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# APPLICATIONS AND BENEFITS OF DIGITAL HUMAN MODELS TO IMPROVE THE DESIGN OF WORKCELLS IN CAR'S MANUFACTURING PLANTS ACCORDING TO INTERNATIONAL STANDARDS

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## ABSTRACT

During last years, the car's manufacturing process has deeply changed because of several factors affected the automotive global scenario. As a consequence, design methodologies of the plant's workcells have changed. In particular, ergonomics for manufacturing system has become a key factor to improve product's quality, safety and work organization. In this paper, the authors show the approach used in Fiat Group Automobiles (FGA) based on simulation tools to analyse ergonomic aspects of work-cells already in design phase. Simulation tools allow a deep postural analysis that is one of the main criticism in the design phase. The principles of Digital Human Modeling have been used to develop an easy internal virtual manikin, the Human Model. The tool, based on ISO standards and on a worldwide anthropometric database, allows designers to simulate the most probable postures engaged by operator during work tasks as well as to validate improvements and corrective actions.

**Keywords**: Human Modeling, ergonomics design, simulation tools

## 1 INTRODUCTION

The protection of health and safety of worker is a key aspect in the design of production systems mentioned in the current Italian regulation, D.Lgs. 81/2008 (Decreto legislative, 2008). At article 15 'General measurement of protection', it affirms that the employer shall ensure 'the respect of ergonomic principles in the work organization, in job design, in equipment selection and in the definition of working and production methods, in order to minimize the adverse effects on health of monotonous and repetitive work.' The employer and designers who act on his behalf, are required to adopt suitable methodologies and tools for ensuring that workers will operate under ergonomically correct working conditions. Simultaneously, the new industrial scenario based on key factors as economics, environment, quality, safety, health and work organization requires a new concept of design.

In order to check the compliance of the design approach with current regulation and to maximize the improvements in the key areas of interest, it is appropriate and effective to make use of simulation tools since the design phase.

This objective is a great challenge considering that, according to principles reported in legislation, designers have to achieve a proper worker-work combination in order to respect capabilities and needs of all workers that may operate in the workplace.

To reach this goal, it's much more convenient both from procedural and economic point of view, to adopt robust tools in design phase. In this way it's possible to design in an ergonomically correct way and to continuously monitor if the project retains the ergonomic features reported in legislation. Working on virtual models of future cars and the corresponding production line, it's possible to make changes of in an extremely easy way because don't impact on physical objects (car parts, equipment, etc..) moreover no high costs and short times of changes enforce virtual model use (Miller and Park, 2001).

Simulation tools have to be sufficiently advanced to be adopted also in the re-design of workstations in order to revise unfavourable conditions. Flexible tools lead to achieve improvements in the working conditions as well as to respect the principle of maximum efficacy and cost-benefit balance.

The paper presents a tool based on multi body approach, developed and actually used in Fiat Group Automobiles (FGA) to analyse ergonomic aspects of work-cells already in design phase. This tool allows a deep postural analysis (for example: angle value engaged by joints, traffic light information by comparison to legislation requirements,..) and has proven to have suitable characteristics to meet the needs of proactive ergonomics as well as of corrective ergonomics.

## 2 THE SIMULATION TOOL: HUMAN MODEL

The tool, called Human Model is a simulation tool for physical ergonomic analysis that supports ergonomic design or redesign of workstations in particular on an assembly line (Geyer and Rösch, 2001). It allows designers to simulate the most probable postures engaged by operator during work tasks as well as to validate improvements and corrective actions.

The principles of Digital Human Modeling (DHM) are at the base of the development of this easy internal developed virtual manikin. Digital human modelling has a forty year old history and many software are commercial available to simulations (for examples: RAMSIS, Jack,...) that are particularly aimed at the automotive industry. These software are almost complex and need an appropriate training and a great computational time. Instead, Human Model is a simple and easily use tool, it can be used by operator with a short training and it gives real time results.

It's an electronic sheet created in Microsoft Excel environment (figure 1) with the support of Visual Basic programming language and therefore it can be integrated with other programs implemented in the same environment .

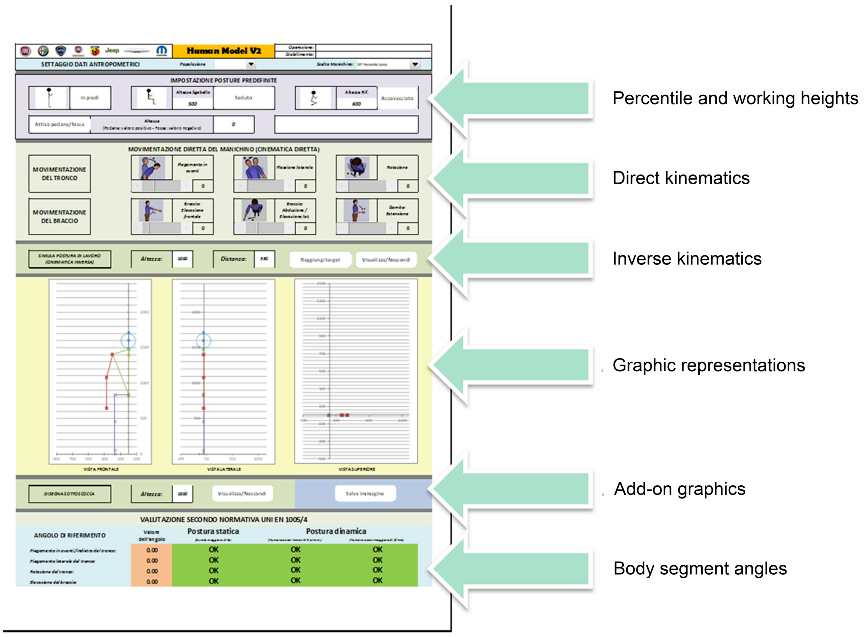


Figure 1: Human Model interface

The tool is based on Multi Body modeling which aims to study systems made of many connected bodies. Manikin structure is in fact an open kinematic chain consisting of rigid segments (body segments) connected by joints characterized by a few degrees of freedom (joints). The worksheet allows to move a 3D virtual manikin using the direct and indirect kinematics and presents some functionalities to estimate the posture of a worker at a workstation.

The principal node, called root, is the pelvis node, all other nodes are derived nodes (sons) (figure 2). This means that imposing a rotation on a upstream node has an impact on all downstream nodes and therefore on the segments connected them (Talamo, 2007).

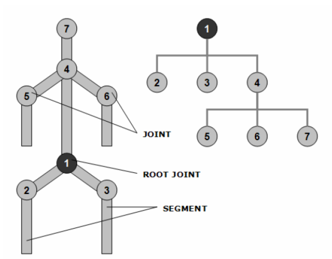


Figure 2: Joints hierarchical structure (Talamo, 2007)

Thus, posture of the upper limbs does not affect posture of inferior limbs and vice versa.
Each node is characterized by one or more degrees of freedom: pelvis and shoulder joints are represented by a spherical joint and have three degrees of freedom, the elbow joint has a degree of freedom while knee and ankle joints have no user-controllable degrees of freedom.

Joint ranges currently implemented in Human Model are data obtained from literature sources and the interaction among articular ranges of various joints is not taken into account. Relating to postures of the lower limbs, tool provides the possibility to select certain configurations: sitting, squatting and upright. The tool implements a worldwide anthropometric database to reproduce different percentile manikins. Dimensions of the segments are obtained by anthropometric measures of the workers' population and they can be changed in real time, to simulate differences for sex and percentiles.
The source from which these measures were obtained can be referred to the international standards where statistical tables provides measurements of the human body (differentiated by gender and percentile) of the working population in countries which are ISO members (ISO, 2000; ISO, 2010; Pheasant, 1996). This process ensures the best way to scale the manikin for applications in many countries of the world.

Once the gender and the anthropometric percentile of the worker have been specified and the work heights introduced, the tool simulates the postures that the worker is likely to assume during the execution of the work task and it returns angles assumed by the joints of 3D manikin and a graphic representation of posture on three planes (frontal, sagittal and transverse).
The user can choose between two distinct approaches of use:

1. Direct kinematics: working directly with the cursor on single joints, it's possible to make the manikin to assume the desired posture to reach the working point. Consequently, the tool basically works as a goniometer, computing the angles for each joint to get the desired posture.
2. Inverse kinematics: the operator introduces the presence of constraints (obstacles, restricted space, lower limbs configuration..). The software automatically places the manikin in the required posture to reach the working point. Therefore, the posture assumed by the manikin to reach the working point and returns, as for the direct kinematics approach, angle values for each joint.

   To make the tool easy and quick to use, segments connecting joints are not associated with a mass: they were considered as a point model. In addition, some potentially important degrees of freedom, as for example those of the hand, are not represented. The hand is in fact positioned in correspondence of the grasp line at about half of palm.

   The virtual manikin can perform most of the movements that a real operator makes during working operations. The main objective is to verify already in the design phase that the work task does not require the engagement of awkward postures.

The tool gives in output numerical values of the angles between the relevant manikin's segments which reproduce the position of the worker.
These outputs can be compared with the limits defined by international standards (figure 3, shows the limits for the back inclination). In this way the user gets a numerical rating (also represented in the classical colour form: red, yellow and green) of the posture related to the work task having so a direct suggestion of how to change design solutions to solve critical postural issues.

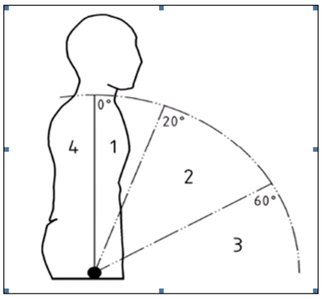


Figure 3: Reference limits for back inclination

Threshold values of body segment angles and their traffic light evaluation are consistent with legislation values (ISO, 2000).

Being though as a screening tool, indication on angles assumed by body segments is not related to the exposure time, that means the tool indicates the presence of awkward postures even if they are engaged for a few instants.

The tool is useful in the design phase of new workstations as well as in the identification of what percentiles may work at an already planned workstation without having to engage in awkward postures. This type of analysis, suggested by many authors in the scientific literature [n], may also help in assigning working tasks to different operators.
The reference percentile chosen for the simulation is 50th percentile male; percentiles reported in literature for design of extremes (1,5,95 and 99 percentile male) and 75 percentile male, indicated by a few authors as the more realist measure of the average worker, were also analyzed (an example of simulation with different percentiles is shown in figure 4).

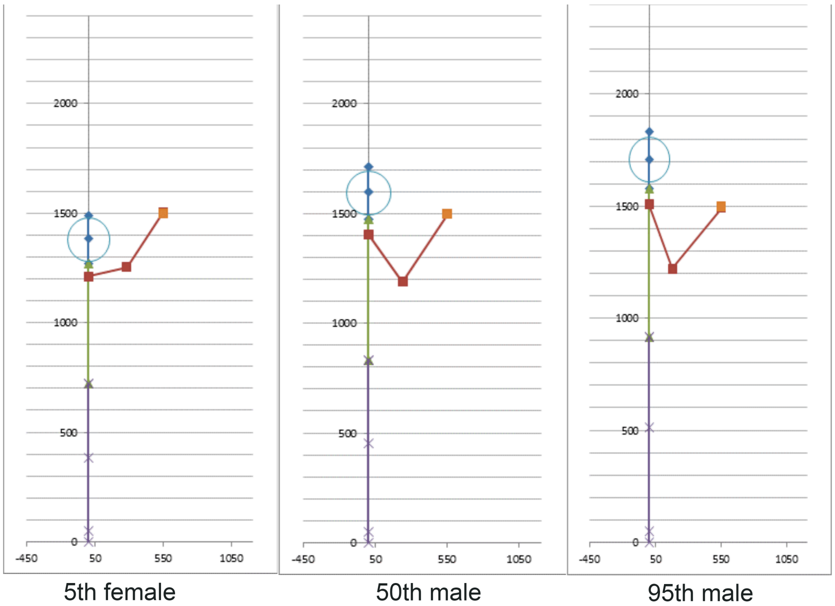


Figure 4: Simulation with different percentiles

Numerical data obtained by the software, can be also given in input for the postural section of more complex ergonomics indices as, for example, EAWS (Schaub et al. 2012a; Schaub et al. 2012b) and

OWAS (Louhevaara and Suurnakki; 1992). In this way, the user can be helped in assessing the work-cell comfort according to the assigned assembly task.

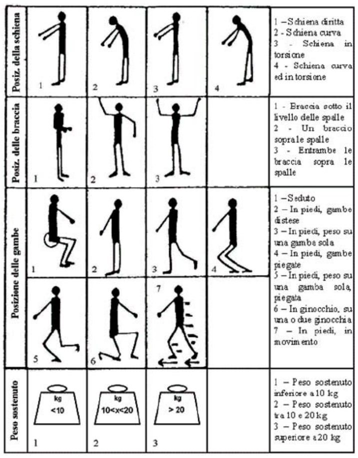

Figura 5: OWAS worksheet

Finally, an extension of the application allows to use the same methodology not only to the individual work-cell but also to an entire section of the assembly line. This function is very important because it allows to analyze and optimize some general features of the production line (as, for example, the altitude) that may have deep impacts on equipment costs.

## 3 CASE STUDY

The case study presents the use of Human Model during the redesign phase of a workstation to be adapted for a new production. Starting to a preliminary analysis of the pre-existing workstation layout to support the redesign phase simulating different percentiles.

In the first simulation, figure 6a, work heights, to be reached by the operator during such task, have been identified using the initial layout in which the car was on ground level. The particular is mounted on the car by manual screwing and because of the operation requires precision in screws placement, the squatting/kneeling posture was assumed for the operator by operator as the most probable. Indeed such posture allows the operator to gain balance, stability and control for manual handling. The simulation, indicates as critical the value of arm-shoulder angle and trunk rotation; for most percentiles they would assume a value higher than the recommended limit.

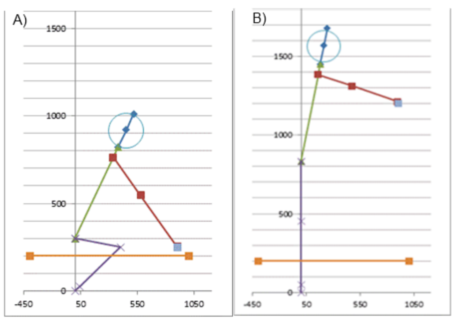

Figure 6: Simulation of working task, 50$^{th}$ percentile

Human Model was used in the analysis of corrective solutions positioning the car at an height from the ground to minimize the number of workers who will have to perform the task engaging in awkward postures. The simulation output values indicate that the car shall be raised from the ground level using a crane. As shown in figure 6b, no critical postures are present when the car is raised from ground level. In the new configuration no biomechanical criticalities for operators are presented regardless of the reference percentile.

## 4 CONCLUSION

The modern car market is extremely dynamic and so industries must deal with new challenges by updating design and production processes. A detailed analysis of working tasks and workstations is already needed in the design phase because of the new approach of industrial sectors due to the global market scenario. For postural aspects, FGA has internally developed a 3D virtual manikin that allows to perform ergonomic analysis compliant with the most important ergonomics standards.

The tool returns a posture diagram on three planes and allows to compute the angle values assumed by main body segments. Such angles can be analyzed according to the traffic light coding system reported in legislation. Simulations indicated the body segments most critical in terms of biomechanical overload. In this context, the use of an easy simulation tool as the Human Model, is a valid support tool for the design phase to perform preliminary ergonomic analysis on future work-cells in the early phases of a new car development. The simplified structure and the parametric model give flexibility to the tool making it particularly useful in predicting different scenarios for production in terms of location, working population and reference standards.

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