A COMPUTERIZED METHODOLOGY AND AN ADVANCED APPROACH FOR THE EFFECTIVE DESIGN AND PRODUCTIVITY ENHANCEMENT OF AN INDUSTRIAL WORKSTATION

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ABSTRACT

It is the intent of the research work to propose a methodology for achieving the ergonomic effective design of a real industrial workstation and an advanced approach for enhancing its productivity. In particular the design methodology is based on multiple design parameters, Design of Experiments (DOE) and multiple performance measures. The Design of Experiments supports the comparison of the actual configuration of the workstation with alternative operative scenarios (different workstation configurations). The advanced approach for workstation productivity enhancement aims at comparing different work methods in order to reduce the workstation process time. The evaluation of the process time as well as of the best work method is achieved by contemporaneously using the Methods and Tine Measurement and the Maynard Operation Sequence Techniques. Simulation, 3D Visualization and human modelling are used as support tool for recreating workstation operations, executing experiments (ergonomics effective design) and apply work measurement methodologies (selection of the best work method).

Keywords: Industrial plants, Industrial Workstation, Modeling & Simulation, Ergonomic analysis, Work measurement

1. INTRODUCTION

An overview of the state of the art, starting from the second half of the 1990s, reveals that industrial plants continuously provide challenging problems in terms of both workstations ergonomic design and workstations productivity enhancement. The ergonomic effective design of an industrial workstation attempts to achieve an appropriate balance between the worker's capabilities and worker's requirements as well as provide the worker with physical and mental well-being, job satisfaction and safety (Das and Sengupta, 1996). The industrial workstations productivity enhancement attemps to achieve a reduction of workstations process time obtaining higher productivity levels (Cimino et al., 2008a). According to Zandin (2001) the study of workstations process times is indicated as work measurement and aims at evaluating and improving the times standard for performing workstations operations.

Let us consider the workstations ergonomic effective design within industrial plants. Most of the works developed in the late '90s consider single ergonomic performance measures (based upon a specific ergonomic standard) for the ergonomic redesign of workstations belonging to industrial plants. Among ergonomic standards, the following are the most widely used: (i) the NISOH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for *National Institute for Occupational Safety and Health*); (ii) the OWAS for working postures analysis (OWAS stands for *Ovako Working Analysis System*); (iii) the Burandt Schultetus analysis for lifting tasks involving a large number of body muscles; (iv) the Garg analysis for assessing the energy expenditure for performing an operation. Further information about the cited ergonomic standards can be found in the Niosh Technical Report 81-122 (1981), the Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation (1991), Waters et al. (1994), Kharu et al. (1981), Schultetus (1980) and Garg (1976). Examples of research works that propose the ergonomic redesign of industrial workstations based on single ergonomic performance measure are reported in Temple and Adams (2000), Waters et al. (2007).

The integration of two or more ergonomic standards was the successive step carried out by the researchers working in this specific area for achieving multiple and simultaneous ergonomic improvements. Examples of ergonomic standards integration can be found in Russell et al. (2007) and Cimino and Mirabelli (2009).

Consider now the workstations productivity enhancement within industrial environments. Among different solutions for improving workstations productivity, the work measurement plays a critical role supporting the definition and design of alternative and more efficient work methods. In this regards, work measurement as part of Methods Engineering is a systematic technique for the design and the improvement of work methods as well as for their adoption within industrial workstations (Zandin, 2001). Motion and time study are the heart of work measurement (Ben-Gal and Bukchin, 2002). As reported in Lawrence (2000) the motion study determines the best work method to perform an operation and the time study measures the time required to complete the operation by using the best method. The following time study tools (also known as work measurement tools) have to be regarded as the most important: MTM (Methods and Time Measurement) and MOST (Maynard Operation Sequence Techniques). Further information about the cited work measurement tools can be found in Maynard et al. (1948), Karger and Bayha (1987) and Zandin (2001).

Another important issue to take into consideration in the industrial workstations ergonomic design and productivity enhancement is the relation between the ergonomics and work measurement. Laring et al. (2002) and Udosen (2006) take into consideration in their research works both ergonomics and work measurement aspects. Finally the last important issue is whether the workstation ergonomic effective design and/or the productivity enhancement are carried out directly in the real industrial workstation or by using simulation models. Researchers and practitioners very often use simulation as problem solving methodology for creating an artificial history of the system, analyzing its behaviour, choosing correctly, understanding why, diagnosing problems and exploring possibilities (Banks, 1998). Moreover, simulation can be jointly used with virtual three-dimensional environments in which observe the system evolution over the time and detect ergonomic and work measurement problems that otherwise could be difficult to detect (an overview on attributes and capabilities of virtual environments can be found in Wilson, 1997). Feyen et al. (2000) propose a PC-based software program for studying ergonomic issues during the industrial workstation design process. Longo and Mirabelli (2009) use Modeling&Simulation in combination with ergonomic standards and work measurement (multi- measures based approach) for the effective design of an assembly line still not in existence (note that in this last case the authors take simultaneously into consideration ergonomic aspects and work measurement).

The main contribution of this paper to the state of the art is to propose a methodology for achieving the ergonomic effective design of a real industrial workstation and an advanced approach for enhancing its productivity. In particular the design methodology is based on multiple design parameters, Design of Experiments (DOE) and multiple performance measures. The advanced approach for workstation productivity enhancement aims at comparing different work methods in order to reduce the workstation processes time. The design methodology and the advanced approach are proposed to the reader contextually to their application to the most critical workstation (the Seal Press workstation) belonging to an industrial plant that manufactures high pressure hydraulic hoses. As support tool for applying both the design methodology and the advanced approch the authors use a 3D simulation model of the industrial workstation for investigating different ergonomic configurations of the workstation as well as comparing alternative work methods. Each workstation ergonomic configuration comes out from a design of experiments based on multiple design parameters and the choice of the final configuration (the ergonomic effective design of the workstation) is made according to multiple ergonomic performance measures. As concerns the work methods comparison, the choice of the best work method is made according to a single time performance measure (the process time evaluated by using the simulation model).

Before getting into details of the study let us give a brief overview of each section of the paper. Section 2 provides a brief description of the industrial plant as well as the Seal Press Workstation. Section 3 proposes the methodology for the industrial workstation ergonomic effective design. Section 4 presents the simulation model of the Seal Press Workstation. Section 5 presents the simulation results analysis and the Seal Press effective design. Section 6 presents the advanced approach for productivity enhancement within the Seal Press workstation. The last section reports the conclusions (that summarize the scientific contribution of the work) and the research activities still on going.

2. THE INDUSTRIAL PLANT AND THE SEAL PRESS WORKSTATION

The industrial plant, AlfaTechnology s. r. l., manufactures high pressure hydraulic hoses and is located in the South of Italy (Calabria). The authors already carried out research activities (in cooperation with AlfaTechnology s. r. l.) on workstation ergonomic effective design (Cimino et al., 2009) and production planning and control (Cimino et al., 2008b). However in order to provide the reader with enough information for understanding the research work proposed in this paper, a brief description of the operations performed in each workstation in reported below.

1) *Preparation workstation*: 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 Shop Orders (S. Os) requirements (by using an automated or manual cutting 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), they also put the hydraulic hoses in the shipping cases.

Figure 1 shows the final products (the high-pressure hydraulic hoses). Each hydraulic hose is made up of a rubber hose, two fittings and two ring nuts.

Figure 1: The final products of the manufacturing plant

A preliminary analysis carried out by production managers shows that the productivity of the Seal Press workstation (evaluated on monthly basis) always falls below target levels causing delays in S.Os completion. The operator of the Seal Press workstation performs the following operations: (1) seal press machine set up and preparation; (2) components positioning (ring nuts or fittings) within the machine; (3) printing operations (quality and traceability identifying numbers on the component); (4) components removal from the machine (components are then placed in a box); (5) update of the operation status on the company informative system (end of the operation); (6) transportation of the components to the successive workstation by using a manually operated dolly. Moreover, note that the worker can perform the above mentioned operations by using 4 different work methods each one characterized by a different number of ring nut/fitting to be simultaneously positioned into the seal press machine (operation 2). By using the first work method the operator inserts one ring nut/fitting into the seal press machine, by using the second work method, the operator inserts two ring nuts/fittings into the seal press machine, by using the third and the fourth work methods, three and four ring nuts/fittings, respectively.

3. THE DESIGN METHODOLOGY FOR WORKSTATION ERGONOMIC EFFECTIVE DESIGN

The first goal of the paper is to propose a methodology for the ergonomic effective design of the most critical workstation of a manufacturing plant (the Seal Press workstation) by simultaneously considering multiple design parameters and multiple performance measures based on ergonomic standards. To this end, the methodology being advanced in this paper uses a well-planned Design of Experiments (DOE) for supporting the comparison of the actual configuration of the Seal Press workstation with alternative operative scenarios (different workstation configurations). The generation of alternative configurations comes out from the variation of multiple design parameters that affect multiple performance measures (ergonomic performance measures). The quantitative evaluation of the effects of the multiple design parameters on the multiple performance measures is achieved by using the Design of Experiments (DOE). Such evaluation allows to choose the final configuration of the workstation. The design methodology consists of the following steps: design parameters definition (section 3.1), performance measures definition (section 3.2), workstation simulation model development (section 4), workstation effective design (section 5). Finally after the ergonomic effective design, the workstation will be tested under the 4 different work methods with the aim of enhancing productivity and select the optimal work method.

3.1. Definition of the design parameters

A preliminary analysis has detected the design parameters (factors) that could have an impact on the workstation performance (in terms ergonomic risks and work methods). The analysis reveals that some distances and angles (associated to objects and tools position) could be significant factors for the Seal Press workstation. The investigation and comparison of all possible workstation configurations require a correct design of experiments. We take into consideration the following factors:

- *Support table angle*: let us indicate this angle with α, it defines the orientation of the support table respect to the actual position (see figure 2);
- *Raw materials bin height*: let us indicate this height with *rmh*, it defines the height of the bin containing the raw materials (see figure 2);
- *Ring nuts bin height*: let us indicate this height with *rnh*, it defines the height of the bin containing ring nuts exiting from the seal press machine (see figure 2).

Table 1 reports factors and levels.

Table 1: Design parameters and levels

Seal Press Workstation				
Factors	**Factor ID**	**Level 1**	**Level 2**	
Support Table Angle	α	0	π/2	rad
Raw Materials bin height	rmh	17	86	cm
Rings nuts bin height	rnh	30	65	cm

The factors levels combination generates 8 different configurations, so the design of experiments will investigate 8 different workstation configurations.

3.2. Definition of the performance measures

As reported into the introduction, the effective ergonomic design of a workstation should consider a multi-measures based approach. Let introduce now the performance measures used for evaluating each workstation configuration. We propose a multi-measures approach based on ergonomic indexes. The ergonomic performance measures, based on ergonomic standards, are the lift index (evaluated by using the Burandt Schultetus analysis), the stress level associated to each working posture (evaluated by using the OWAS analysis) and the energy expenditure associated to each activity (evaluated by using the Garg analysis). Further information concerning these ergonomic standards can be found in Schultetus (1980), Kharu et al. (1977), Kharu et al. (1981), Garg (1976).

4. THE SIMULATION MODEL OF THE SEAL PRESS WORKSTATION

The design of experiments requires to test 8 different workstation configurations, involves different design parameters and ergonomic performance measures. Similarly the approach proposed for workstation productivity enhancement requires to test four different work methods. Any investigation or analysis directly carried out within the real systems disturbs the normal workstation operations, causing as consequence efficiency losses and additional costs. Therefore the authors decide to support experiments execution and work methods analysis by using a simulation model of the Seal Press workstation. The simulation model recreates, within a 3 D virtual environment, all the workstation operations including human model (worker), kinematics and activities.

The Modelling & Simulation tools, used for developing the Seal Press workstation simulation model, are the CAD software Pro-Engineer by PTC (further information can be found at http://www.ptc.com/products/proengineer/) and the simulation software eM-Workplace by Tecnomatix Technologies (further information can be found at http://www.plm.automation.siemens.com/en_us/products/tecnomatix/assembly_planning/process_simulate_human/index.shtml). Before getting into the details, let us summarize the most important steps of the simulation model development. The first phase is the creation of the three-dimensional geometric models representing the workstation and tools being used during the production process (*workstation virtual layout development*). The completion of this phase requires to import the geometric models into the virtual environment provided by the simulation software. The second phase is the *insertion and training of the human model* (the human model has to be inserted into the virtual environment and trained to perform workstation operations). The last phase is the *simulation model validation* in order to check the simulation model accuracy in recreating the real workstation.

4.1 Workstation virtual layout development

The implementation of the geometric models of the Seal Press workstation follows three different approaches: (i) geometric models implementation by using the CAD software Pro-Engineer; (ii) geometric models implementation by using the eM-Workplace internal CAD software; (iii) geometric models imported from eM-Workplace libraries.

The geometric models implementation requires an accurate data collection on objects types, dimensions and weights. The data collection includes the following elements of the Seal Press workstation: machine, equipment and tools, worktables, manual operated dollies, raw materials, containers and bins. Table 2 reports the objects description, dimensions and weights.

Table 2: Data collection for geometric models implementation

Object Description	**Object Type**	**Weight (Kg)**	**Dimensions (cm) L x W x H**
Ring nut	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	52.700	150 x 70 x 86
Support table	Equipment	50.120	106 x 76 x 94
Seal Press machine	Machine	131.250	65 x 65 x 160
Pallet	Equipment	25.000	80 x 120 x 15

The figure 2 shows the real hands operated dolly (left side) and the geometric model (right side).

Figure 2: Real and virtual hand operated dolly

The geometric models, created by using the CAD software Pro-Engineer, have to be imported and positioned into the eM-Workplace virtual environment (geometric models created by using the eM-Workplace internal CAD software or imported from the software libraries are directly created and positioned into the virtual environment). Figure 3 shows the real Seal Press workstation and figure 4 shows the workstation geometric models imported into the eM-Workplace virtual environment and the human model (refer to the next section for human model insertion and training procedure).

Figure 3: Real Seal Press workstation

Figure 4: Simulation model of the Seal Press workstation

4.2 Human models insertion and training

The selection of the human models type is based upon an accurate analysis of operators' characteristics (age, gender, height, weight and health conditions). The objective is to select and import, from eM-Workplace libraries, human models representing as much as possible the real workers. After the insertion into the virtual environment, the human model is only able to stand in the waiting position; the model has to be trained to perform workstation operations. eM-Workplace provides the user with a programming language for teaching different types of activities and recreating correctly each type of operation.

The human model training requires an accurate analysis of the operations (performed in the Seal Press workstation) in terms of basic motions. In effect, the programming language provides the user with specific commands for teaching basic motions (i.e. reach, grasp, release, move, etc.). Consequently, each operation has to be subdivided in basic motions.

4.3 Simulation model validation

To increase significantly the probability of success of a simulation study, one of the most important phases is the simulation model validation. The main goal of the validation is to verify if the simulation model is capable of recreating the real system evolution over the time with satisfactory accuracy.

The validation phase has been carried out by using the debugging technique. As reported in Banks (1998) the debugging is an iterative process whose purpose is to discover errors and misconceptions that cause the model failure and to define and carry out the model changes that correct the errors. Such tecnique has been applied with the help of the workstation operators and production engineers: some wrong working postures, wrong motions and redundant motions were corrected or deleted and the simulation model was correctly validated.

5. SIMULATION RESULTS ANALYSIS AND WORKSTATION EFFECTIVE DESIGN

In this section the authors propose the application of the methodology and achieve the ergonomic effective design of the Seal Press workstation. In particular the authors use the simulation model for comparing the 8 workstation configurations obtained by considering all the factors levels combinations (see section 3.1). The analysis of the multiple performance measures defined in section 3.2 will determine the workstations final configuration. Table 3 reports the results of the simulation experiments. First, let us consider separately the effect of each design parameter on the performance measures. The variation of the support table angle α ($0 < \alpha < \pi/2$, keeping fixed the remaining factors levels) does not affect the Burandt Schultetus and the OWAS performance measure. In effect, in both cases ($\alpha = 0$ and $\alpha = \pi/2$) the *Permissible Force* (PF) and the *Stress Level* (SL) remain unchanged (PF = 121.3 N and SL = 3). The variation of the support table angle does not affect lifting tasks and working postures. However, the support table rotation causes an ergonomic improvement: the higher is the angle α the lower is the Energy Expenditure (EE). Note that for $\alpha = 0$ the EE = 1480.0 Kcal, for $\alpha = \pi/2$ the EE = 1439.4 Kcal (the reduction is about 2.7%). As additional information, table 3 reports the *Actual Force* (AF); the AF is the same for each scenario and it is the weight of the objects being handled during the operations. For each scenario, the Burandt Schultetus analysis compares PF and AF: if PF > AF than the ergonomic risk can be accepted otherwise a corrective intervention is required for increasing the PF (or reducing the AF). For both $\alpha = 0$ and $\alpha = \pi/2$ it results PF < AF, it means that the ergonomic risk cannot be accepted.

The variation of the raw material bin height, *rmh* ($17 < rmh < 86$ cm, keeping fixed the remaining factors levels) affects all the performance measures. The greater is the *rmh* the higher is the PF, the lower are the SL and the EE. By increasing the *rmh*, the operator can easily reach and grasp the bin of the raw materials without torso and legs bending (see figure 5). The stand up position during grasping operations guarantees greater PF values (PF = 137.7 N, note that PF is still lower than AF) as well as more comfortable working postures (SL = 2, however such stress level could create ergonomic problems in the near future). Furthermore by avoiding torso and legs bending, smaller amount of energy is required for performing the same operations (EE = 1403.6 Kcal). In this workstation configuration (see the right part of figure 6), the increase of the PF is about 13.5 %, the SL falls now into the second category, the reduction of the EE is 5.2%.

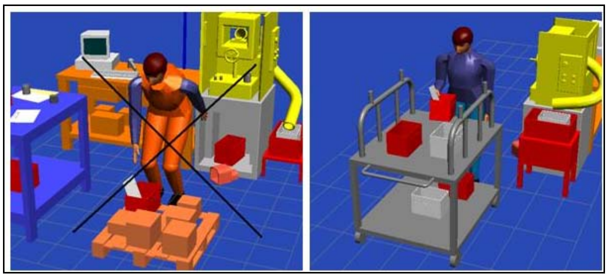

Figure 5: Alternative workstation configuration (raw material bin height)

Let us consider now the variation of the ring nuts bin height *rnh* (30 < *rnh* < 65 cm, keeping fixed the remaining factors levels). As in the previous case, the greater is the *rnh* the higher is the PF, the lower are the SL and the EE. By increasing the *rnh*, the operator reaches and grasps the bin of the ring nuts (exiting from the seal press machine) without torso and legs bending (see figure 6). Consequently, he can exert a greater permissible force (PF = 135.0 N), he works in a more comfortable position (SL = 2) and performs the operations with a smaller amount of energy (EE = 1438.8 Kcal). The increase of the PF is about 11.3 %, the SL falls now into the second category (as before mentioned) and the reduction of the EE is about 2.8%. Figure 6 shows the modified configuration of the workstation in case of *rnh* = 65 cm.

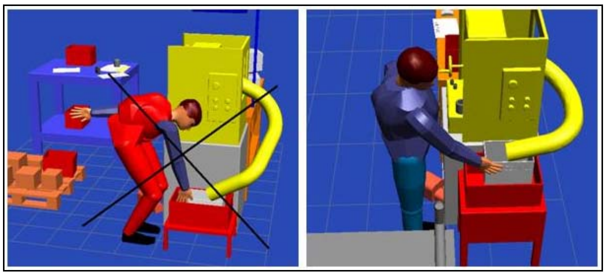

Figure 6: Alternative workstation configuration (ring nuts bin height)

Let us consider now the factors levels interactions. Table 3 reports the following results:

- The interaction between □ and *rmh* gives, as result, a greater PF (PF = 137.7 N, increase 13.5%), the second category stress level for the working postures and a smaller EE (EE = 1363.0 Kcal, reduction 7.9%). Note that the PF is still lower than the AF and the SL associated to the working postures still falls in the second category.
- The interaction between □and *rnh* gives as result a greater PF (PF = 135 N, increase 11.3%), the second category stress level for the working postures and a smaller EE (EE = 1398.3 Kcal, reduction 5.5%). As in the previous case, the PF is still lower than the AF and the SL still falls in the second category.
- The interaction between *rmh* and *rnh* gives as result a greater PF (PF = 151.4 N, increase 24.8%), the first category stress level for the working postures and a smaller EE (EE = 1362.4 N, reduction 7.9%). Note that the PF is now greater than the AF (it means no ergonomic risks during lifting activities) and the SL falls in the first category (it means the SL associated to working postures is optimum).
- The interaction among all the factors levels guarantees the best workstation ergonomic performances. In effect, table 3 reports the following results: the PF = 151.4 N (the highest value, the increase is 24.8%), the SL for the working postures falls into the first category and the EE = 1321.9 Kcal (the lowest value, the reduction is 10.7%). Note that by choosing this workstation configuration the PF > AF (the ergonomic risks related to lifting activities can be accepted), the working postures are characterized by the first category stress level (no further ergonomic interventions are required).

Figure 7 shows the real Seal Press Workstation, the simulation model actual configuration and the effective ergonomic design (final design) respectively on the left, middle and right part. Note that the support table has been completely removed and the length of the main worktable has been slightly increased. In addition, the raw materials are now placed on a hand-operated dolly and the height of the bin containing the ring nuts exiting from the Seal Press machine is greater than the initial height in the actual workstation configuration.

Figure 7: Effective ergonomic redesign of the Seal Press workstation

6. SEAL PRESS PRODUCTIVITY ENHANCEMENT: AN ADVANCED APPROACH

The second goal of the paper is to propose an advanced approach for the productivity enhancement of the Seal Press workstation by comparing four different work methods in terms of process time. To this end, the approach advanced in this research work uses the simulation model of the Seal Press workstation for supporting the comparison of the different work methods. The evaluation of the process time is achieved by using the most widely used work measurement tools: the Methods and Time Measurement (MTM) and the Maynard Operation Sequence Techniques (MOST). In the section 6.1 the authors apply the MTM and MOST to the Seal Press workstation.

6.1 Seal Press workstation productivity enhancement

In this section the authors propose the application of MTM and MOST to the Seal Press workstation.

As already stated in section 2, each work method is characterized by a different number of ring nuts/fittings to be simultaneously inserted into the seal press machine: one single ring nut/fitting (scenario 1) two, three and four ring nuts/fittings simultaneously inserted (respectively scenario 2, scenario 3 and scenario 4) by taking into consideration a typical Shop Order made by 12 ring nuts/fittings.

The operations performed in the Seal Press workstation have been subdivided in 4 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 printing operations.
- *Macro-activity 2* – the operator moves the component (ring nut/fitting) into the Seal Press machine and starts the printing phase.
- *Macro-activity 3* – after the printing phase the operator performs visual checks and place the components into a bin;
- *Macro-activity 4* – the operator completes the Shop Order (setting the status of "end of the operation" on the informative system, moving all the components to the successive workstation.

The authors suppose to subdivide the macro-activities in two different categories: preparation operations (performed just once for the entire Shop Order) and cyclic operations. The macro-activities 1 and 4 (workstation set-up and Shop Order completion) belong to the first category. The macro-activities 2 and 3 belong to the second category. Note that the number of the ring nuts/fittings being simultaneously inserted into the seal press machine does not affect the time of the preparation operations. On the contrary, the work method used by the operator affects both frequency and time of cyclic operations. In effects, higher number of ring nuts/fittings inserted into the seal press machine, correspond to: (1) lower frequency of the cyclic operations, (2) higher time for inserting components into the machine, (3) higher time for the printing phase, (4) higher time for removing the components from the machine. On the contrary, lower number of ring nuts/fittings inserted into the seal press machine, correspond to: (1) higher frequency of the cyclic operations, (2) lower time for inserting components into the machine, (3) lower time for printing phase, (4) lower time for removing the components from the machine. Table 4 and table 5 consist of process times for each macro-activity (expressed in seconds and evaluated respectively by using MTM and MOST).

Table 6 and table 7 consists of process times for each scenario expressed in seconds and evaluated respectively by using MTM and MOST (a scenario includes a Shop Order made by 12 ring nuts/fittings).

The third scenario (three ring nuts/fittings simultaneously inserted into the Seal Press machine) is characterized by the minimum Shop Order process time (according to both MTM and MOST). As concerns the

MTM, the total process time is 201.92 s (about 3 min and 22 s). Note that the process time improvement is about 41% respect to the first scenario, 9.6% respect to the second scenario and 13.9% respect to the fourth scenario. As concerns the MOST, the total process time is 208.82 s (about 3 min and 28 s).

Note that the process time improvement is about 38,8% respect to the first scenario, 7% respect to the second scenario and 11.6% respect to the fourth scenario. Figure 9 shows the scenarios comparison in terms of process times evaluated by means of MTM (left side) and MOST (right side). Let us focus on the Seal Press

Table 3: Simulation results for the Seal Press workstation

Seal Press Workstation						
α	**rmh**	**rnh**	**Burandt Schultetus**		**OWAS**	**Garg**
			Permissible Force (N)	**Actual Force (N)**	**Stress Level**	**Energy Expenditure (Kcal)**
0	17	30	121.3	147.2	3	1480.0
0	17	65	135.0	147.2	2	1438.8
0	86	30	137.7	147.2	2	1403.6
0	86	65	151.4	147.2	1	1362.4
π/2	17	30	121.3	147.2	3	1439.4
π/2	17	65	135.0	147.2	2	1398.3
π/2	86	30	137.7	147.2	2	1363.0
π/2	86	65	151.4	147.2	1	1321.9

Table 4: MTM results for each macro-activiy in the Seal Press Workstation

MTM				
Seal Press Workstation	***1ring nut/fitting***	***2ring nuts/fittings***	***3ring nuts/fittings***	***4ring nuts/fittings***
Macro-activity 1	3.19	3.19	3.19	3.19
Macro-activity 2	9.42	11.23	15.48	23.84
Macro-activity 3	17.76	23.44	31.21	49.24
Macro-activity 4	11.97	11.97	11.97	11.97
Total (s)	42.34	49.83	61.85	88.24

Table 5: MOST results for each macro-activiy in the Seal Press Workstation

MOST				
Seal Press Workstation	***1ring nut/fitting***	***2ring nuts/fittings***	***3ring nuts/fittings***	***4ring nuts/fittings***
Macro-activity 1	3.41	3.41	3.41	3.41
Macro-activity 2	9.54	11.48	16.01	23.78
Macro-activity 3	17.54	23.22	32.14	49.51
Macro-activity 4	12.81	12.81	12.81	12.81
Total (s)	43.30	50.92	64.37	89.51

Table 6: MTM results for each scenario of the Seal Press Workstation

MTM				
Preparation	***Macro-activity 1***	***Macro-activity 4***	***Total Preparation Time (s)***	
Scenario 1	3.19	11.97	15.16	
Scenario 2	3.19	11.97	15.16	
Scenario 3	3.19	11.97	15.16	
Scenario 4	3.19	11.97	15.16	
Cyclic	***Macro-activity 2***	***Macro-activity 3***	***Total Cyclic Time (s)***	
Scenario 1	113.04	213.12	326.16	
Scenario 2	67.38	140.65	208.03	
Scenario 3	61.92	124.84	186.76	
Scenario 4	71.52	147.72	219.24	
	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Total time (s)	341.32	223.19	201.92	234.4

workstation productivity and let us consider the total time required for completing a Shop Order (process time), the 8 hours shift time and the operators' allowance for physiological needs, fatigue and delay (calculated as 20% of the process time).

Regardless of the work measurement tools (MTM or MOST), the workstation productivity (in the third scenario) is about 118 Shop Orders per day. The productivity enhancement is about 69% respect to the first scenario, 11% respect to the second scenario and 16 % respect to the fourth scenario.

Table 7: MOST results for each scenario of the Seal Press Workstation

MOST				
Preparation	***Macro-activity 1***	***Macro-activity 4***	***Total Preparation Time (s)***	
Scenario 1	3.41	12.81	16.22	
Scenario 2	3.41	12.81	16.22	
Scenario 3	3.41	12.81	16.22	
Scenario 4	3.41	12.81	16.22	
Cyclic	***Macro-activity 2***	***Macro-activity 3***	***Total Cyclic Time (s)***	
Scenario 1	114.48	210.48	324.96	
Scenario 2	68.88	139.32	208.2	
Scenario 3	64.04	128.56	192.6	
Scenario 4	71.34	148.53	219.87	
	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Total time (s)	341.18	224.42	208.82	236.09

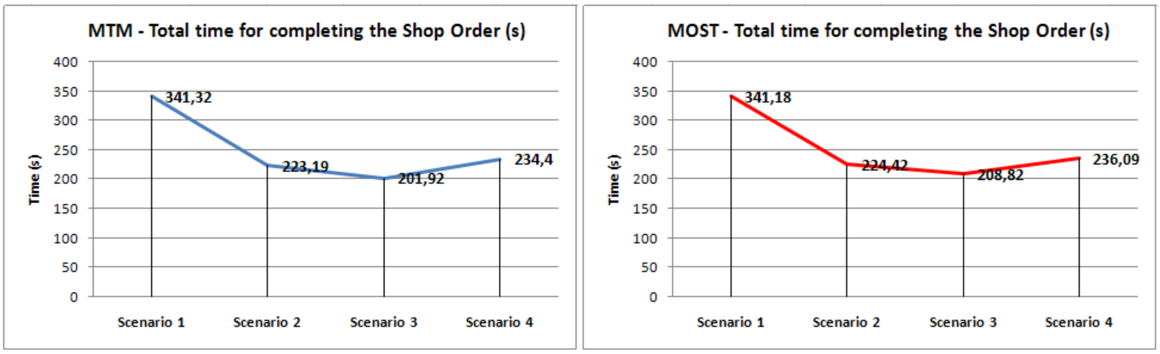

Figure 9: Scenarios comparison

CONCLUSIONS

The paper advances the ergonomic redesign and the productivity enhancement of a real workstation (the Seal Press workstation) within an industrial plant. In the first part of the paper, the authors propose a methodology based on the investigation of multiple workstation configurations by using three different ergonomic standards: the Burandt Schultetus, the OWAS and the Garg analysis. Each workstation configuration is characterized by different levels of three critical design factors: the evaluation of all the factors levels combination required a factorial experimental design executed by using a 3D simulation model of the Seal Press workstation (the simulation model includes a human model able to recreate all the worker's operations). For each workstation configuration the impact of the design parameters has been determined and discussed in terms of permissible force for lifting activities, stress levels for working postures and energy expenditure. As concerns workstation productivity enhancement, the authors use the simulation model of the Seal Press Workstation for supporting the comparison of the four work methods. Each work method is characterized by a different number of ring nuts/fittings to be simultaneously inserted into the seal press machine. The simulation model calculates the process time related to each work method by means of the most widely used work measurement tools (MTM and MOST). Such evaluation allows to choose the best work method in terms of ring nuts/fittings to be simultaneously inserted into the seal press machine.

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