# WORKPLACES EFFECTIVE ERGONOMIC DESIGN: A LITERATURE REVIEW

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**ABSTRACT**

The paper proposes a literature review on the workplaces ergonomic effective design in the manufacturing systems and industrial plants sector. The main objective is to provide the reader with an accurate overview on the main scientific approaches proposed (during the last decades) by researchers and scientists working in this specific area. The paper passes through the description of several research works as they run through the literature. The initial search identifies a huge number of articles which were reduced to about 50 studies based on content and quality. The descriptive analysis of the literature reveals heterogeneity in the content of the scientific approaches due to the different principles, methods and tools applied for improving the interaction between humans and their working environment.

Keywords: manufacturing systems, ergonomics, effective ergonomic design, workplaces, workstations.

## 1. INTRODUCTION

The high complexity of manufacturing systems in terms of interaction between humans and their working environment continuously provides challenging problems for researchers working in this specific field.

An ergonomic approach to the design of an industrial workplace (ergonomic effective design) attempts to achieve an appropriate balance between the worker capabilities and worker requirements, to optimize worker productivity, as well as provide worker physical and mental well-being, job satisfaction and safety.

During the last years this research area has became more and more important due to its effects on system efficiency and productivity. In this regards, different research works have been proposed and several scientific approaches have been developed trying to achieve the ergonomic effective design of the workplaces belonging to the manufacturing system.

It is the intent of the paper to present a literature review on this specific area clustering the high quality research works according to the scientific approach they propose. In this regards, the authors identify three different scientific approaches based on different principles, methods and tools. The description of the research works for each scientific approach represents the core part of this literature review.

Before getting into the details of the study, in the sequel a brief overview of each section of the paper is presented. Section 2 describes the scientific approach based on the use of video tape systems. Section 3 presents a number of research works using several ergonomic standards for achieving the ergonomic effective design. Section 4 discusses about the third scientific approach based on the interaction between ergonomics and work measurement aspects. Section 5 presents briefly an ergonomic effective design application example based on a scientific approach proposed by the authors.

Finally, the last section reports the conclusions that summarize the scientific contribution of the work.

## 2. VIDEO TAPE SYSTEMS FOR THE ERGONOMIC WORKPLACES DESIGN

The evaluation of the ergonomic risk levels affecting a workplace represents the first step for achieving the ergonomic effective design. In industrial plants, for existing workplaces the ergonomic risks can be assessed through observation (Karhu et al. 1981). In this context, a video tape based approach is easy and time saving (Vedder and Hellweg, 1998). In effect the interference of video camera with the tasks being performed by the observed worker is minimal. However, note that if the operations require to move to different plant areas, multiple cameras have to be used. Neverthless, during the years a number of research works proposes the use of the video tape systems as main tool for the ergonomic effective design. Such research works are here presented as they run through the literature.

Hagström et al. (1985) and Engström et al. (1987) use video recording respectively in the meat-cutting and vehicle design research areas.

Das and Sengupta (1996) provide the guidelines for a good workstation design by observing workstation procedures and collecting data by video taping the operators as well (an application example is proposed in the field of supermarket checkstand workstations).

Engstrom and Medbo (1997) develop a video based observation method for time data collection and analysis of work time consumption. The method allows to measure the efficiency of the production system by separating between value-added and not value-added works activities.

Vedder (1998) presents an easy-to-use video-based posture analysis method for workplaces, where tasks interference have to be minimized and postures have to be observed over a longer period of time. The author identifies hazardous postures and their causative factors and then decides the appropriate re-design measures.

The approach based on video tape systems for data collection and analysis has been also used by Kadefors et al. (2000). In this case the video film is displayed on the computer terminal for evaluating (by using an interactive procedure) workers' ergonomic problems (pain and discomfort).

Neumann et al. (2001) present a video-based posture assessment method capable of measuring trunk angles and angular velocities in industrial workplaces.

Forsman et al. (2002) propose a method based on video recordings synchronized with physiological measurements for characterizing work time consumption and physical work load of manual work. The method was developed throught two casies studies within the Swedish automotive industry. It is concluded industrial interventions could be designed by means of such method.

Actually the use of the video tape could generate a vast amount of recordings which are tedious to analyze. Even in this case, such scientifc approach allows to identify the tasks causing hazardous postures and suggest appropriate redesign measures as well. In this regards, Vedder and Hellweg (1998) record twenty days and nights shifts in a fibbre spinning area of a chemical plant by means of a stationary camera. A very long analysis of the videotapes allows them to provide the guidelines for a correct redesign of the system under consideration.

## 3. ERGONOMIC STANDARDS

The second scientific approach regards the application of ergonomic standards as support tools for the ergonomic effective design. Among the ergonomic standards, the following have to be regarded as the most widely used: the NISOH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for *National Institute for Occupational Safety and Health*); the OWAS analysis for analyzing working postures (OWAS stands for *Ovako Working Analysis System*); the RULA method for estimating the risks of work-related upper limb disorders (RULA stands for *Rapid Upper Limb Assessment*);

In the sequel research works are introduced according to the ergonomic standard used. The section consists of 5 subsections. Three subsections for presenting the research works concerning the most widely used ergonomic standards (one subsection for each ergonomic standard). The forth subsection is then reported for introducing the less used ergonomic standards: the OCRA methods for analyzing worker's exposure to tasks featuring various upper-limb injury risk factors (OCRA stands for *Occupational Repetitive Action*); the Garg analysis for assessing the energy expenditure for performing an operation; the Burandt-Schultetus analysis for lifting tasks involving a large number of muscles. In conclusion, the last subsection proposes the research works based on the integration of several ergonomic standards.

Before getting into the details of each subsection, a brief description of the ergonomic standard under consideration is provided.

### 3.1. NIOSH 81 and NIOSH 91 method

NIOSH 81 and NIOSH 91 evaluate the ergonomic risk levels affecting the lifting tasks.

The NIOSH 81 method calculates the action limit (AL) and the maximum permissible limit (MPL). AL is the weight value which is permissible for 75% of all female and 99% of all male workers. MPL is the weight value which is permissible for only 1% of all female and 25% of all male workers.

The NIOSH 91 analysis, additionally to the NIOSH 81, includes the recommended weight limit (RWL) and the lifting index (LI). The RWL is the load that nearly all healthy workers can perform over a substantial period of time for a specific set of task conditions. The LI is calculated as ratio between the real object weight and the Recommended Weight Limit.

Further information about the cited ergonomic standards can be found in Niosh Technical Report (1981) and Waters et al. (1994).

Let us present the research works aiming at achieving the workplace ergonomic effective design by means of NIOSH analysis.

Grant et al. (1995) analyze musculoskeletal trauma among preschool workers in the United States by means of NIOSH methods. The authors evaluate the possible causes of back and lower extremity pain among 22 workers at a Montessori day care facility. Finally they present recommendations for modifying the workplace and changing the organization and methods of work as well.

Grant et al. (1997) evaluate the magnitude of lifting hazards in the shipping department of a wooden cabinet manufacturing company. The representative lifts are analyzed using the Revised National Institute for Occupational Safety and Health (NIOSH) Lifting Equation. The results suggest that work in shipping department imposes a high level of physical demand, which may increase the risk of work related back pain and other musculoskeletal injury. In this regards the authors provide recommendations for reducing physical workload through automation, introduction of mechanical assists, changes in work organization and more frequent job rotation.

Mital and Ramakrishnan (1999) analyze a complex manual materials handling task, which involved lifting, turning, carrying, and pushing activities, by using both the old and revised NIOSH lifting guidelines (Niosh Technical Report 1981; Waters et al., 1993) as well as the guidelines provided by Mital et al. (1993, 1997).

Hermans et al. (1999) evaluate the effect of using a mechanical device on physical load during the end assembly of cars. According to the NIOSH equation, 8 out of 10 of the tasks should only be performed by trained workers and preferably with tools.

Chung and Kee (2000) analyze lifting tasks using the 1991 revised NIOSH lifting equations for a fire brick manufacturing company with a high prevalence of low back injuries. The results suggest that the tasks should be redesigned ergonomically to eliminate the risk factors that may cause low back injuries. The authors propose a tasks redesign based on making horizontal locations closer to a worker or reducing the symmetric angles.

Temple and Adams (2000) use the NIOSH analysis in order to establish ergonomic acceptable limits for an industrial lifting station. Through the analysis of several factors the authors define a cumulative lifting index and use such index for detecting ergonomic problems during lifting tasks. They successively modify the lifting station for reducing ergonomic risks and preventing lower back related injuries.

Lin and Chan (2007) carry out an ergonomic workstation re-design for reducing musculoskeletal risk factors and musculoskeletal symptoms among female's workers of a semiconductor fabrication room. By means of walk-through observations of the working environment, discussing with company's managers and using NIOSH analysis, the authors identify the most prevalent and urgent ergonomic issues to be resolved and modify the layout of the workplace for reducing ergonomic hazards.

**3.2. OWAS Analysis**

The OWAS analysis carries out a qualitative analysis of the worker's movements during a working process. The analysis calculates the stress associated to each body posture and classifies them in one of the following four stress categories:

- Category 1: the stress level is optimum, no corrective interventions are required;
- Category 2: the stress level is almost acceptable, corrective interventions are necessary in the near future;
- Category 3: the stress level is high, corrective interventions are required as soon as possible;
- Category 4; the stress level is very high, corrective interventions must be carried out immediately.

Further information about the cited ergonomic standard can be found in Kharu et al. (1981).

During the last years several research works have adopted the OWAS analysis for evaluating the workers body postures.

Carrasco et al. (1995) describe an ergonomic evaluation of three different designs of checkouts workstation, which require the operators to stand when they scan the products, pack them into plastic bugs and transfer the packed bags to the customer. Musculoskeletal load and exertion associated with the different checkouts are measured using the OWAS analysis. The results of the evaluation form the basis of recommendations for an improved workstation design.

Nevala-Puranen et al. (1996) analyze physical workload and strain when milking in a parlor. OWAS analysis is accomplished for evaluating the postural load. The authors assert that the information of this study can be utilized in the development of the working environment of milking.

Scott and Lambe (1996) implement the OWAS in a poultry industry. The authors apply the ergonomic analysis highlighting wrong postures and providing the guidelines for an improved workstation design.

Van Wendel de Joode et al. (1997) conduct a workplace survey in order to quantify the physical load in a population of male workers in two ships maintainace companies. The Ovako Working Postire Analizyng System is used for measuring the postural load. The results reveal that awkward postures of the back occurr in 38% of the work time and the stress on the neck/shoulder region due to one or both arms above shoulder level is present in 25% of the work time.

White and Kirby (2003) use the OWAS analysis for evaluationg health-care workers in the methods used to fold and unfold selected manual wheelchairs. The authors conclude that many of the methods used include bent and twisted back postures that are known to be associated with a high risk of injury.

Perkiö-Makelä and Hentilä (2005) estimate the physical workload and strain of dairy farming in loose housing barns. The feeding and removing manure and spreading of bedding are analyzed by means of OWAS analysis. On the basis of the analysis results, the authors provide some recommendations for the building of new loose-housing barns (for example, providing enough space for automated feeding and cleaning systems).

**3.3. RULA method**

RULA is a postural targeting method for estimating the risks of work-related upper limb disorders. A RULA assessment gives a quick and systematic assessment of the postural risks to a worker. The analysis can be conducted before and after an intervention to demonstrate that the intervention has worked to lower the risk of injury. The RULA action levels give you the urgency about the need to change how a person is working as a function of the degree of injury risk.

- Action level 1: it means the person is working in the best posture with no risk of injury from their work posture;
- Action level 2: it means that the person is working in a posture that could present some risk of injury from their work posture, so this should be investigated and corrected;
- Action level 3: it means that the person is working in a poor posture with a risk of injury from their work posture, and the reasons for

this need to be investigated and changed in the near future to prevent an injury;

- Action level 4: it means that the person is working in the worst posture with an immediate risk of injury from their work posture, and the reasons for this need to be investigated and changed immediately to prevent an injury.

A full description of the RULA method is contained in McAtamney and Corlett (1993).

In the last decades, several authors have used the RULA method as support tool for achieving the workplace ergonomic effective design.

Gonzáles et al. (2003) evaluate the relationship between the ergonomic design of workplaces and achieved product quality levels. In particular, a metalworking firm with ISO-9002 certification was selected, and its quality results were analyzed with respect to reprocessed and rejected parts after varying the initial work method on the basis of the results of an ergonomic evaluation by means of RULA. It was concluded that a reduction in ergonomic problems implies better quality records.

Massaccesi et al. (2003) investigate work related disorders in truck drivers using the RULA method. A sample of 77 drivers, of rubbish-collection vehicles who sit in a standard posture and of roadwashing vehicles, who drive with the neck and trunk flexed, bent and twisted, is studied. After the analysis, the authors conclude that ergonomic interventions aiming at modifying the truck's workstation are recommended for preventing musculo-skeletal disorders.

Choobineh et al. (2004) propose ergonomic intervention in carpet mending operations. Seventy-two menders are questioned regarding musculoskeletal disorders. Based on the problems found, a new workstation is developed and eight menders are asked to work in the new workstation. They are observed and evaluated with the RULA technique and their opinion on the improvement is asked working on four frequently seen tasks. The new workstation improves working posture noticeably.

Shuval and Donchin (2005) propose an application of the RULA method in the HI-TECH industry. Results of the RULA underline the need for implementing an intervention program focusing on arm/wrist posture.

### 3.4. Others ergonomic standards

Here the OCRA method, the Garg and Burandt Schultetus analysis are briefly described.

#### 3.4.1. OCRA methods

The Occupational Repetitive Action methods (OCRA) analyze worker's exposure to tasks featuring various upper limb injury risk factors (repetitiveness, force, awkward postures and movements, lack of recovery periods). The OCRA methods are the OCRA index and the OCRA checklist. The OCRA index can be predictive of the risk of upper extremity work related musculoskeletal disorders in exposed populations. It is generally used for the (re)-design or in depth analysis of workstations and tasks (Colombini et al. 1998, 2002). The OCRA checklist, based on the OCRA index, is simpler to apply and is generally recommended for the initial screening of workstations featuring repetitive tasks (Occhipinti et al. 2000; Colombini et al. 2002).

The OCRA method is based on a consensus document of the International Ergonomics Association (IEA) technical committee on musculoskeletal disorders (Colombini et al. 2001). Further information regarding OCRA methods can be found in Occhipinti and Colombini (1996).

#### 3.4.2. Burandt Schultetus analysis

The Burandt-Schultetus analysis allows evaluating the load limits for a specific working posture (keeping into consideration the weight of the grasped objects). The Burandt-Schultetus analysis is usually applied to lifting activities in which a large number of muscle groups are involved. The main result is the maximum weight (Permissible Limit, PL) that the worker can lift. The Permissible Limit can be evaluated by using equation (1):

$$PL = G * C * AJ * RF \tag{1}$$

- $G$ is a coefficient for the worker's gender;
- $C$ is a coefficient for the worker's health condition;
- $AJ$ is a coefficient for worker's age and type of job;
- $RF$ is the reference force.

Note that the $AJ$ (Age and Job factor) depends on the effort type (i.e. static or dynamic), the worker's age, the shift time (i.e. 8 hours) and the effort frequency. The $RF$ takes into consideration the torso weight movement, the hands use (i.e. one or two hands), the number of persons performing the operation (i.e. one or two persons), the effect of secondary jobs and the maximum force. In turns, the torso weight movement depends on the lower and upper grasp height and motion frequency; the maximum force depends on body size class (anthropometric measure), upper grasp height and distance of grasp from the body.

The maximum permissible force is then compared to the current actual force (AF) being exerted. Three different cases can be distinguished:

- Case 1: the maximum permissible force does not exceed the actual force then an ergonomic intervention is required;
- Case 2: the maximum permissible force is equal to the actual force, then a corrective intervention is necessary in the near future;
- Case 3: the actual force is lower than the maximum permissible force, then no ergonomic intervention is required.

Further information can be found in Schultetus (1980).

### 3.4.3. Garg analysis

The Garg analysis calculates the total amount of energy spent during the manual operations. The analysis splits up a specified operation into smaller steps calculating for each of them the Energy Expenditure (EE); the sum of these separate steps represents the total Energy Expenditure for the activity. As input parameters, such analysis requires information concerning load weight and body weight as well as gender of the working person. Further information can be found in Garg (1976).

### 3.5. Ergonomic standards integration

In order to achieve relevant ergonomic improvements some authors propose an effective ergonomic design based on the integration of different ergonomic standards.

Wright and Haslam (1999) investigate manual handling risks within a soft drinks distribution centre using the OWAS postural analysis and the NIOSH equations. The authors compare two working methods involving pallets and cages. The analysis detects significant manual handling risks and reports musculoskeletal disorders.

Jones et al. (2005) present an examination of three common pub occupations (bartending, waitressing and cooking). Risk of musculoskeletal injury is evaluated for the three occupations analyzed by means of RULA method and NIOSH Lifting Equation. Finally recommendations for reducing the risks are provided.

Jones and Kumar (2007) quantify physical exposure information collected from 15 saw-filers in four sawmill facilities by means of the RULA, REBA, ACGIH TLV, Strain Index and OCRA procedures based on multiple posture and exertion variable definitions.

Russell et al. (2007) compare the results of different ergonomic standards (NIOSH, ACGIH TLV, Snook, 3DSSPP and WA L&I) for evaluating ergonomic risks in lifting operations. Each ergonomic standard is applied to a uniform task (lifting and lowering two different types of cases) with the aim of choosing the best work methods by appropriately interpreting the results of the ergonomic analysis.

## 4. ERGONOMICS AND WORK MEASUREMENT

Another important issue to take into consideration in the workplace design is the strict relation between the concepts of work measurement and ergonomics. The measurement of the work aims at evaluating the time standard for performing a particular operation. On the contrary, the concept of ergonomics is often indicated as study of work (Zandin 2001) and studies the principles that rule the interaction between humans and their working environment. In effect, the work measurement and the ergonomics affect each other: ergonomics changes affect the time required for performing the operations as well as any change to the work method affects the ergonomics of the workplace.

Different research works have taken into consideration both ergonomics and work measurement aspects.

Das and Sengupta (1996) propose a workstation design procedure based on the optimization of the worker and total system productivity as well as worker physical and mental well-being, job satisfaction and safety.

Resnick and Zanotti (1997) underline that ergonomic principles can potentially be used to improve productivity as well. An application example is proposed for remarking that a workstation can be designed to maximize performance and reduce costs by considering both ergonomics and productivity together.

Laring et al. (2002) develop an ergonomic complement to a modern MTM system called SAM. In particular the authors propose a tool that gives the possibility to estimate simultaneously the consumption of time in the envisaged production and the biomechanical load inherent in the planned tasks.

Udosen (2006) propose a tools for construction, evaluation and improvement (in terms of ergonomic and time issues) of a workplace for the assembly of a domestic fan.

Another important issue cited in many research works developed in the last decades of the 20th century is the application of the ergonomic standards and work measurement methods directly in the real system.

Usually such approach requires a huge amount of money and time for exploring all the possibilities in terms of workstations configurations, work assignment, works methods, etc. Therefore researchers and practitioners started to develop research works by using Modelling & Simulation (M&S) as support tool for choosing correctly, for understanding why, for diagnose problems and explore possibilities (Banks, 1998). From an animation point of view, the simulation provides virtual three-dimensional environments that strongly support the workstation ergonomic design. A three-dimensional visualization is certainly an important support that can be used to detect problems and critical factors that otherwise would be difficult to detect.

Wilson (1997) proposes an overview on attributes and capabilities of virtual environments (devoted to support ergonomic design) and describes a framework for their specification, development and evaluation.

Marcos et al. (2006) aim at reducing the stress of the medical staff during laparoscopic operations simultaneously increasing the safety and efficiency of an integrated operation room. To this end, the authors develop a simulator by integrating the CAD software (CATIA) and the simulation software (RAMSIS).

Over the years the M&S approach has became more and more appealing thanks to the numerous advantages such as the possibility to study ergonomic issues at the earliest stages of design in order to avoid potential future ergonomic redesign in the real-world system.

Feyen et al. (2000) propose a PC-based software program (based on the integration of a Three-Dimensional Static Strength Prediction Program, 3DSSPP, for biomechanical analysis with a widely used computer-aided design software package, AutoCAD). As consequence, the authors are able to study ergonomic issues during the design phase taking into consideration different design alternatives.

Chang and Wang (2007) propose a method for conducting workplace ergonomic evaluations and re-design in a digital environment with the aim of preventing work-related musculoskeletal disorders during assembly tasks in the automotive sector.

Longo et al. (2006) use M&S in combination with ergonomic standards and work measurement for the effective design of an assembly line still not in existence. The authors propose a multi-measures approach with the aim of obtaining a different work assignment to each workstation, better line-balancing and better ergonomic solutions.

Santos et al. (2007) propose an ergonomic study on working positions in a manufacturing company (by using the simulation software eM-Workplace) and providing, as result, remarkable ergonomic improvements. In particular, the study is based on the integration of several ergonomic standards (NIOSH 81, NIOSH 91, Burandt Schultetus, OWAS and Garg analysis) and the Method Time Measurements (MTM) methodology.

## 5. APPLICATION EXAMPLE

The authors propose their scientific approach for the ergonomic effective design by means of a real case study. The case study regards the most critical workstation (the Seal Press workstation) of a manufacturing process devoted to produce high-pressure hydraulic hoses. The effective ergonomic design of the workstation takes into consideration both ergonomic risks and work measurement. The actual workstation configuration is compared with several alternative scenarios by using a well planned experimental design. To this end, the authors propose an approach based on multiple design parameters and multiple performance measures with the aim of considering both the interaction of the operators with their working environment and the work methods. In addition, the authors use Modelling & Simulation (M&S) as a support tool for implementing a three-dimensional environment capable of recreating, with satisfactory accuracy, the real Seal Press Workstation.

### 5.1. Simulation model development

The first step was the development of a simulation model capable of recreating the production process of the workstation. The simulation model development involves three different phases: collecting data concerning the Assembly area (data collection phase), reproducing the real system in the virtual environment from both a geometric and work method point of view (simulation modelling phase) and verifying if the simulation model is an accurate representation of the real system (validation phase).

Figure 1 shows a panoramic view of the virtual layout of the Seal Press Workstation.

Figure 1: Simulation model of the Seal Press workstation

### 5.2. Design of Experiment

A well-planned Design of Experiments (DOE) is used for supporting the comparison of the actual configuration of the Seal Press workstation with alternative operative scenarios (different workstation configurations). The DOE requires to select a set of design parameters (a group of factors to be changed during the simulation runs). 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).

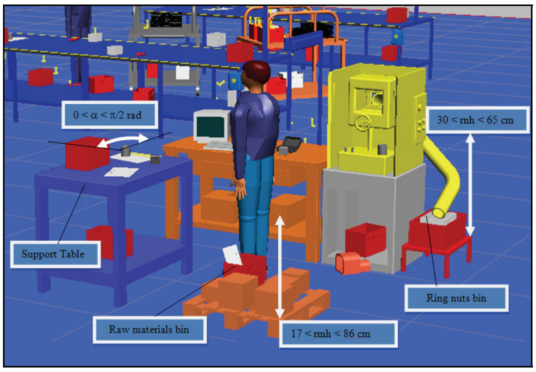


Figure 2: Actual configuration of the Seal Press workstation (with design parameters).

Note that the figure 2 shows the actual configuration of the Seal Press workstation.

Table 1 reports factors and levels; the factors levels combinations create a comprehensive set of different scenarios in terms of workstation layout and tools disposition (8 different configurations to be tested with the simulation model).

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 |

As previously stated, the effective ergonomic design of a workstation consider a multi-measures approach based on ergonomic and work measurement 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). The most important performance measure for work measurement is the process time; we use the Method and Time Measurement methodology (MTM-1) for evaluating the process time.

### 5.3. Simulation results and workstation final configuration

The experiments before described (8 different configurations to be tested with the simulation model) have been completely carried out by using the simulation model, monitoring for each alternative scenario the multiple performance measures. Table 3 reports the simulation results.

The authors analyze the effects of each design parameter on the performance measures and according to such analysis develop a new workstation configuration.

Figure 3 shows the effective ergonomic re-design of the Seal Press workstation (final design).

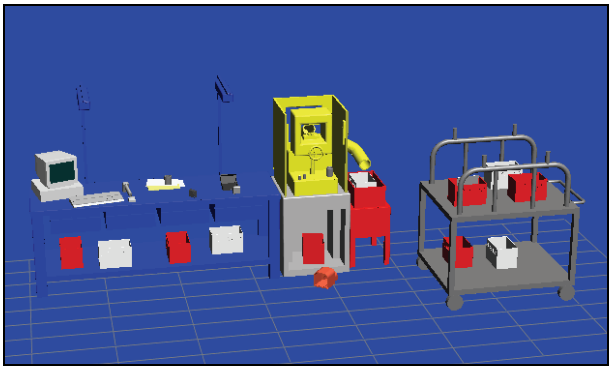

Figure 3: Effective ergonomic design of the Seal Press workstation.

Further research works on workstation ergonomics effective design using Modeling & Simulation combined with ergonomic standards and work measurement can be found in Longo et al. (2005), Longo et al. (2006-a), Longo et al. (2006-b), De Sensi et al. (2007-a), De Sensi et al. (2007-b), Bocca and Longo (2008).

## 6. CONCLUSIONS

The main objective of the paper is to present a literature review concerning the ergonomic effective design. The initial search identifies a huge number of articles which were reduced to about 50 studies based on content and quality. The research works were clustered according to the scientific approach they propose. In this regards, the authors identify three different scientific approaches based on different principles, methods and tools.

Several authors propose an approach based on the use of video tape systems for evaluating the ergonomic risks affecting the workplaces. Note that such evaluation represents the first step for achieving an ergonomic effective design.

Table 3: Simulation results

| *Seal Press Workstation* | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | **Burandt-Schultetus** | | **OWAS** | **Garg** | **MTM-1** |
| **α** | **rmh** | **rnh** | **Permissible Force (N)** | **Actual Force (N)** | **Stress Level** | **Energy Expenditure (Kcal)** | **Process Time (sec)** |
| 0 | 17 | 30 | 121.3 | 147.2 | 3 | 1480.0 | 470.32 |
| 0 | 17 | 65 | 135.0 | 147.2 | 2 | 1438.8 | 464.75 |
| 0 | 86 | 30 | 137.7 | 147.2 | 2 | 1403.6 | 460.23 |
| 0 | 86 | 65 | 151.4 | 147.2 | 1 | 1362.4 | 454.66 |
| π/2 | 17 | 30 | 121.3 | 147.2 | 3 | 1439.4 | 456.71 |
| π/2 | 17 | 65 | 135.0 | 147.2 | 2 | 1398.3 | 451.14 |
| π/2 | 86 | 30 | 137.7 | 147.2 | 2 | 1363.0 | 446.62 |
| π/2 | 86 | 65 | 151.4 | 147.2 | 1 | 1321.9 | 441.05 |

A number of research works propose the application of ergonomic standards. The review identifies NISOH 81, NIOSH 91, OWAS and RULA as the most widely used ergonomic standards.

The third scientific approach regards the interaction between ergonomics and work measurement aspects. In this regards, the authors identify two different thought tendencies: (i) the application of ergonomic standards and work measurement methods directly in the real system; (ii) the application of ergonomic standards and work measurement methods by means of Modelling & Simulation (M&S) as support tool for the ergonomic effective design.

Finally, the literature review is completed with a scientific approach proposed by the authors for achieving the ergonomic effective design of workplaces. Note that such scientific approach is explained by means of an application example.

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