still on going for analyzing the remaining workstations of the manufacturing plant.

REFERENCE

Arzi, Y., 1997. Methods engineering: using rapid prototype and virtual reality techniques. *Human Factors and Ergonomics in Manufacturing*, 7, 79-95.

Ben-Gal, I., Bukchin, J., 2002. The ergonomic design of workstations using virtual manufacturing and response surface methodology. *IIE Transaction*, 34, 375-391.

Bocca, E., Longo, F., 2008. *Simulation Tools, Ergonomics Principles and Work Measurement Techniques for Workstations Design*. Proceedings

of Summer Computer Simulation Conference, 15-18 June, Edinburgh (UK).
Braun, W.J., Rebollar, R., Schiller, E.F., 1996. Computer aided planning and design of manual assembly systems. *International Journal of Production Research*, 34, 2317-2333.
De Sensi, G., Longo, F., Mirabelli, G., 2007-a. *Modeling & Simulation Based Approach for Optimizing Seal Press Workstation in a Manufacturing System*, Proceedings of Business and Industry Symposium, March 25-29, USA.
De Sensi, G., Longo. F., Mirabelli, G., 2007-b. *Ergonomic work methods optimization in a three dimensional environment*, Proceedings of Summer Computer Simulation Conference, July 15-18, San Diego, California, USA
Gilad, I., Karni, R., 1999. Architecture of an expert system for ergonomics analysis and design. *International Journal of Industrial Ergonomics*, 23, 205-221.
Karger, O., Bayh, F., 1987. *Engineered Work Measurement*, New York: Industrial Press.
Lawrence, S.A., 2000. *Work Measurement & Methods Improvement*, New York: John Wiley & Sons.
Longo, F., Mirabelli, G., Papoff, E., 2005. *Techiche di analisi avanzate per la progettazione efficiente delle postazioni di assemblaggio manuale*, SdA – Soluzioni di Assemblaggio, VNU Business Publications Italia.
Longo, F., Mirabelli, G., Papoff, E., 2006-a. *Material Flow Analysis and Plant Lay-Out Optimization of a Manufacturing System*, International Journal of Computing, 5(1), 107-116.
Longo, F., Mirabelli, G., Papoff, E., 2006-b. *Effective Design of an Assembly Line Using Modeling & Simulation*, Proceedings of the Winter Simulation Conference, December 3rd – 6th, Monterey, California, USA
Rice, R.S., 1977. Survey of Work Measurement and Wage Incentives. *International Journal of Industrial Engineering*.
Zandin K.B., 2001. *Maynard's Industrial Engineering Handbook*, 5th ed. New York: McGraw-Hill.
Zandin, Kjell, 1990. *MOST® Work Measurement Systems*. 2d ed. New York: Marcel Dekker.

AUTHORS BIOGRAPHY

ANTONIO CIMINO was born in Catanzaro (Italy) in October the 1th, 1983. He took his degree in Management Engineering, summa cum Laude, in September 2007 from the University of Calabria. He is currently PhD student at the Mechanical Department of University of Calabria. His research activities concern the integration of ergonomic standards, work measurement techniques, artificial intelligence techniques and Modeling & Simulation tools for the effective workplace design. He collaborates with the Industrial Engineering Section of the University of Calabria to research projects for supporting innovation technology in SMEs.

FRANCESCO LONGO took the degree in Mechanical Engineering from University of Calabria (2002) and the PhD in Industrial Engineering (2005). He is currently researcher at the Mechanical Department (Industrial Engineering Section) of University of Calabria. His research interests regard modeling & simulation of manufacturing systems and supply chain management, vulnerability and resilience, DOE, ANOVA. He is Responsible of the Modeling & Simulation Center – Laboratory of Enterprise Solutions (MSC-LES), member organization of the MS&Net (McLeod Modeling & Simulation Network) He is also member of the Society for Computer Simulation International and Liophant Simulation.

GIOVANNI MIRABELLI was born in Rende in 1963 and he took the degree in Industrial Engineering at the University of Calabria. He is currently researcher at the Mechanical Department of University of Calabria. His research interests include ergonomics, methods and time measurement in manufacturing systems, production systems maintenance and reliability, quality. He has published several scientific papers participating as speaker to international and national conferences. He is actively involved in different research projects with Italian and foreign universities as well as with Italian small and medium enterprises. He has acquired experience with Office package, simulation packages and software for designing maintenance and quality processes in industrial plants.

ENRICO PAPOFF was born in Naples (Italy) on February the 03rd, 1948. He took the degree in Mechanical Engineering from University of Napoli Federico II, in 1973. He is currently Associate Professor at the Mechanical Department (Industrial Engineering Section) of the University of Calabria. His research interests regard project management and business plans.