Scientific approaches for the industrial workstations ergonomic design: a review

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KEYWORDS

Industrial workstations, industrial design, modeling & simulation, computerized models

ABSTRACT

Over the last years ergonomic problems have received growing attention due to their effects on industrial plants efficiency and productivity. Many theories, principles, methods and data relevant to the workstation design have been generated through ergonomics research. However, no general frameworks have been suggested, yet. The time seems to be right for presenting a review paper on the scientific studies whose aim is to achieve the ergonomic design of industrial workstations. To this end, it is the intent of the authors to provide the readers with an accurate overview on the main scientific approaches proposed (during the last two decades) by researchers and scientists working in this specific area. In particular, two main scientific approaches have been identified. The first approach is based on the direct analysis of the real workstations, while the second one uses computerized models to design workstations ergonomically. Each scientific approach will be presented through a detailed description of the research works it involves. The initial search identifies a huge number of articles which were reduced to about 60 studies based on content and quality. Note that the research works description represents the core part of this literature review.

INTRODUCTION

Ergonomics is the application of scientific principles, methods, and data drawn from a variety of disciplines for the development of engineering systems in which people play a significant role (Kroemer 1994). The Institute for Occupational Ergonomics (1999) defines ergonomics as an understanding of the needs, limitations, and abilities of people, and the use of this understanding for the design of products and environments in which people live. Over the last two decades, ergonomics researchers and practitioners have devoted considerable resources to solve the problems associated with the ergonomic design of the working environment. Designers of workplaces have usually three major tasks: one, integrating information about processes, tools, machines, parts, tasks, and human operators; two, satisfying design constraints which often conflict; and three, generating a design acceptable to all parties involved. However, while completing these tasks, designers often have difficulty incorporating ergonomics information about the human operators into their designs. Note that, although today the tasks or processes are being mechanized or automated as the technology has advanced, many tasks are still performed manually in several industrial settings (Chung and Kee 2000). In this context, it seems to be clear that matching the abilities of the operator with the task requirements as well as with working environment physical constraints are important aspects to be faced within the ergonomic workplace design. Over the years many theories, principles, method and data relevant to the workstation design have been generated through ergonomics research. However, no general frameworks have been suggested, yet. It is the intent of the authors to provide the readers with an accurate overview on the main scientific approaches proposed (during the last two decades) by researchers and scientists for achieving the ergonomic design of industrial workstations. In particular, two main scientific approaches have been identified. The first approach is based on the direct analysis of the real workstations, while the second one use computerized models to design workstations ergonomically. Each scientific approach will be presented through a detailed description of the research works it involves. Note that the research works description represents the core part of this literature review.

The paper is structured as follows. Firstly, the international state of the art on the scientific approaches addressing the ergonomic workstation design is proposed. Note that the state of the art description is splitted into two different subsections: the first subsection presents the research works related to the approach based on the direct analysis of the real workstations, while the second one describes the research studies that use computerized models to design workstations ergonomically. Then, some gaps are identified and ongoing research solutions are presented together with some application examples in different manufacturing areas. Finally, a conclusion is drawn.

Proceedings 24th European Conference on Modelling and Simulation ©ECMS Andrzej Bargiela, Sayed Azam Ali
David Crowley, Eugène J.H. Kerckhoffs (Editors)
ISBN: 978-0-9564944-0-5 / ISBN: 978-0-9564944-1-2 (CD)

STATE OF THE ART OVERVIEW

An ergonomic approach for the design of industrial workstations is the attempt 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). In order to help industrial engineers to achieve effective workplace design, a number of research works have been developed. This section presents an overview of this studies by organizing them into two approaches: the first approach is based on the direct analysis of the real workstations, while the second one use computerized models to design workstations ergonomically. Such studies have been identified by means of Google Scholar, Scopus, and Scirus as research engines. A first run has been made by typing (sometimes alone, some other times combined) the keywords "industrial workstations", "industrial design", "ergonomic effective design", "workstation design", "ergonomic standards", "modelling & simulation", and "computerized models". At a second stage, the abstracts of the peer-reviewed and of the specific-interest-groups publications outcomes have been read, to evaluate the actual pertinence of the abstracts to the research issue. At a later stage, starting from the evaluation of the abstracts only the more relevant papers have been read and classified/considered in the literature review.

Ergonomic design by workstation direct analysis

Here the scientific approach based on the direct analysis of the real workstations is presented by a detailed description of the research studies proposed over the last two decades.

A number of studies in literature try to achieve the ergonomic effective design of manufacturing system workstations by using based observation methods for collecting data, i.e. observation of the worker performing the manufacturing operations is used for collecting information about the work methods. In order to achieve the ergonomic effective design of the manufacturing system workstations, such research works analyze the videotape of the work methods and assume a trial and error methodology (in effect the design methodology is never supported by a well-defined experimental design). The final ergonomic design of the workstations depends on researcher's experience and his/her knowledge about the manufacturing system. Das and Sengupta (1996) provide the conceptual basis for a good workstation design by presenting a systematic ergonomic approach capable of determining the workstation dimensions and layout. The workstation design procedure starts off with the collection of the workstation relevant data through direct observation and videotaping and ends up with constructing a prototype workstation based on the final design. Moreover the authors apply the systematic ergonomic approach to the design of a supermarket checkstand workstation. Kadefors and Forsman (2000) present a method for ergonomic evaluation of complex manual work based on interactive operator assessment of video recordings. The video recordings are displayed on a computer terminal, and the video recorded operators assess the work by clicking on virtual controls on the screen, whenever a situation inducing pain or discomfort appears. The application of the method to a workshop belonging to Volvo Cars shows it is easy to understand and operate by practitioners as well as it provides structured information on the high priority tasks that are relevant and useful for instance in industrial interventions and industrial workstation design. Neumann et al. (2001) identify the trunk position and movement velocity as important parameters to be considered and measured in industrial settings design. To this end, the authors present a video-based posture assessment method capable of measuring trunk angles and angular velocities in industrial workplaces. The video analysis workstation consists of a desktop computer equipped with digital video capture and playback technology, a VCR, and a computer game type joystick. An application example confirms the importance of these factors and demonstrates the utility of a video based method to measure them. Forsman et al. (2002) present a method to amalgamate technical and human aspects in the industrial workstation design. The technical aspects are represented by results from a computer- and video based observation method for time data collection. The human aspects comprised physiological measurements of muscular activity, and of body postures and movements. The integrated procedure allows work activities to be assigned significantly different levels of physical work load. These different levels may be used to predict physical work load in the design and change of production systems.

The possibility to integrate based observation methods and specific ergonomic standards was also investigated by researchers. Even in this case the based observation methods are used as data collection tools, while the ergonomic standards allow the researchers to investigate and analyze the ergonomics of the workplace. Among the ergonomic standards, the following have to be regarded as the most widely used:

- the NIOSH 81 and the NIOSH 91 equations for lifting tasks (NIOSH stands for National Institute for Occupational Safety and Health)
- the OWAS for analysing working postures (OWAS stands for Ovako Working Analysis System)
- the Burandt–Schultetus analysis for lifting tasks involving a large number of muscles
- the Garg analysis for assessing the energy expenditure (EE) for performing an operation

Further information about the cited ergonomic standards can be found in Garg (1976), Schultetus

(1980), Niosh Technical Report 81-122 (1981), Karhu et al. (1981), the Scientific Support Documentation for the Revised 1991 NIOSH Lifting Equation (1991), Waters et al. (1994).

Scott and Lambe (1996) implement the OWAS in a perchery system. The workers have been video recorded performing normal duties within the perchery and the positions of the body have been assessed using the OWAS analysis. Several wrong working postures have been identified and suggestions, in light of the OWAS results, have been proposed for an improved perchery design. Engström and Medbo (1997) develop a procedure for the workstation design that integrates prototype equipment used for workstation data collection and ergonomic analysis for working postures evaluation (OWAS). The prototype equipment consists of a video camera, a video tape recorder, a TV monitor and a personal computer. The OWAS technique carries out a qualitative analysis of the worker's movements during a working process and calculates the stress associated to each body posture. Note that the procedure promotes a design based on empirical data considering ergonomic aspects and work performance analysis. Vedder (1998) presents an easy-to-use video-based posture analysis method for workplaces where task interference has to be minimized and postures have to be observed over a longer period of time. The different worker postures have been video recorded by using a stationary camera and then evaluated by using the OWAS posture analysis system. Such method allows to identify hazardous postures and their causative factors so that appropriate re-design measures can be taken. Herman et al. (1999) propose a practical methodology to analyze the influence of material handling devices on the physical load during the end assembly of cars. First the worker under observation describes the manual actions in detail while performing the task and explains why he does or does not use the tool (important information is recorded in writing), then the NIOSH method (1991) is used to analyze the lifting and lowering aspects of each task, taking into account several distance measurements and the lifting frequency. Finally the authors, according to objective and subjective results of the data analysis, propose several recommendations to the company regarding the use of existing tools for the end assembly of cars. Shuval and Donchin (2005) examine the relationship between ergonomic risk factors and upper extremity musculoskeletal symptoms at a Hi-Tech company in Israel. Ergonomic risk factors were assessed through direct observation of employees' postures at their workstations using the rapid upper limb assessment (RULA) tool. Results of the RULA observations indicate excessive postural loading with no employee in acceptable postures so that the authors point out the need for implementing an intervention program. Lin and Chan (2007) evaluate the effect of ergonomic workstation design on musculoskeletal risk factors (MRFs) and musculoskeletal symptoms (MSSs) reduction among female semiconductor fabrication room (fab) worker. 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.

In addition to the previous studies, the following use interviews as support tools for the workstation data collection. Grant et al. (1995) describes an investigation conducted to identify and evaluate possible causes of back and lower extremity pain among the workers of a day care facility. The investigation is based on the use of questionnaire, video tape systems and NIOSH lifting equations. Questionnaire results indicated that back/pain discomfort was a common musculoskeletal complaint. Observation and analysis of the work activities indicated that employees spend significant periods of time kneeling, sitting on the floor, squatting, or bending at the waist. The revised NIOSH lifting equation indicated that several employed performing lifting tasks may be at increased risk of low back pain and lower extremity injury. Finally the authors present recommendations for reducing or eliminating these risks by modifying the workplace and changing the organization and methods of work. Grant et al. (1997) analyze lifting tasks at a cabinet company. Workers interviews have been used to assess the magnitude of the musculoskeletal problems. Videotape systems have been used for observing material handling activities and finally the revised NIOSH lifting equation has been used for analyzing representative lift tasks. The research study identifies several lifting hazards and specific recommendations for reducing physical workload have been suggested. Chung and Kee (2000) propose a procedure based on the use of a questionnaire survey as well as the 1991 revised NIOSH lifting equations for the evaluation of lifting tasks frequently performed during fire brick manufacturing processes. A questionnaire survey shows that weight of the load significantly influence the incidence of back injuries. The NISOH lifting equation identifies risk factors that may cause musculoskeletal disorders among the operators. The research results suggest that several tasks should be redesigned ergonomically simply by making horizontal locations closer to a worker or by reducing the asymmetric angles. White and Kirby (2003) propose an ergonomic evaluation of health-care workers in a rehabilitation center. The authors present a procedure based on the integration of questionnaire, video tape systems and OWAS analysis. Workers completed a brief questionnaire that elicited information on the subject's age, gender and occupation. The videotape system was used to ensure relevant qualitative data, as well as providing data that could be coded and scored. The OWAS analysis was used for identifying the wrong working postures. The research study reveals that health-care workers use a variety of methods, many of which include bent and twisted back postures that may carry a risk of injury. Note that the authors do not provide any information concerning the improvement of the operators work methods.

The literature overview analysis reveals that the majority of the studies developed for facing the ergonomic effective design problem are based on the single use of specific ergonomic standards. Examples of such research works are proposed on the sequel as they run through the literature. Carrasco et al. (1995) use the OWAS analysis for evaluating three different designs of checkout workstation, which require the operator to stand when they scan the products, pack them into the plastic bags and transfer the packed bags to the customer. The evaluation points out significant musculoskeletal load and exertion associated with the different checkouts and several suggestions have been presented for an improved workstation design in terms of postural load reduction and productivity increase as well. Van Wendel de Joode et al. (1996) use the OWAS analysis in order to quantify workers physical load within two ship maintenance companies. Postural load was measured and awkward postures were identified affecting workers back, neck/shoulder and arms. On the light of such results, the authors reduced workers physical load by proposing several technical adaptations and applications as well as by enlarging task rotation. 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. González et al. (2003) apply the RULA method for the ergonomic evaluation of industrial workplace. The authors propose a methodology that consists of three steps: the first includes the selection of the profile of the firm to study, while the second and the third will, respectively, consist in the choice of the workplace and the gathering and treatment of the representative data of the levels of ergonomics and quality. Having identified the ergonomic problems (by using the RULA method) within a metalworking firm, a series of improvements were then implemented, analyzing whether significant alterations in quality levels took place in parallel as a result of these ergonomic improvements. Massaccessi et al. (2003) investigate work-related disorders in truck drivers using the RULA method. Such method allowed to perform a rapid and correct evaluation of the loading to which neck and trunk are exposed while driving. RULA evidences that the posture adopted in street washing trucks during cleaning operations was associated with a major risk for back pain, especially with non-adjustable seats. On the light of the analysis results, the authors recommend ergonomic interventions aiming at modifying the truck's workstation with a view to prevent musculo-skeletal disorders. Choobineh et al. (2004) use the RULA technique for carrying out ergonomic intervention in carpet mending operation. The authors identify several ergonomic problems affecting workers knees, back and shoulders and propose a new workstation configuration improving working postures noticeably. Mäkelä and Hentilä (2005) estimate the physical workload and strain of dairy farming in loose housing barns. The authors use the OWAS analysis for evaluating workers postures during the feeding and removing manure and spreading of bedding activities. On the basis of the OWAS results, the authors provide some recommendations for building new loose-housing barns providing enough space for automated feeding and cleaning systems.

In order to achieve achieving multiple and simultaneous ergonomic improvements, several researchers propose the integration of two or more ergonomic standards. Jones et al. (2005) use the RULA method and the NIOSH lifting equation in order to examine three common pub occupations (bartending, waitressing and cooking) with the aim of determining the biomechanical loads of job tasks, assessing the potential risk of musculoskeletal injury in these job tasks, and recommending injury prevention measures. Jones and Kumar (2007) compare the results of 5 ergonomic risk assessment methods (RULA, REBA, ACGIH TLV, Strain Index and OCRA) in a repetitive high-risk sawmill occupation, examine the effect of multiple definitions of the posture and exertion variable on the risk assessment methods, describe the variability in risk assessment scores between workers, examine the ability of risk assessment component scores to differentiate between facilities with significantly different levels of exposure, and examine the association between risk output and recorded incidence rates. 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.

Finally, another important issue to take into consideration is the relation between the concepts of work measurement and ergonomics. In effect the work measurement and the ergonomics affect each other: ergonomic interventions affect the time required for performing the operations as well as any change to the work method affects the ergonomics of the workplace. Such relation was investigated by some researchers. Resnick and Zanotti (1997) underline that ergonomic principles can potentially be used to improve productivity as well. The authors propose an application example 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 that gives the production engineer a first insight into the future ergonomic quality of a planned production. 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. The method was tested at the Torslanda final assembly plant of Volvo Car Corporation and at the ITT Flygt plant. The results show that the method identifies the events causing high biomechanical load on the operator so that they can be redesigned.

Ergonomic design by computerized models

In the past, workplace ergonomic considerations have often been reactive, time-consuming, incomplete, sporadic, and difficult. Usually the analysis of the real workstations is quite expensive (in terms of money and time) because it requires to ‘‘disturb’’ processes and activities of the manufacturing system. There are now emerging technologies supporting simulation-based engineering to address this in a proactive manner. These allow the workplaces and the tasks to be simulated even before the facilities are physically in place. Over the years, researchers propose several computer aided methodologies to face the ergonomic effective design problem within industrial workstations. A number of such existing research works considers virtual environment (VE) as a potential tool to support the ergonomic design of workstations. 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. According to the author, virtual environment has potential as a tool to support many types of ergonomics contribution, including assessments of office and workplace layouts giving egocentric viewpoints for testing consequences for reaching and accessing, reconfiguring and testing alternative interface designs, training for industrial and commercial tasks, and teaching in special needs or general sectors. Jayaram et al. (2006) propose two distinct approaches to link virtual environments (VE) and quantitative ergonomic analysis tools in real time for occupational ergonomic studies. The first approach aims at creating methods to integrate the VE with commercially available ergonomic analysis tools for a synergistic use of functionalities and capabilities. The second approach aims at creating a built-in ergonomic analysis module in the VE. The authors present the two integration strategies and test them using case studies conducted with real industrial company. Chang and Wang (2007) propose a method of conducting workplace ergonomic evaluations and re-design in a digital environment for the prevention of work-related musculoskeletal disorders. First, the real workplace and human task can be converted into the digital environment through building digital mock-ups and using a motion capture technique. Second, the ergonomics evaluation models can be applied to evaluate the assembly task in the digital environment. The method has been applied to evaluate automobile assembly tasks and some ergonomic improvements have been implemented during assembly tasks in the automotive sector. Note that the proposed method allows to verify the improvements in the digital space and then implement them in the real space.

During the 1990s many researchers developed virtual models to work with CAD systems in order to achieve the workstation ergonomic effective design. SAFEWORK (Fortin et al., 1990) is one example of this technique. More commonly, human form models and analysis tools have been designed for access from within a CAD system. These systems take advantage of the designers familiarity with the terminology, techniques, and command structures of commercially available CAD programs. Examples include MINTAC (Kuusito and Mattila,1990), ErgoSHAPE (Launis and Lehtela, 1992), HUMAN (Sengupta and Das 1997), RAMSIS (Seidl 1997), and commercial systems such as ANYBODY (Porter et al. 1995) and Mannequin. Ulin et al. (1990), Grobelny (1990), Kayis and Iskander (1994) and Jung and Kee (1996) describe other examples.

Moreover the literature analysis reveals also that the majority of the research studies propose three-dimensional CAD programs with built-in ergonomics assessment capabilities. Such ergonomic CAD systems have been described in the literature and among the others the following has to be regarded as the most known: APOLIN (Grobelny et al. 1992), CAAA (Hoekstra 1993), COMBIMAN and Crew Chief (McDaniel 1990), Deneb/ERGO (Nayar 1995), ERGOMAN (Mollard et al. 1992), JACK (Badler et al. 1995), and TADAPS (Westerink et al. 1990). In addition to the previous cited research works, Feyen et al. (2000) propose a PC-based software program that allows a designer to quantify a worker's biomechanical risk for injury based on a proposed workplace design. The program couples an established software tool for biomechanical analysis, the Three-Dimensional Static Strength Prediction Program (3DSSPP), with a widely used computer-aided design software package, AutoCAD. The software program allows the authors to study ergonomic issues during the design phase taking into consideration different design alternatives. The use of this 3DSSPP/AutoCAD interface in the proactive analysis of an automotive assembly task is described and the results compared with an independent assessment using observations of workers performing the same task.

The workstation ergonomic design has been also achieved by using commercial simulation software available for ergonomic studies. Hanson (2000) presents a survey of the following three tools: ANNIE-Ergoman, JACK, and RAMSIS, used for human simulation and ergonomic evaluation of car interiors. The tools are compared and the comparison shows that all three tools have excellent potential in evaluating car interiors ergonomically in the early design phase. Gill et al. (1998) provide an analysis of the Jack (a simulation software used for human simulation and ergonomic evaluation of car interiors) to highlight the usefulness for applications in the manufacturing industry. Eynard et al. (2000), describe a methodology using Jack to generate and apply body typologies from anthropometric data of Italian population and compare the results with a global manikin. The study identified the importance of using accurate anthropometric data for ergonomic analysis. Sundin et al. (2000), present two case studies to highlight benefits of the use of Jack analysis, one in the design phase of a new Volvo bus and the other in the design phase of the Cupola, a European Space Agency (ESA) module for manned space flights for the International Space Station. Marcos et al. (2006) aim at reducing the stress and strain of the medical staff during laparoscopic operations, and, simultaneously, at increasing the safety and efficiency of an integrated operation room (OR) by an ergonomic redesign. This was attempted by a computer simulation approach based on the integration of the CAD software (CATIA) and the simulation software (RAMSIS). The proposed approach, after defining ergonomically ideal postures, allows to evaluate the optimal solutions for key elements of an ergonomic design of the OR (position and height of the image displays, height of the OR table and the Mayo stand) with special regard to the different individual body size of each member of the team. Cimino and Mirabelli (2009) use the simulation software eMWorkplace to develop a simulation model capable of recreating, with satisfactory accuracy, the evolution over the time of the real workstations. The actual workstation configuration is then analyzed and several workstation modifications are incorporated in the simulation model. The effects (ergonomic risk level) of those changes are analysed for designing an improved workstation configuration in terms of interaction between operators and their industrial working environment. Cimino et al. (2009) address the industrial workstations design issue by proposing an approach based on the integration of Modeling & Simulation tools, several ergonomic standards and the most known work measurement tools. The Modeling and simulation tools allow to implement a three-dimensional environment capable of recreating in a virtual environment the real workstations. The ergonomic standards consent to evaluate the ergonomic risks level within the system being considered. The work measurement tools permit to calculate the time required for performing all the workstations operations. The effective design of the workstations is achieved by using the simulation model for comparing workstations' alternative configurations designed according to the authors' experience. The comparison is based on ergonomic and time indexes related to the ergonomic standards and the work measurement tools. Such comparison allows to choose the workstations final configurations. Finally, Bruzzone et al. (2004) develop a methodology for modeling the human behavior in industrial facilities.

Gap identification and ongoing researches

The high number of studies addressing the workstation design problem reveals that huge research efforts have been carried out in this specific area over the last two decades. However, it seems to be clear that even if research activities have brought significant and high quality results, some further improvements could be achieved. In effect, the literature analysis points out that the majority of the research works assume a trial and error methodology in order to design the workstations ergonomically: the final ergonomic design of the workstations usually depends on researcher's experience and his/her knowledge about the manufacturing system and it is never supported by a well defined experimental design. On the basis of such considerations, further researches can be carried out for giving a significant contribution to the state of the art related to this specific area. A new methodology based on the integration of commercial simulation software, specific standards for the ergonomic analysis and a well planned Design of Experiments (DOE) could be developed. The commercial simulation software would allow to recreate in a virtual environment the real workstations in order to not "disturb" the industrial processes. The ergonomic standards could be applied through the simulation model and would allow to evaluate the ergonomic risks level of the workstations under consideration. Finally, a well defined experimental design (DOE) would allow to generate different workstation configurations; the evaluation of each workstation configuration in terms of ergonomic risks level, carried out by using the ergonomic standards, would allow to choose the final design of the considered workstation.

Workstations Ergonomic Effective Design: some application examples

In the following the authors propose some application examples in which they used the approach described in the previous section to achieve the effective ergonomic design of real industrial workstations.

Figure 1 depicts the 3D virtual model of an assembly line for heaters production (Longo and Mirabelli, 2009). The effective design of assembly line is achieved by simultaneously considering assembly workstations time balancing and ergonomic issues and risks in each workstation. In this case the simulation model is used for a twofold objective: (i) to carry out time analysis in order to increase the assembly line output (heaters/time unit); (ii) reduce ergonomic risks such as musculoskeletal disorders and wrong working postures.

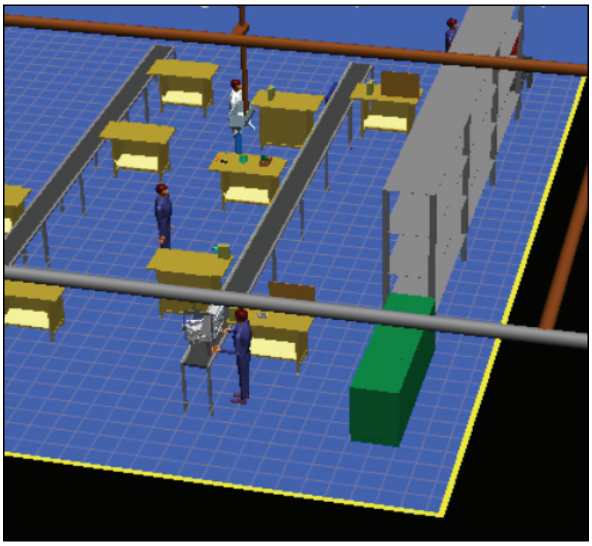

Fig. 1 – 3D Virtual Simulation model of an assembly line for heaters production

Figure 2 depicts a 3D virtual simulation model of a workstation devoted to assemble high pressure hydraulic hoses (Cimino et al. 2009). After a preliminary phase conducted within the real industrial plant (with the aim of collecting data and information to be used for simulation model implementation) the authors used the simulation model combined with Design of Experiment for investigating the behaviour of multiple ergonomic performance measures under the effect of multiple design parameters.

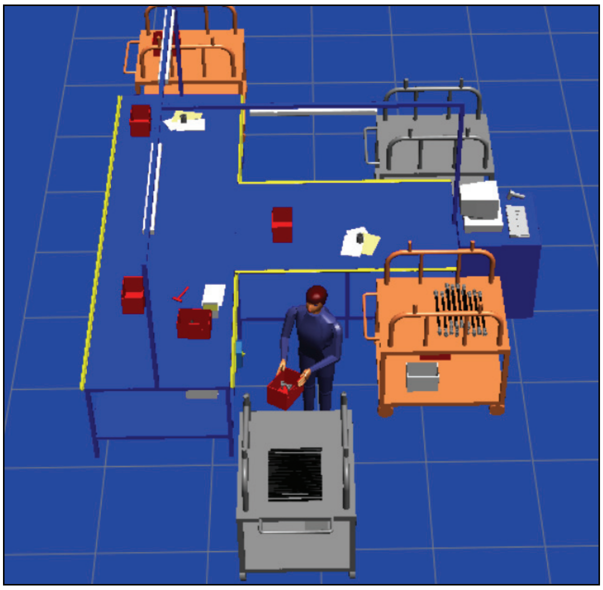

Fig. 3 – 3D virtual simulation model of an assembly workstation devoted to assemble high pressure hydraulic hoses

In this case some of the simulation results include the following: 19% reduction of the total amount of energy required for performing assembly operations, about 14% reduction of the total assembly time, new T-shape layout for the assembly workstation and reduction of not-allowed lifting activities.
Finally figure 3 depicts two workstations devoted to produce leathers goods (De Sensi et al., 2007). In this case simulation is used for the validating the new workstations modular design proposed by the company top management (according to the initial simulation results obtained by the actual workstations layout). The animation during the simulation ha been used for detecting ergonomic problems that otherwise would be difficult to detect (i.e. wrong working postures and wrong disposition of tools).

Fig. 3 – Modular design for two workstations used for producing leather goods.

CONCLUSION

The main objective of the paper is to present a literature review concerning the ergonomic effective design of industrial workstations. The initial search identifies a huge number of articles which were reduced to about 60 studies based on content and quality. Such studies have been identified by means of Google Scholar, Scopus, and Scirus as research engines. A first run has been made by typing (sometimes alone, some other times combined) the keywords "industrial workstations", "industrial design", "ergonomic effective design", "workstation design", "ergonomic standards", "modeling & simulation", and "computerized models". At a second stage, the abstracts of the peer-reviewed and of the specific-interest-groups publications outcomes have been read, to evaluate the actual pertinence of the abstracts to the research issue. At a later stage, starting from the evaluation of the abstracts only the more relevant papers have been read and classified/considered in the literature review. The research works were clustered according to the scientific approach they propose. In this regards, the authors identify two different scientific approaches based on different principles, methods and tools. The first approach is based on the direct analysis of the real workstations, while the second one use computerized models to design workstations ergonomically. Finally, the literature review is completed with the identification of some gap and a brief description of ongoin research activities that give a significant contribution to the actual state of the art. To this end three different application examples in three different manufacturing areas (heaters production, high pressure hydraulic hoses production and leather goods production) are briefly presented and discussed.

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