INDUSTRIAL WORKSTATIONS DESIGN BASED ON DIGITAL HUMAN MODELLING AND SIMULATION: A REVIEW

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Abstract
Despite the advances in the manufacturing process automation, human operators still continue to play a central role in the definition and performance of most of the production systems operations. DHMS can be used to build models for production systems where abilities of the operators are related to the task requirements. This paper provides for a general framework and includes a review of successful cases studies where the purpose is to design industrial workstations combining ergonomics and an engineering approach. The objective is to provide with a starting point for more research and with a classification scheme for DHMS based studies. As a result, this paper will help the reader to understand how a DHMS study can be usefully developed in different sectors and by means of different methods and tools.

1. Introduction
Over the last two decades, researchers and practitioners have devoted considerable resources to solve the problems associated with the effective design of industrial and manufacturing working environments.
An ergonomic approach for the design of industrial workstations is (i) the attempt to achieve an appropriate balance between the worker's capabilities and worker's requirements and (ii) the attempt to provide the worker with physical and mental well-being, job satisfaction and safety (Das and Sengupta, 1996). Designers of workplaces have usually three major tasks:

- the integration of information about processes, tools, machines, parts, tasks, and human operators;
- the satisfaction of design constraints which often conflict each other;
- the generation of acceptable workplace designs to all parties involved.

However, while completing these tasks, designers face the difficult task to incorporate ergonomic information about the human operators into their designs. Note that, although today tasks and processes are 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 clear that matching the abilities of the operator with the task requirements as well as with working environment and physical constraints are important aspects to be necessarily considered within the effective workplace design.
Many theories, principles, methods and data relevant to the workplace design have been proposed over the years thanks to the invaluable works of researchers and practitioners. In particular, three main scientific approaches have been identified: the first and the second are based on the use of ergonomic and work measurement methodologies; while the third one deals with the integration of ergonomic and work measurement methodologies with the most widely used Digital Human Modelling & Simulation (DHMS) tools.
The use of computer-aided techniques, specifically the use of DHMS, has proven to be very useful to overcome some difficulties arising in workplace design. Simulation can be used as a problem solving tool for creating an artificial history of the system, analyzing its behaviour, choosing correctly, understanding why, diagnosing problems and exploring possibilities (Banks, 1998). Moreover DHMS aims at capturing experts' knowledge in different areas including anthropometry, mechanical work capacity, human kinematics and kinetics, work physiology, visual process and motion control. When integrated with Virtual Environment, DHMS facilitates the virtual evaluation of workstations layout, workflow simulation, assembly accessibility, human reach,

clearance and strength capability studies and safety analysis (Stephens and Jones, 2009).
In next section, a classification scheme for models for DHMS-based workplace design is presented. Then, previous researches on workplace design by means of human models is reviewed and classified. Finally, the conclusions and directions for further research are given in Section 4.

2. A classification framework for DHMS approaches and tools

Research studies in DHMS (that involve workplace design) has always provided researchers and practitioners with challenging problems. The study characteristics, analysis and evaluation tools, modelling approaches and results achieved have been revised. In fact, a survey of the literature shows that many different solutions have been proposed in different industry sectors.

2.1. Study characteristics, aim and results

The use of digital human models to improve ergonomic design started in the 60s at the aeronautics industry (Chaffin, 2001). In effect, only large companies within the aeronautic and automotive sectors are the usual manufacturing environments where ergonomic assessment simulation has been successfully conducted (Landau, 2000; Chaffin, 2001). They are characterized by a high level of standardization. Applying simulation in other different manufacturing systems proposes specific problems that the different researchers have tried to solve in different ways. Besides, DHMS-based studies ask for different levels of detail according to whom is carrying out the study -practitioners or researchers- (Berlin et al, 2009). The way that the study is structured and communicated is the primary reason that slows down the transferring from laboratories to real manufacturing systems or even to commercial software tools Therefore, industrial sectors where the study takes place, and researchers institutions will be highlighted, as well as their goals and results.

2.2. Modelling approach, analysis and evaluation tools.

As said in Bubb (2009), there are more than 150 ergonomic manikins, although, three of them, Jack, Safework and Ramsis, represent more than 95% of the market. These manikins are offered in a wide selection of commercial simulation based packages. However there is still a lack of clarity about the potentialities of the analysis tools that are used jointly with the digital human model (the manikin) to achieve an effective workplace design. According to Lämkull et al. (2009-a), DHMS offers a set of analysis tools that can be divided in quantitative evaluation tools and semi-quantitative tools. Quantitative tools are used to evaluate working postures and physical workloads. These tools require as input the digital human models postures (representing an operator performing the task being analyzed) with some other information (i.e. age, health conditions, etc.) and they give as output quantitative results. These quantitative results can be related to several task characterization aspects, such as postural risk, spine compression forces, cycle time or energy expenditure, weight lifting limits, etc.. Semi-quantitative tools are used to visualize or analyze the digital human model interactions with the working environment and are usually integrated within 3D-CAD packages. Examples of semi-quantitative tools are field of vision, reach envelopes, and accessibility and clearance analysis.
Besides, several methods have been developed to guide simulation experimentation in industrial and manufacturing workstations design. The main idea is to test alternative workstations designs using simulation and selecting the most suitable design based on multi-criteria decision-making techniques or knowledge-based decision tools. In the case of the simulation of manufacturing tasks and workplaces, the relationship between the modelling stages and the experimentation phase defines the ability of the model to serve as an Input/Output element for the effective assessment of tentative solutions. Two main general approaches are presented, covering the full range of cases from the analysis of the literature: parameterized experimentation and ad hoc simulation-driven experimentation.
In parameterized experimentation model variables are properly parameterized allowing the implementation of systematic and controlled experimentation actions. In this case, modelling and experimentation are clearly different stages, although they both obtain results from the parameterized model. A typical systematic approach consists of the implementation of the Design of Experiments (DOE) framework in order to analyze different scenarios. The effort is put then in the identification of those factors (also called design parameters) that may significantly affect the performance of the workplace (or workstation) under consideration (Cimino et al.

2009). Generally, the literature only accounts for cases where geometrical and categorical factors are considered; such factors represent the position or the presence/absence of certain elements in the model. These factors may take only deterministic values – levels – which represent an initial optimization approach. The different combinations of the design parameters levels generate different workstation configurations. It is a systematic method for studying both single and simultaneous variable effects; however, the election of those factors and their levels is mostly based on experience.

Ad hoc simulation-driven experimentation also allows studying specific alternative designs aimed at improving the workstation. An expert criteria-based is the basis of this experimentation, in which changes in the workplace, organization of the task or tools can be proposed. This approach is adequate for assessing a whole set of design solutions for which their detailed parameterization would become unaffordable, due to time, cost and scope constraints. However, it relies on the designer experience and optimization techniques, because of the previously mentioned constraints, are seldom applied.

In an effort to gain a better understanding of the ways of managing ergonomics and operational requirements in workstation design by means of DHM-tools and to provide a base for future research, a review of relevant works on the topic is presented. We only describe briefly each paper. The motivation of this work is not to explain every available reference rather it is intended to provide the reader with a starting point for investigating the literature and understand different ways and solutions to face the workplace design problem in different areas and domain of application.

3. DHMS-based case studies review

The paper passes through the description of several research works, as they run through the literature, according to the methodology or scientific approach they propose. The initial search identifies a huge number of references which were reduced to about 12 articles based on contents and quality. The descriptive analysis of the literature reveals heterogeneity in the content of the scientific approaches due to the different techniques, methods and tools used for facing the workstation design problem.

In effect on each of the selected papers a DHMS tool is used for the assessment of one or several real-world workstations (a major emphasis is given to manufacturing systems for the intrinsic importance of the workstation design problem in this area). All the reviewed papers follow a process engineering approach but different industry sectors, study approaches and analysis methodologies are involved.

The scheme proposed in the sequel will be used as a classification framework to describe the reviewed models.

Table 1. Classification framework for a DHMS-based case study of a workplace design

Study characteristics
- Involved sector on the study
- Research Institution
- Year

Analysis & Evaluation tools
- Quantitative tools
- Semiquantitative tools

Modelling approach
- Commercial Tools
- Input data
- Experimentation methodology

Aim & Results
- Study approach
- Achieved results

3.1. Study characteristics, aim and results

The reviewed references describe studies that are usually carried out by universities (50%) and by Universities and private companies (33%). The most common sectors are automotive (33%) and manufacturing (33%). More details can be found in Table 1 and **¡Error! No se encuentra el origen de la referencia.**.

Table 1. References by sector case study and Research Institution

	U	R	C	U&R	C&U	Total
Automotive	1	0	0	0	3	4
Manufacturing	3	0	0	0	1	4
Healthcare	1	0	0	0	0	1
Mining	1	1	0	0	0	2
Others	0	0	0	1	0	1
Total	6	1	0	1	4	12

U: University; R: Research Center; C: Private Company; U&R: Combined University and Research Center; C&U: Combined University and Company

Reference and Id	Sector	Researcher institution	Country
[1] Feyen et al., 2000	Automotive	Industrial and Operation Engineering, The University of Michigan (USA) & Ford Motor Company (USA)	USA
[2] Ben Gal and Bukchin, 2002	Beverage & Food	Department of Industrial Engineering, University of Tel Aviv (Israel)	Israel
[3] Ambrose et al., 2005	Mining	National Institute for Occupational Safety and Health (USA)	USA
[4] Marcos et al. 2006	Medicine	Technische Universität München	Germany
[5] Chang and Wang, 2007	Automotive	Department of Industrial Engineering and Engineering Management, National Tsing Hua University (China)	China
[6] Santos et al., 2007	Furniture manufacturing	Tecnun—University of Navarra	Spain
[7] Kazmierczkak, 2007	Automotive	Autoliv Sverige AB, Ryerson University, Gothenburg University	Sweden
[8] Lämkull et al., 2009	Automotive	Volvo Car Corporation,Department of Design Sciences, Department of Product and Production Development.	Sweden
[9] Longo and Mirabelli 2009	Manufacturing	MSC-LES, University of Calabria	Italy
[10] Cimino et al. 2009	Manufacturing	MSC-LES, University of Calabria and AlfaTechnology Srl	Italy
[11] Zhang et al., 2010	Beverage & Food	(CERPIE) Research Centre for Corporate Innovation, UPC (Technical University of Catalonia)	Spain
[12] Rego et al., 2011	Mining	Integrated group for engineering research (University of A Coruna)	Spain

Table 2. References' details

Regarding the case studies goals, 92% considered ergonomics for the workplace design, and 50% considered both ergonomic and operational requirements. In some studies, safety was also considered.

Table 3. Case studies goals and results

Approach	Number	References
Ergonomic	11 (92%)	[1]; [2]; [4]; [5]; [6]; [7]; [8]; [9]; [10]; [11]; [12]
Safety	1 (8%)	[3]
Operational	7 (57%)	[2]; [3]; [6]; [7]; [9]; [10]; [11]; [12]
Results	**Number**	**References**
Layout re-arrangement	7 (58%)	[2]; [4]; [5]; [9]; [10]; [11]; [12]
Specific movements	6 (50%)	[6]; [7]; [9]; [10]; [11]; [12];
Organizational Changes	1 (8%)	[7]
Others	4 (33%)	[1]; [3]; [7]; [8];

All the results achieved as a consequence of the DHMS study were divided in four categories: layout re-arrangement, changes in specific hazardous movements, organizational changes and others.The most common proposal was the layout re-arrangement (58%). Half of the studies achieved at least two types of improvements. More details can be found in **Table 3**.

3.1. Modelling approach and analysis tools

In the following part the reviewed papers are classified and described according to the modeling approach (in particular experimentation methodology); while describing the papers information about aim and results of the study and analysis and evaluation tools are also provided.

3.1.1. Parameterized experimentation

To provide evidence on the transversality of the parameterized experimentation approach for the workstations effective design, five references in manufacturing, automotive, mining and healthcare sectors are reviewed and briefly described.

Ben Gal and Bukchin (2002) propose a methodology for the ergonomic design of workstations; an application example is given by applying the methodology to a packaging fruits workstation. The aim of the study is to maximize throughput and to create a suitable ergonomic working environment for the workers. A virtual manufacturing workstation that integrates the workstation layout with the digital human models is developed by using the eM-Power solution provided by Siemens-UGS (formerly Tecnomatix). Design of experiments is used as a systematic method to investigate the space of available solutions in terms of workstation design configurations. The parameterized simulation model gives as outcome ergonomic and operational indicators and the overall workstation assessment is done by using a multi-objective function. Finally, the response surface methodology is used to refine the better design solution. As a result, an improved layout is proposed.

Cimino et al. (2009) propose an approach based on the integration of Modeling & Simulation tools, several ergonomic standards and the most known work measurement tools to address design issues of workstations devoted to manufacture high pressure hydraulic hoses. Workstations are recreated in a virtual three-dimensional environment through the combined use of CAD and DHMS tools (specifically Rhinoceros by McNeel and eM-Workplace by Siemens-UGS). Different ergonomic risks related to working postures and lifting activities are simultaneously considered and evaluated by using ergonomic standards and methods (i.e. Niosh 81, Niosh 91, Owas analysis, Garg analysis, etc.). A full factorial design is used to guide simulation experimentation and design parameters considered include specific geometrical factors. Additionally the most used work measurement tools (MTM and MOST) are used to calculate the time required for performing workstations operations and for comparing different working methods.

Kazmierczkak et al. (2007) propose a case study of a serial-flow car disassembly facility investigating ergonomic problems, productivity and system performance enhancement. Alternative system configurations are investigated by using a combination of flow simulation and human simulation. Input data collection is based on both qualitative approaches (documents analysis, interview and data collection, etc.) and video recording. The flow simulation (that recreates the operations of the disassembly facility workstations) is based on a simulation model developed by using Simul8 (by Simul8 Corporation); the operators' exposure to peak spinal loads (the major ergonomic problem based on video analysis) was quantified using the Watbak biomechanical model (Neumann, Wells, & Norman, 1999). Finally To understand how different system configurations affect cumulative load on operators, the authors combine the biomechanical analysis with the flow simulation. The different system configuration are obtained according to a full factorial experimental design that includes up to 7 factors with two different levels.

Ambrose et al. (2005) develop a virtual human simulation model representing the interaction between underground coal mines operators and the roof bolting machines. The aim of the study is to examine the speed range of a roof bolter boom arm for different workplace scenarios and to compare which scenarios are most likely to cause injuries to miners. So, neither ergonomic nor operational requirements are being directly considered. The analysis uses both semi-quantitative and quantitative tools. Clearance, visualization and reach analysis together with time values are used to evaluate the collision probability The most relevant aspect of this work is the inclusion of randomness by means of variables that can be changed runtime during the simulation. These variables take into consideration operation features, operator anthropometrics (including risk behavior) and machine parameters; based on these parameters the possible number of contacts between the operator and the machine is estimated. The contribution of this paper to the state of the art is the use of a parameterized approach based on Design of Experiments to combine different variables and evaluate the operator injury risk under different conditions.

Marcos et al. (2006) present a computer simulation approach in which CATIA (a CAD software by 3DS) and RAMSIS (by Human Solutions) have been integrated. The work aims at reducing the stress and strain during laparoscopic operations and increasing the safety and efficiency of an integrated operation room.

In the proposed approach, first, ideal postures are defined, then the key elements of an ergonomic design of the operation room are evaluated in order to select the optimal solution. Such elements include position and height of the image displays, height of the OR table and the Mayo stand etc.

3.1.2. Non parameterized experimentation

Non parameterized experimentation for workstations design has been extensively used in many sectors, from automotive to manufacturing, from mining to fishing and healthcare. In the sequel some interesting references are reviewed. The importance of these papers is mostly related to the fact that they provide practical information on how to develop a simulation model involving digital human models (with different DHMS tool) and useful insights on how to carry out ergonomic and time analysis for workstations effective design.

Feyen et al. (2000) present a case of proactive analysis of an automotive assembly task by using the Three-Dimensional Strength Prediction Program (by University of Michigan) and the CAD software AUTOCAD (by Autodesk). The goal of such analysis is studying the convenience of using a lifting aid during the manual converter assembly task. To do so, both situations were modeled and results regarding biomechanical requirements, clearance, visual and reach features have been obtained. As a result of the study, it is suggested to avoid the use of the materials-handling device because of clearance and view interferences. For validation purposes, the study is presented together with a “traditional” study of a workplace made ten years before, with similar recommendations.

Chang and Wang (2007) develop a methodology for the workplace evaluation, and they apply this methodology to two assembly tasks in the automotive sector. An algorithm is used to connect data from a Motion Capture system to the DHMS-based model. Their results are complemented with a biomechanical model developed in Matlab. As a result, the continuous biomechanical risk (L5/S1 compression force) during the whole task is presented. RULA is used as a restriction, ensuring that the maximum postural risk is not achieved. The workstation improvements come from a specific effort of reducing the maximum L5/S1 value.

Still in the automotive sector, Lämkull et al. 2009 present a study to evaluate the use of Digital Human Modeling tools in correctly predicting ergonomic issues related to manual assembly tasks. For the purpose of the study 155 ergonomics simulation cases, in the assembly of automobiles (at Volvo Car Corporation), have been considered showing that DHM tools provide good results in case of standing and unconstrained working postures design while for more complex workstations design a greater expertise and knowledge are essential. The DHM tool used is eM-Human (with Ramsis) by Siemens-UGS. The study includes four different phases: retrospective approach for selection of ergonomic simulation cases, prospective approach for selection of ergonomic simulation cases, classification of ergonomic conditions of simulations and real outcomes, and analysis of possible explanations behind deviations between simulation results and the real outcomes in the plants.

In the manufacturing sector, interesting references can be found in Longo and Mirabelli (2009) and Santos et al. (2007).

Longo and Mirabelli (2009) take simultaneously into consideration ergonomic aspects and work measurement for the effective design of an assembly line for heater production (still not in existence) through the use of simulation. The authors propose a two-step approach. In the first step the authors design the geometric models of the heater and the geometric models of the assembly line by using the CAD software Pro-Engineer. Both the geometric models are then imported in a simulation environment provided by the simulation package eM-Workplace (by UGS-Siemens). The simulation model is completed by adding and training human models to perform the assembly operations and is used for carrying out work measurement, time and ergonomic analysis. The second step is the effective design of the assembly line. The authors propose a multi-measures approach (based on the results of work measurement and ergonomic analysis) with the aim of obtaining a different work assignment to each workstation, a better line balancing and better ergonomic solutions.

Santos et al. 2007 focus on the advantages and practical barriers involved in the implementation of 3D simulation tools in Small and Medium Enterprises. A case study based on a non-repetitive manufacturing process is considered. A simulation model has been developed by using the eM-Workplace tool (by UGS-Siemens). Three different ergonomic analyses are carried out: OWAS, the Burandt–Schultetus Hand-Arm Forced Analysis, and the LIFT Analysis. In addition a study of the working method has been conducted by using the MTM-1. In this paper is clearly shown how DHMS tools can be profitably in improving current processes but also in testing new processes before they are implemented.

As already seen for the parameterized experimentation approach, another important area of application for workstation design based on DHMS is the mining sector. Rego et al. (2010) present a multiobjective methodology combining ergonomic and operational task features in a continuous framework. A model of the slate splitter task is developed in Delmia V5 software. The evaluation involves postural risk and cycle time. As a result of an ad-hoc experimentation stage, a set of improvements are proposed. These new scenarios are modeled and quantified in terms of ergonomic and operational improvement.

Finally it is worth to say that the DHMS based approach for workstation design has been used also in some minor sectors, where usually research activities on this specific topic are very limited. Zhang et al (2010) present an approach for the workplace redesign on board fishing vessels in order to increase safety for fishermen. First, the equipment and procedures for catching, handling, and storing fish are studied so that risks can be identified and assessed. Then the work postures are simulated using the ergonomic digital human modeling system ManneQuin Pro (by NextGen Ergonomics, a PC-based, 3D human modeling software package). On the basis of results achieved whit the work postures simulation, the work environment design on board vessels is modified to prevent repetitive movements and lower back biomechanical stresses.

4. Conclusions

In this paper the use of DHMS as enabling technology is investigated, highlighting the contribution of this approach in workstations and workplace design in different industrial sectors.. Some important references in this specific area are surveyed and discussed highlighting modeling approaches, DHMS tools and analysis methodologies used.

Lessons learned include operational procedures for developing workstation simulation models including digital human models, methodologies for carrying out ergonomic and time analysis based on parameterized and non parameterized experimentation procedures.

It is neither the intent of this paper to investigate all the problems related to the workstations design nor to present all possible solutions based on DHMS. However the literature review and the related application examples should help the reader in understanding how DHMS can be profitably used for recreating workstations complexity and tackle specific problems with ad-hoc solutions.

References

Ambrose, D., Bartels, J., Kwitowski A., Gallagher S., Battenhouse T, 2005. "Computer simulations help determine safe vertical boom speeds for roof bolting in underground coal mines. Journal of safety research 36, no. 4. pp.387-97.

Banks, J., 1998. Handbook of Simulation. John Wiley and Sons, New York.

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

Berlin C., Örtengren R., Lämkull D., Hanson L.,. 2009. Corporate-internal vs. national standard – A comparison study of two ergonomics evaluation procedures used in automotive manufacturing, International Journal of Industrial Ergonomics 39, no. 6 pp. 940-946

Bubb H., Fritzsche F., 2009, A Scientific Perspective of Digital Human Models: Past, Present, and Future, from Handbook of Digital Human Modeling, Edited by Vincent G. Duffy

Chaffin, D.B. (2001), Digital Human Modelling for Vehicle and Workplace Design. Warrendale, PA, Society of Automotive Engineers. ISBN 0-7680-0687-2

Chang S.W. Wang M.J, 2007. Digital Human Modeling and Workplace Evaluation: Using an Automobile Assembly Task as an Example. Human Factors and Ergonomics in Manufacturing, 17, pp. 445-455.

Chung, M.K., Kee, D., 2000. Evaluation of lifting tasks frequently performed during fire brick manufacturing processes using NIOSH lifting equations. International Journal of Industrial Ergonomics, 25, 423-433.

Cimino A, Longo F., Mirabelli G (2009). A Multi-Measures Based Methodology for the Ergonomic Effective Design of Manufacturing System Workstations. International Journal of Industrial Ergonomics, vol. 39; p. 447-455

Das, B., Sengupta, A. K., 1996. *Industrial workstation design: a systematic ergonomics approach*. Applied Ergonomics, 27, 157-163.

Du J., Duffy D., 2007 ,A methodology for assessing industrial workstations using optical motion capture integrated with digital human models, Occupational Ergonomics 7, pp. 11-25

Feyen R., Liu Y., Chaffin D., Jimmerson G., Joseph B., 2000. Computer-aided ergonomics: a case study of incorporating ergonomics analyses into workplace design. Applied Ergonomics, 31, pp.291-300.

Fritzsche L, 2010,. Ergonomics Risk Assessment with Digital Human Models in Car Assembly : Simulation versus Real Life. Human Factors and Ergonomics in Manufacturing 20, no.4, pp. 287-299

Gill S.A. and Ruddle R.A., 1998. Using virtual humans to solve real ergonomic design problems, in: Proceedings of the 1998 International Conference on Simulation, IEEE Conference Publication 457, pp. 223–229.

Kazmierczak K., Neumann W.P., Winkel J., 2007. A Case Study of Serial-Flow Car Disassembly: Ergonomics, Productivity and Potential System Performance. Human Factors and Ergonomics in Manufacturing, Vol. 17 (4) 331–351

Lämkull D., Berlin C., Örtengren R., 2009-a, Digital Human Modeling: Evaluation Tools. Handbook of Digital Human Modeling, edited by Vincent Duffy, CRC Press

Lämkull D., Hanson L., Örtengren, R., 2009-b, A comparative study of digital human modelling simulation results and their outcomes in reality: A case study within manual assembly of automobiles, International Journal of Industrial Ergonomics 39, no. 2, pp. 428-441

Landau, K. (2000). Ergonomics Soft ware Tools in Product and Workplace Design - A review of recentdevelopments in human modeling and other design aids. Landau, K. (Ed.). Stuttgart, Germany, ISBN 3-932160-11-8.

Lin R.T. Chan C.C., 2007. Effectiveness of workstation design on reducing musculoskeletal risk factors and symptoms among semiconductor fabrication room workers. International Journal of Industrial Ergonomics, 37, pp. 35-42.

Longo F., Mirabelli G. (2009). Effective Design of an Assembly Line using Modeling & Simulation. JOURNAL OF SIMULATION, vol. 3; p. 50-60.

Marcos P., Seitz T., Bubb H., Wichert A., Feussner H., 2006. Computer simulation for ergonomic improvements in laparoscopic surgery. Applied Ergonomics, 37, pp. 251-258.

Neumann, W.P., Wells, R.P., & Norman, R.W. (1999). 4D Watbak: Adapting research tools and epidemiological findings to software for easy application by industrial personnel. In Proceedings of International Conference on Computer-Aided Ergonomics and Safety, Barcelona, Spain.

Rego Monteil, N., del Rio Vilas, D., Crespo Pereira, D., Rios Prado, R., A Simulation-Based Ergonomic Evaluation for the Operational Improvement of the Slate Splitters Work, 22nd European Modeling & Simulation Symposium, pp. 191-200, 2010

Santos, J., Sarriegi, J. M., Serrano, N., Torres, J. M., 2007. Using ergonomic software in non-repetitive manufacturing processes: A case study. International Journal of Industrial Ergonomics, 37, pp.267-275.

Stephens A., Jones M., 2009,Workplace Methods and Use of Digital Human Models", Handbook of Digital Human Modeling, edited by Duffy.

Zhang, B., Álvarez-Casado E., Tello S., Mondelo P., 2010, Using ergonomic digital human modeling in evaluation of workplace design

and prevention of occupational hazards onboard fishing vessel, (CERPIE) Research Centre for Corporate Innovation, UPC (Technical University of Catalonia)

Biography

Francesco Longo received his PhD in Mechanical Engineering from the University of Calabria; he is currently an Assistant Professor and Director of the Modelling & Simulation Center, Laboratory of Enterprise Solutions (MSC-LES). His research interests include modelling and simulation for training procedures in complex environments, supply chain management and security. He has published more than 80 papers in international journals and conferences.
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Nadia Rego Monteil obtained her MSc in Industrial Engineering in 2010. She works as a research engineer at the Engineering Research Group (GII) of the University of A Coruna (UDC) as well as studying for PhD. Her areas of major interest are in the fields of Ergonomics, Process Optimization and Production Planning.