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HUMAN MODELING BENEFITS IN WORKSTATION DESIGN

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Abstract

Human modeling has been used for a number of years, mainly by the aeronautical and automobile industries, to design products and means of production. Are the benefits of using human modeling for these companies transferable to other industrial sectors, mainly for designing and correcting tools or common workstations? If so, in which specific contexts? In the framework of a research project to answer these questions, a series of hypotheses was developed, based on the context and expected consequences of using human modeling. Case studies were carried out to verify these hypotheses and thus determine the contextual elements favorable to the use of human modeling in designing or correcting workstations. The preliminary results of this study verified some of the predefined hypotheses. First, as expected, human modeling allows more rapid iterations for validating the concepts considered. The results also show that the more complex the problem workstation, the more effective the validation using human modeling. The results also suggest that the user's ergonomic competence has a direct impact on the quality of the solution, whether human modeling is used or not. Finally, human modeling improves the quality of communication with managers and workers.

Keywords: Ergonomics in design; Human modeling; Engineering design software.

1. Introduction

Human modeling is done using software tools that simulate anthropometric and biomechanical phenomena in a virtual environment. Until just recently, these software programs were exclusively used by the aeronautical and automobile industries. The growing availability of sufficiently powerful affordable computer equipment is allowing a wider distribution of these software tools. However, their utilization costs remain high, requiring a serious analysis of their benefits. The known advantages of this type of software are related to the reality of automobile and aeronautical manufacturers and a few other comparable companies [1 - 4]. The question emerging from this observation is: Does this technology offer a benefit for other types of companies, particularly for designing or correcting common industrial tools or workstations. To answer this question, a relationship is proposed (in the form of hypotheses for verification) between the context of the projects, the consequences on their development, and the solution obtained using human modeling.

2. Human modeling

The expression "human modeling" is used to describe the simulation activity based on models that describe human anthropometric and biomechanical phenomena. These simulations are carried out using software, with the best known being “Jack” (Electronic Data Systems) and “Safework” (Dassault Systems).

Human modeling software uses a 3D model of the work environment. This virtual environment can be modeled directly in the human modeling software or be imported from computer-assisted design software (CAD) [5]. In the simulations, a virtual mannequin is added to this model of the environment. The mannequin can be dimensioned in a detailed way by specifying the size of each segment or in a more approximate way in relation to the sex and the percentile rank for size and weight. Figure 1 presents the results of modeling using Jack software.

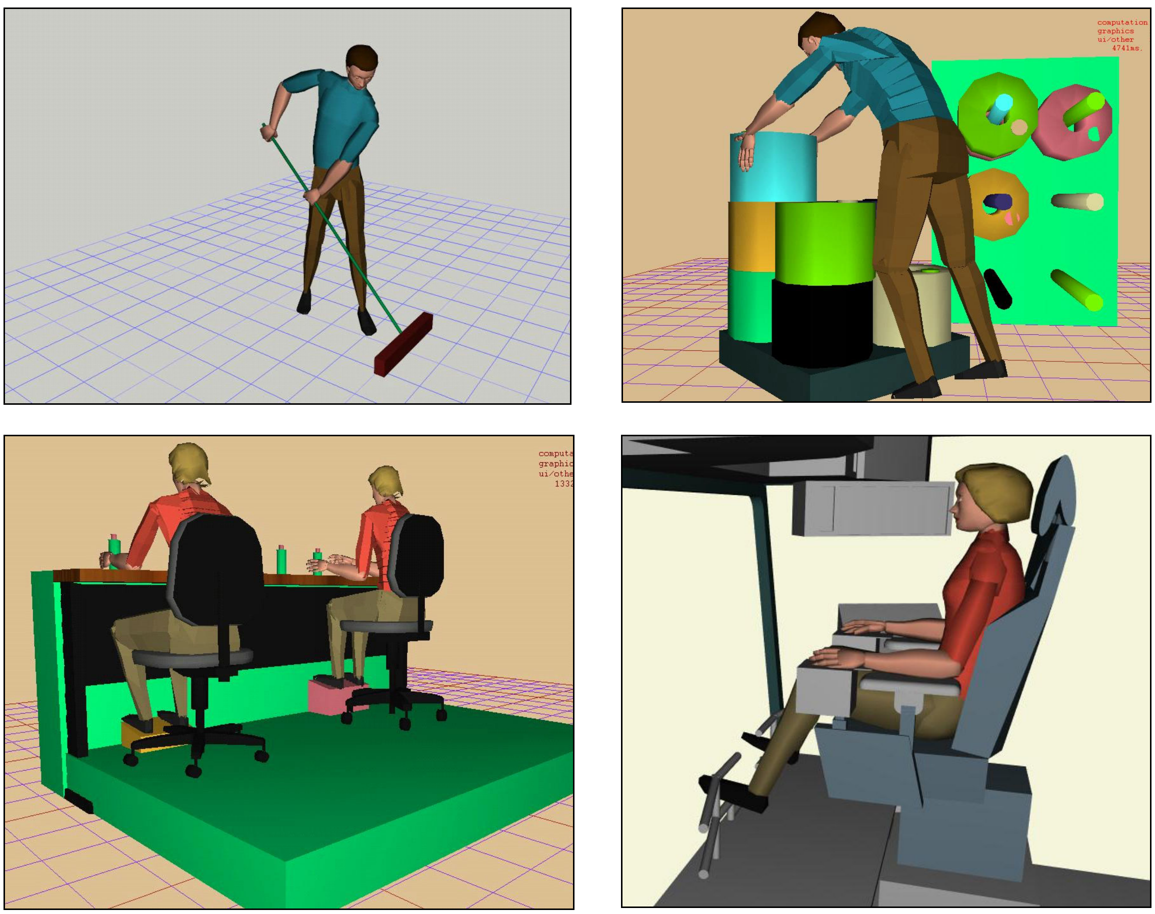

Figure 1. Examples of human modeling using Jack software

The software generally allows the virtual mannequin to be manipulated rather directly and intuitively, placing it in the posture to be studied. Options in the software allow posture-related biomechanical studies to be carried out, and for example, moments at different joints or compression at L5-S1 to be obtained. The most likely problems in human modeling are dimensioning (for reach and size) and visibility (see figure 2) [6,7]. The software also allows the mannequin and environment to be animated. The aim of most current research in human modeling is to improve the prediction of postures and movements so that they can be studied without having to resort to motion capture.

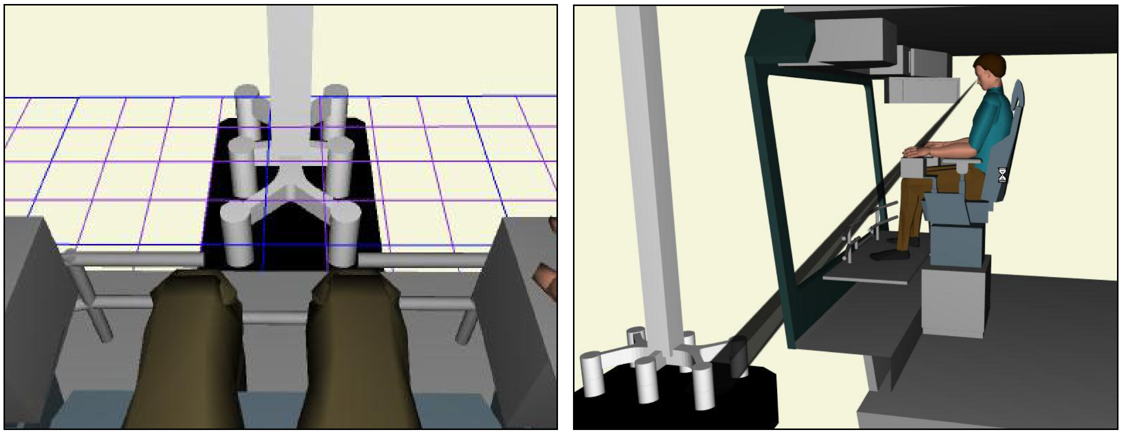

Figure 2. Human modeling application to visibility problems using Jack software

Human modeling originated at the end of the 1960's by modeling reach in a seated position. The purpose of this model developed by Boeing was to predict the reach of an average man in a fighter plane cockpit. During the 1980's, there were major advancements with the development of several software programs. The two most popular are "Jack" (Electronic Data Systems) and "Safework" (Dassault Systems), intended for rather general use. "Jack" was developed by the University of Pennsylvania's Center for Human Modeling and Simulation. This project, financed by NASA, was to be used to simulate space station assembly by astronauts. The reach and visibility problems handled by this simulation tool in preparing space walks also exist for land situations. The software's mandate was therefore broadened and the tool's potential has been used by American military aviation to design cockpits and for maintenance aspects.

3. Benefit of using human modeling

The word "benefit" can be defined as the value obtained from something. The benefit of using human modeling in a given context is obtained by summing the advantages (positive or negative) of human modeling over the traditional method of solving ergonomic problems. These advantages can be such things as the positive (or negative) consequences of a project's length, or the quality of the solution, which depend on the use of one method over another. Here, the "traditional method" describes an approach for designing and validating an ergonomic problem's solution without using human modeling software, virtual mannequins or similar tools. 2D drawings, and scale or full-scale mockups are some of the so-called traditional tools.

To assess human modeling's positive or negative impact, it must be compared to the traditional method. The advantages of human modeling over the traditional method that are described below were reported by Porter [8,9]. These advantages were based on the author's years of experience, but are not accompanied by data.

3.1 Allows proactive ergonomics

Porter's definition of "proactive ergonomics" is summarized as follows: "This simultaneous consideration of people issues and engineering issues promotes the identification of optimum compromises, which are essential for a successful design" [8, 9]. Ford used this type of proactive approach called "Design for Ergonomics" in designing the new F-150 [10]. Proactive ergonomics is difficult to contemplate without human modeling, since the latter uses geometry (the virtual environment) modeled for other engineering uses. This reuse of geometry facilitates a simultaneous and continuous contribution of ergonomics.

3.2 Reduction in time

Full-scale mockups take a long time to build and to modify, but are essential for most projects with an important ergonomic component. The use of human modeling does not completely eliminate the need for full-scale mockups since human "feedback" is often essential, but it minimizes the number of design errors and resulting changes. Along these same lines, Porter [8] reported one case in which only minor details had to be changed on a mockup that had first been validated with human modeling. Since the time devoted to design must be minimal in our competitive universe, the time saved by preventing errors is invaluable.

3.3 Iterations of ideas and evaluations

Most of the literature on design methodologies agrees about the benefits of using iterative loops to improve a solution [11,12]. An iterative loop uses the conclusions of the previous evaluation to attempt to produce a better idea. Human modeling, with its possibility of easily validating ideas, allows more iterations in the same amount of time. Chaffin [13,14] reports the possibility of exploring alternative scenarios with human modeling, which is consistent with iterative loops. By testing promising solutions whose success is not guaranteed, interesting advancements can be made that increase the quality of the final solution.

3.4 Profitable ergonomics

Different aspects of human modeling can reduce ergonomics-related costs [8]. The reductions in time, in the number of full-scale mockups and in late changes to the solution reduce costs. Figure 2 presents a hypothetical comparison of the costs of a project with and without human modeling (adapted from [13], ch.1). This graph illustrates the author's hypothesis: human modeling is more costly during the preliminary steps but slows the explosion of costs in the later steps.

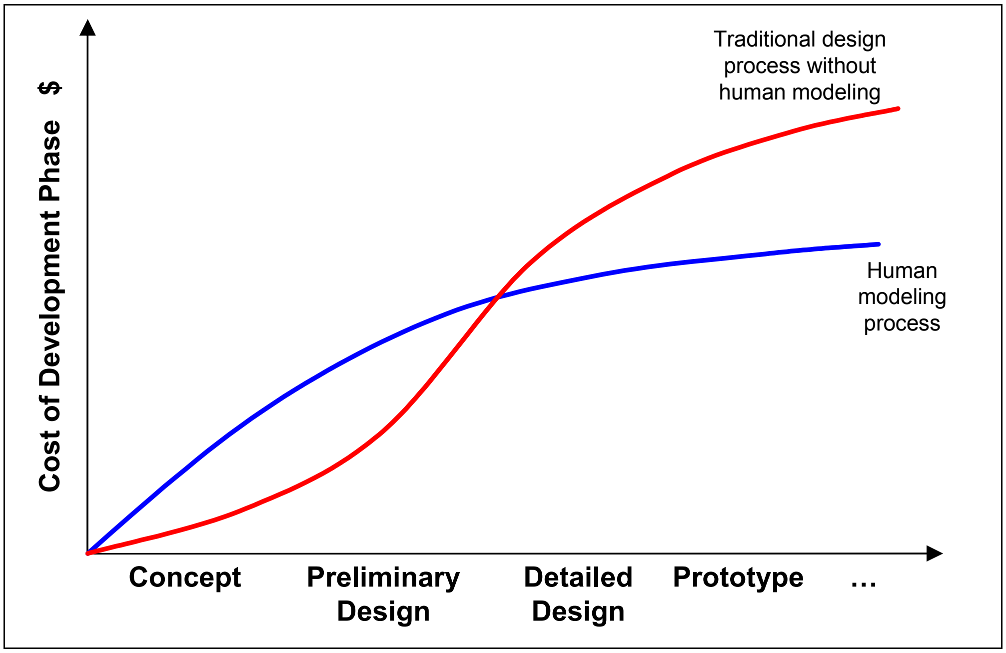

Figure 3: Hypothetical comparison of costs with and without human modeling.

3.5 Improvement in communication

Ergonomic work is not always understood by all the participants in a project. With human modeling, "the ergonomics problems with a proposed design can be presented visually and accurately, both in perspectives with color surface rendering or as engineering drawing. This ensures efficient communication within the design team and leads naturally to solution-oriented action" [8]. Jimmerson [15], Peacock et al. [16] and Sundin et al. [17] come to the same type of conclusion.

These advantages are interesting but must be dealt with by taking reality into consideration. The context in which the tool is used has a positive or negative impact on the advantages, and therefore, on the benefit.

4. The context

The context refers to the overall situation of an event. In the case of a design project involving ergonomics, the context is the combination of human and material resources available, the time, the type of project, etc. Studying the context has several positive aspects, including the simplicity and anticipatability of the benefit. The aspects of the context would be rather easy to estimate by a project manager who has to decide whether human modeling can be beneficial in a specific context. Also, the context's aspects exist and can be evaluated before starting a project.

The different authors who report the consequences of using human modeling do not quantify or qualify the contexts of their studies. However, certain indications can be identified that provide insight into how many resources were available in the majority of cases reported in the literature. The context of large automobile and aeronautical manufacturers and a few other leading-edge industries is characterized by the use of concurrent engineering and "virtual manufacturing" tools in developing products and means of production. The projects are extensive and involve hundreds of specialists from different fields with large budgets.

In the province of Québec (Canada), very few ergonomics practitioners participate in projects with as many resources. The majority of the potential ergonomic resources are in the manufacturing industries (for example metallurgical, wood processing and food processing companies, etc.) or natural resource processing industries. In addition, a large proportion of these potential interventions can be described as tool correction or workstation correction ergonomics. Even though this type of project is a reality for large and small companies, most of the cases detailed in the literature refer to design or redesign projects for complex products such as airplane cockpits or automobile passenger compartments.

These different contexts explain why the conclusions of large aeronautical and automobile companies on the use of human modeling are difficult to transpose to the reality of the usual ergonomic interventions in manufacturing companies. The question is therefore: Are the benefits of using human modeling in the literature transferable to other industrial sectors, mainly for the design or correction of common tools or workstations? If so, in which specific contexts?

5. The hypotheses

In the context of a research project to answer these questions, a series of hypotheses was established, based on the context and expected consequences of using human modeling. The hypotheses were based on the principle that, by evaluating aspects of the context and consequences, one can determine how the context affects the benefit of using human modeling. Based on the means available, a certain number of contextual aspects were selected for different reasons resulting from the literature analysis or observations made during a preliminary case study. In the same way, potential consequences to be measured were identified in the literature and in the preliminary study. These consequences are in some cases compared to situations in which human modeling was not used.

5.1 Human modeling allows more iterations than the traditional method in a given time.

The word iteration "qualifies a treatment or a procedure that executes a group of operations repetitively until a well-defined condition is met" (OLFQ)[1]. The iteration process allows an idea to evolve that does not meet the requirements with an acceptable solution. With each cycle, the information obtained by validation is reintroduced into the process in order to optimize the solution. For the time being, no data is available on the number of iterations done in ergonomic design projects. It is therefore difficult to establish how many iterations are necessary before human modeling can be considered an advantage. Arbitrarily, three iterations seem to be an interesting minimum limit. With the traditional method, refining an ergonomic solution twice requires a lot of resources and time.

[1] Translated from the French definition of the Office de la Langue Française du Québec (OLFQ)

5.2 The more complex the problem workstation, the more effective the validation using human modeling.

Complexity is defined as "the degree of interrelationship of the elements in a system" (OLFQ). In a workstation design project, the elements are the workstation's components and the anthropometric variables involved. The interrelationships of these elements affect the number of tests to be performed during the ergonomic validation. Also, these tests performed in a traditional way cannot be systematic because they are limited by the availability of representative test subjects.

As with the iterations, no data is available on the impact of a workstation's complexity on the designer's task. However, since human modeling first established itself in the design of complex products, the use of human modeling can be assumed to be advantageous when the complexity is high. To establish human modeling's effectiveness, the costs and time necessary to carry out a traditional validation will be evaluated. This evaluation will be compared to the costs of the software and the time devoted to the validation using human modeling.

5.3 The more competent the designer with human modeling and CAD, the faster the ergonomic validation.

Since there is only one user in this study, his competencies cannot be compared. To address the question anyway, the level of competence in these fields will be defined qualitatively by analyzing the designer's CV and from interviews with collaborators and clients. This level of competence will be compared to the proportion of time devoted to validation over the total design time. The user's competence should be reflected by a low proportion of the total time devoted to validation.

5.4 The user's competence in ergonomics directly affects the solution's quality with or without the use of human modeling.

This hypothesis is difficult to verify since the person who should be able to evaluate the solution's quality is the end-user who does not necessarily have the competence to do so. However, questions will be asked about the perception of the designer's competence in ergonomics and the perception of the results obtained using human modeling. The important aspect to underline is that someone who is not competent in ergonomics can easily, using human modeling, provide answers that appear to be correct. This fact was observed in a study carried out in a university undergraduate ergonomics course where the students had to dimension components of a workstation and illustrate their response using human modeling. Those who did not correctly dimension the workstation illustrated their mistakes without recognizing them. Therefore, being able to use the software is not enough; one must also master the necessary concepts of ergonomics.

5.5 The easier the geometric modeling of a workstation, the more advantageous it is to use human modeling.

The expected impact on the process is the time devoted to collecting data and to modeling. Human modeling is supposed to allow a maximum number of elements to be validated in a minimum amount of time. The shorter the time devoted to modeling the environment, the longer the time available for validation. However, this advantage must be weighted in relation to the type of mandate. Weighting is advantageous in a design mandate because human modeling is the only means of validation without using a full-scale mockup. In the case of a mandate to modify or correct an existing workstation, weighting is less advantageous because validation can often be done directly in the existing environment.

5.6 Human modeling improves the quality of communication with managers and workers.

Two major difficulties are involved in the communication of ergonomic problems or their solutions. The first is communication about the environment, which is traditionally done using 2D drawings. Not everyone has the skills and knowledge required to read these drawings. The second difficulty is communication about postures. Ergonomic problems are often directly related to specific postures, which are difficult to describe or illustrate.

To confirm this hypothesis, the participants will be assessed regarding their skills in reading drawings and their ergonomic knowledge. This data will be compared to the comments collected following presentations using images and information generated by human modeling. The contribution of human modeling to the quality of communication is expected to be positive. It is also expected that the assessment by participants with a poor knowledge of ergonomics and blueprint reading will be even more positive.

6. Preliminary results

As a first step to verify these hypotheses and thus determine the contextual elements favorable to the use of human modeling in designing or correcting workstations, four (4) case studies were carried out to:

- Redesign of a seated operator's workstation in heavy industry;
- Design of a new push broom for special applications;
- Modification of a workstation in a pipe manufacturing plant;
- Design of the driver's station in an industrial truck.

These case studies were carried out in companies where projects were initiated for designing or correcting common industrial tools or workstations. The task, assigned to the authors by the company, was to make sure that the new design respected the ergonomics principles of industrial tools and workstations. Jack human modeling software (EDS) was then proposed to the company as a tool to assist in integrating the ergonomics into the design process. Each project was carried out by a multidisciplinary team including, in addition of the authors, engineers, operators and maintenance personnel from the company. Team sizes varied from four to eight persons.

During each project, data were collected for documentation and hypothesis verification purposes. These data aimed at characterizing the project's context (project type, human resources involved, complexity of the design from the ergonomic point of view, difficulty of geometrical modeling) and at collecting perceptions of the people involved (relative duration of the project, quality of the communications, general perception of the contribution of human modeling within the framework of the project, general perception of the relative quality of the results). Information regarding the competencies and the aptitudes of the personnel involved was also collected (competencies level in ergonomics, skills in reading drawings). These data were collected using a questionnaire administered to the team at the beginning of project, and by individual semi-structured interviews conducted with team members at the end of the project. The authors also documented their observations as the project progressed.

The preliminary results obtained from these case studies verified some of the predefined hypotheses. First, as expected, human modeling allows more rapid iterations for validating the concepts considered. The results also show that the more complex the problem workstation, the more effective the validation using human modeling. In the case of a workstation design project, the system's elements are the workstation components and the anthropometric variables involved. The interrelationships between these elements have an impact on the number of tests to be carried out in the ergonomic validation. These tests are limited by the availability of representative test subjects if they are carried out in a traditional way, a problem that is easily avoided with human modeling. The preliminary results also suggest that the user's ergonomic competence has a direct impact on the quality of the solution, whether human modeling is used or not. With human modeling, a person not very competent in ergonomics can easily obtain answers that appear to be correct. Being able to use the software is therefore not enough; one also has to master the necessary ergonomic concepts. Finally, human modeling improves the quality of communication with managers and workers. Difficulties in communicating ergonomic problems or their solutions usually involve the environment and postures. In fact, ergonomic problems are often directly related to specific postures in specific environments, which are more easily illustrated with human modeling.

6. Conclusion

Global competition is increasing and society does not want workers' health and safety to pay the price. As a result, design tools that make it possible to do more with less are essential. In the ergonomics context of our manufacturing companies, human modeling is perhaps among these tools, but before this can be established, its use must be better understood. The current study attempts to establish an approach for considering this subject in greater detail by verifying, in a series of industrial projects, the hypotheses presented here. Over the medium term, with sufficient data, a model can be built for forecasting the benefit of using human modeling in relation to the context.

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