4-1-2010

The Use of Virtual Human Factors Tools in Industry – A Workshop Investigation

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Technical report
Human Factors Engineering Lab – Department of Mechanical and Industrial Engineering
April 2010

Human Factors Engineering Lab Technical Report #2010:03

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Abstract

This report presents the views of participants in a series of workshops on Human Factors (HF) in virtual production planning. The participants, ergonomists and engineers from both public and private sectors, were presented with 6 different Virtual Human Factors (VHF) tools: Discrete Event Simulation, Predetermined Motion Time Systems, Complex and Simple Digital Human Models, Virtual Reality and SIMTER . Comments expressed by participants were recorded on digital audio tapes and by note takers and questionnaires were handed out. Eight main characteristics were identified as influencing factors for the use of VHF tools: cost, time, training, difficulty of use, reliability, graphics, flexibility and usefulness. Other findings included a need to modify report layouts and improvement recommendations particular to each tool. The findings in this report present the initial steps of an ongoing research program with the aim of developing improved approaches to using simulation to integrate human factors proactively into the early stages of a work system design.

Introduction to Virtual Human Factors (VHF)

We adapted the IEA definition of ergonomics (IEA Council, 2000) to define Virtual Human Factors (VHF) as "the scientific discipline concerned with the understanding of interactions among humans and other elements of a '*virtual*' system, in order to optimize human well-being and overall system performance".

Today, industry faces increasing product complexity, more frequent model changes and shorter development periods. Therefore, improvements made in early design stages are much less costly than retrofitting reactive processes.

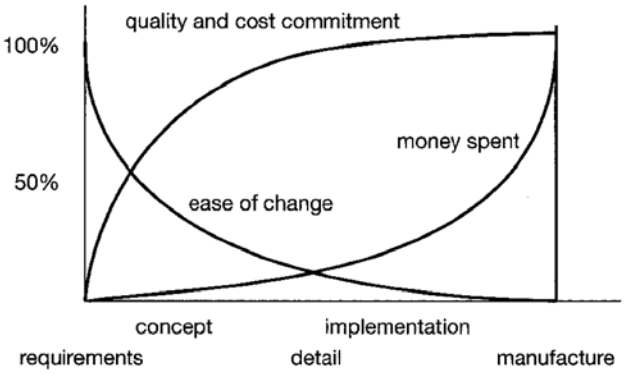

Figure 1. *This graphic shows how important it is to use HF early in concept design. As time passes, ease of change is reduced and cost increased (Miles and Swift, 1998).*

Hence, VHF tools are especially useful because they can be applied early in design without putting humans at risk in the testing phase, ensuring good productivity and reducing times and costs. Unfortunately, some organizations don't like to make changes due to perceived lack of time. Sometimes, however, that "lack of time" means human factors are just not a priority. The result of this is reduced productivity, decreased quality, and increases in operator injury and absence.

Methodology

This explorative investigation was conducted through a series of 4 workshops. A total of 46 industry representatives from both public and private sectors, including managers, engineers, ergonomists and designers responsible for developing new production and service systems participated in the workshops. Each VHF tool was individually presented to the audience by international experts during each of the day-long workshops. Participants were invited to ask questions and express comments during the presentations. A general question period was conducted at the end of each session, followed by break-out discussions where participants were allowed to talk about relevant issues in a free manner. One person in each break-out group was designated as representative in charge of collecting relevant ideas and sharing them with the rest of the audience. Note takers collaborated with the data collection; their responsibility

was to capture the main verbal and written ideas, comments and experiences shared by the workshop participants; audio recording devices were also used.
All the information collected through the questionnaires, break-out sessions and note takers was analyzed by the researchers and distilled into a summary. A copy of that summary was sent to participants for further feedback as a validity check.

Virtual Human Factors Tools

The participants were presented with 6 different VHF tools during the workshops: Discrete Event Simulation (DES), Predetermined Motion Time Systems (PMTS), Simple Digital Human Models (SDHM), Complex Digital Human Models (CDHM), Virtual Reality (VR) and SIMTER. These tools are briefly described below.

Discrete Event Simulation (DES)
Discrete Event Simulation is the representation of a system in terms of sequence and times of the process stages (Banks et al., 2005). This tool is especially useful for analysis of system design alternatives (e.g. Neumann and Medbo, 2005). Thanks to different software available today, it is possible to model different events to predict outcomes based on the combined dynamics of all of the system elements. Examples of DES in Rockwell Arena simulation software were presented in each workshop, to show participants the importance of integrating this tool and HF.

Predetermined Motion Time Systems (PMTS)
Predetermined Motion Time Systems evaluate the time needed to perform a task based on activity requirements and standard times from a table of predetermined times for given movements. These systems are especially useful to set the ergonomically correct labour rates across work stations (line balancing). Some examples of PMTS are Methods Time Measurement (MTM), Maynard Operation Sequence Technique (MOST), and Universal Analysis System (MTM-UAS, or in Sweden MTM-SAM). During the workshops participants were introduced to a PMTS system with an ergonomics component called ErgoSAM (Laring et al. 2005). ErgoSAM is a Swedish tool for identification and evaluation of risk for musculoskeletal injury based on a PMTS similar to MTM, commonly used by production engineers.

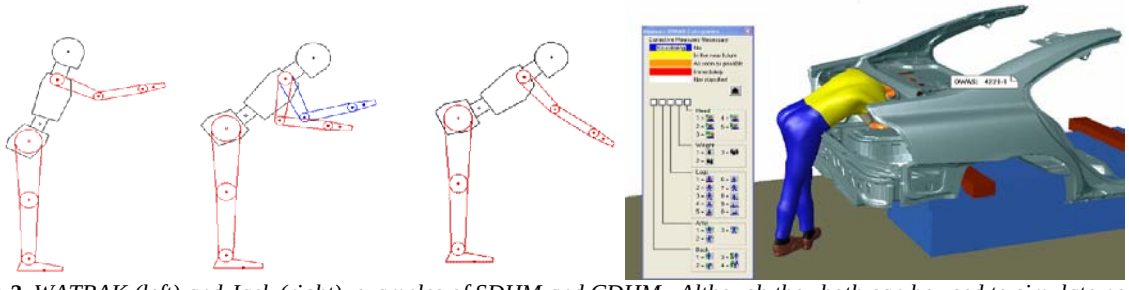

***Figure 2**. WATBAK (left) and Jack (right), examples of SDHM and CDHM. Although they both can be used to simulate postures for different tasks, CDHM (right) has the advantage of incorporating 3D CAD work environments to the evaluations.*

Simple Digital Human Models (SDHM)
Digital Human Modeling (DHM) is the computerized simulation of the human body and its interaction with the environment. DHM is a very popular tool used in modern industry. SDHM are usually 2D (although some 3D models exist e.g. the 3DSSP model) human modeling tools that can include different data such as task, posture, force and time. The biomechanical models produced by this software allow the user to explore tasks in more detail and make it easier to guess and check postural effects. During the

workshops participants were presented with WATBAK (Figure 2) as an example of SDHM (Neumann et al., 1999). This tool is relatively affordable, with a price around $600 for a single license.

Complex Digital Human Models (CDHM)

CDHM are more elaborated human modeling systems (Figure 2). CDHM have the capacity to integrate the human model and a CAD drawing of a workplace; to check risk and fit along with biomechanical load information. The risk level is then indicated by colors (or numbers depending on the analysis subroutines available). CDHM relies on the same kind of anthropometrics databases utilized by SDHM to examine tasks performed by different sizes of people in the same system (large man, small woman, etc.). This tool can provide a lot of information, but in order to do so it requires deep ergonomic knowledge to correctly manipulate the digital mannequins. These kinds of Complex DHM tools are more expensive (ranging from $8,000 to $75,000+), with some models costing much more depending on the 'add-ons' purchased.

Virtual Reality (VR)

During the workshops 2 different VR tools were presented: Ergomix and Vizendo.

Ergomix is a participative VR tool that uses blue screen technology to evaluate workstations and systems (Vink et al., 2008). A worker performs different tasks in front of the blue screen; video of that mock-up can then be superimposed onto different computer generated backgrounds, from a simple drawing in Visio to a more complex CAD layout. Designers can predict adjustments to workstations and systems by discussing and trying alternative layouts with workers. Changes are made to the CAD drawing and the new layout is tested by the worker (De Looze, 2003).

Vizendo is a computer program designed for cognitive training for manual assembly tasks (Vizendo, 2009); a kind of first person videogame. A 3D environment is presented to the workers, including different components and tools to perform a given task. The worker can then practice identifying the right assembly sequences, tools and components for each step in the assembly process (Malmsköld, 2009).

SIMTER

A prototype hybrid VHF tool was presented during the workshops as an example of future approaches.

The SIMTER software is a new Scandinavian software tool for the simulation of manufacturing systems. It allows the integration of ergonomics, level of automation and environmental concerns in a single platform (Berlin, 2009). The users can create a 3D production environment, combining CDHM and DES, with tables of the environmental impact of chosen equipment.

Since SIMTER is still under development and is not yet available in the market, it was presented as an example of how different tools can be combined into a single platform. Perhaps due to that situation, the information provided by the participants wasn't enough as to support the same kind of assessment as done for the other tools.

Results

Based on the information provided by participants, we were able to identified eight critical characteristics in all VHF tools: time, cost, training, difficulty of use, reliability, graphics, flexibility and usefulness. These characteristics have the potential to act as motivation or deterrent for the use of a VHF tool.

Figure 3 shows how participants perceived each tool's performance for each of those key factors.

Time

Time includes how long it takes to use the tool from the data collection stage to getting the results. Some tools like DES and PMTS may need long time to yield results; since the data collection, processing and

analysis may be very lengthy. In some other tools, like CDHM and VR, the time consumption doesn't depend on the tool usage itself, but in the CAD environment preparation instead.

Cost

Cost includes the price of the tool, as well as some other expenses such as the investment needed for training and usage. Given the complexity of DES, which sometimes can become a "team project"; salaries of the employees involved in this type of project can bring up the costs for the company. CDHM and VR, on the other hand, sometimes require the use of expensive computer equipment, the participation of personnel to perform mock-ups and specialists in CAD drawing; all this can bring costs up considerably. In addition, computer tools are always evolving, therefore obsolescence becomes a real problem; especially for small consultant companies which lack the purchasing power of big firms.

	DES	PMTS	SDHM	CDHM	VR
Time	X	X		X	X
Cost	X			X	X
Training	X		X	X	
Difficulty	X	X		X	
Reliability	X		X	X	X
Graphics		X			
Flexibility			X		
Usefulness	X				

Figure 3. *This table presents the way participants perceived the VHF tool's performance for each one of the 8 main characteristics. The mark 'X' implies that that particular tool may present some problems in that aspect.*

Training

How difficult it is to master this tool? According to some of the participants, tools like DES and DHM require more time to be mastered than tools like PMTS. Learning how to properly use these tools sometimes implies acquiring knowledge not directly related usage of the tool itself. DES, for instance, calls for a deep probabilistic knowledge of system behaviour and variability, in addition to learning how to program a simulation. Learning how to get different postures using SDHM or CDHM is a far easier task than acquiring the ergonomic knowledge needed to interpret the results to determine when those postures are problematic and when they are not.

Difficulty of use

Using some tools can still be a difficult process even after receiving adequate training. DES requires field data collection, data probabilistic analysis and programming before a model can even be built; output analysis knowledge is needed to interpret the results yielded by the simulation. Although PMTS is based on predetermined activity requirements and standard times included in tables, finishing a full study can become a meticulous process. CDHM simulation can also be a very difficult process, one that would call for the use of different software, various iterations and even physical mock-ups.

Trustworthiness

Trustworthiness emerged as one of the most common concerns among the participants. The reasons behind the mistrust depend on the particular characteristics of each tool.

Participants didn't doubt the simulation software itself, but instead the data collection and input processes done by the simulation engineer, as well as the analysis of results.

The validity of the results yielded by SDHM and CDHM was questioned by the participants for different reasons. According to them, some of the safe/unsafe limits presented by these tools are based on guidelines established long ago by organizations like NIOSH (National Institute for Occupational Safety and Health). These guidelines were calculated on population decades ago and may not reflect the physiological profile of today's population. Identifying the correct postures represents another challenge, and even when the mannequin posture is correct, the task and workstations design may be flawed. Engineers in the workshops seemed to favour the use of physical mock-ups, while ergonomists tended to think that a DHM simulation could be used instead. When to use a physical mock-up and when a

computer could be used depended on the situation. Physical mock-ups are helpful to show analysts the variability of the "human element". For example, workers tend to adopt awkward postures due to fatigue or in order to "cut corners"; situations that should be considered in ergonomic studies. However, when trying to determine the perfect posture for any given task, analysts may want to leave out that variability.

Graphics

One of the most appreciated characteristics in the tools was their graphic capability. Participants seemed to favour tools with a powerful graphic component, especially CDHM, for the realism it offers when simulating tasks. Both SDHM and CDHM allow users to appreciate postures, but only CDHM can incorporate a 3D environment drawing that adds to the sense of reality and allows the user to evaluate reach, space and fit for a given task. DES, on the other hand, offers a dynamic graphic simulation, which according to the participants gives a better idea of how systems and processes work.

Overall, the quality of the graphics was highly appreciated by the participants, particularly ergonomists, who said that it could help them to convince skeptical managers or engineers for ergonomic changes to systems and products. However, it's important to highlight the fact that while the graphic component may increase the price of the tool, it won't influence the numerical results of any ergonomic or productivity analysis.

Flexibility

The quality of being adaptable to and useable in different situations was also perceived as an important characteristic for VHF. Participants said PMTS could be used with DES for better and more trustworthy data collection; DES itself could be applied technically to any process (from a bank line simulation to a production system); VR could be used for workstation design, training, evaluation of workers' performance and supporting hiring decisions; CDHM is applicable to workstation and tasks designs, risk identification, evaluation of components provided by suppliers and for product design. Participants failed to identify other uses for SDHM besides risk evaluation.

Usefulness

Usefulness was defined as the benefit participants thought they could get from each tool. Generally, participants thought of the VHF tools presented during the workshops as useful from an ergonomic perspective, except for DES.

Results presentation

Another important characteristic identified by participants, was the way in which the reports and risk indicators are presented. They reported that some of the reports, are confusing and overloaded with very detailed information. As a solution, tool developers could modify the report layouts in such a way that the most relevant information (such as risk of injuries and maximum loads) is offered first in simple language and perhaps using some indicators such as charts and colors, while the more complex details reserved to ergonomists are included in further sections of the report.

People in the audience also expressed some concern about the way in which risk levels are presented. Some of the tools show risk levels with numerical scales, others with a simple color code. Participants explained that although using a color risk indicator could simplify interpretation for some by associating colors and risk levels (red – danger, yellow – caution, green – safe), it also leaves room for interpretations that can be made based on personal judgment. For an instance, someone can associate a "yellow" situation with caution when in reality it is very close to the dangerous status. Having this kind of indicators can easily lead to miscalculations and hence to possible accidents. Alternatively, a numerical indicator can be hard to

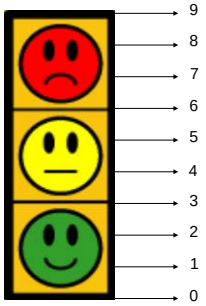

Figure 4. *If based only on a color indicator, a worker might consider a situation "level 6" (yellow) as somehow safe, when in reality is closer to be dangerous*

interpret for someone with limited ergonomic knowledge. As a solution, participants suggested that in order to have an accurate interpretation the risk description should be complemented with a numerical ranking as illustrated in Figure 4.

Tool specific findings

Besides the 8 main characteristics and the information layout, participants identified some other improvement opportunities particular to each of the different VHF tools presented in the workshops. This section summarizes those comments and observations.

DES

To be useful for ergonomic purposes, participants said, DES should consider HF such as fatigue, force, posture and time of exposure; as well as some psychosocial factors like sense of control, autonomy, integration and especially communication with coworkers. At this stage few users of DES include such factors in their models. Although new researches are demonstrating it is possible to incorporate some physical HF into DES, it is not clear how workers' perceptions of psychosocial situations may be predicted from time based simulations such as DES.

PMTS

Participants familiar with PMTS pointed out that although it has proven to be very important for their company (since it helps to identify some key ergonomic components already mentioned), its use can be harder than it seems. They explained that analyzing different categories for each body part (fingers, right arm, neck, etc.) and for every task (reach, move, etc), can be a very slow and difficult process. The empirical evidence of ErgoSAM, however, shows that the ergonomic element adds only about 5% to total analysis time.

DHM

SDHM and CDHM have some common advantages and disadvantages, according to participants. They are both useful for calculating ergonomic limits, identifying risks of injuries and MSDs, optimizing processes and reducing design iterations. However, they don't evaluate hands, wrists or fingers, and can generally leave the unpredictability of the human behaviour out. Neither SDHM nor CDHM seem to have been widely adopted by industry design teams. They are seen as difficult to master, engineers don't seem to trust the results and are reluctant to use them, and they don't consider human factors such as learning curves, sickness, fatigue etc.

According to some of the participants with more experience using CDHM, one of the main advantages for this tool is that it can be used to design workstations since it offers answers to key questions such as: vision (can the worker see it?), reach (can the worker get it?) and strength (can the worker handle it?).

Cost seemed to be a greater factor for CDHM than for the rest of the tools, especially due to the fact that this software is always evolving; obsolescence then, becomes an issue. By the time that a company starts getting some return from its investment, the tool could be obsolete. To overcome this hurdles, participants suggested that software developers could offer a "pay-per-use" option to help small companies to have access to this technology.

Overall, according to some of the participants, the biggest difference between SDHM and CDHM seems to be the cost and the graphics capability, but the results of the evaluation itself are not that different, especially since the core biomechanical "engines" of these models are very similar.

VR

With Vizendo, companies can start training their workers long before the actual system is set up. This tool can also help operators to understand future changes to be done to their workstations. Companies, on the other hand, can utilize VR to evaluate their workers' skill level. Tools like Vizendo, however, lack key

components of a physical mock-up like weight, force and volume. It is also very hard to use for tasks requiring the assembly of very small and delicate parts, when the job requires precision.
Although tools like Ergomix offer many benefits to designers, such as identification of flaws in systems and workstation designs before these are implemented, participants express some concern for the price companies would pay to perform mock-ups and the acquisition of equipment.

One of the advantages of SIMTER perceived by participants is that the tool presents a realistic layout, in which a system is graphically represented along with various mannequins. This realism could become a very important asset to sell the tool. According to some participants, SIMTER is an example of how many different design criteria can be considered in an integral tool, which could be fundamental in design. Throughout the workshops, participants pointed out the need for the integration of tools into a single platform, to accelerate and facilitate ergonomic analysis processes; SIMTER, then, represents a first step in that direction. Some participants, however, were rather skeptical and expressed that environment has nothing to do with ergonomics; a reason why this approach was less interesting for them.

Discussion & Conclusion

Overall, the most important aspect of this research is the identification of 8 main characteristics that act as influencing factors for using or not using a VHF tool: time, cost, training, difficulty of use, trustworthiness, graphics, flexibility and usefulness.

The comments expressed by the participants suggest that industries may not be taking full advantage of the VHF tools for the following reasons:

- Misunderstanding of the tool
- High costs
- Companies' particular needs and capabilities
- Mistrust in the results
- Important HF not being considered

The misunderstanding of these tools could be explained by the fact that they are being used not only in different stages of the design process, but by different stakeholders. Because of this, ergonomists are not being exposed to some tools common for engineers, and vice versa.

Some improvement opportunities were identified to increase the use of VHF tools, including: reorganizing the way in which the output data is presented, considering psychological and psychosocial factors, lowering prices, simplifying software usage and making it compatible with other packages, and combining color and numerical risk indicators.

DES emerged as one of the less understood tools among the participants in these workshops. Although DES has proven to be a very useful tool for the manufacturing industry, its ergonomic use remains underdeveloped. Few scientific articles can be found about the integration of human factors in DES, although a few examples are beginning to emerge.

PMTS with ergo components, such as ErgoSAM, didn't seem to be perceived as a very powerful tool by itself for ergonomic purposes. However, participants identified it as a good add-on to complement other tools, especially when it comes to data collection. The benefits of using PMTS are mainly limited, it seems, to time prediction and task allocation.

Overall, SDHM seem to be a tool with a good balance between cost and results yielded. However, some improvements may be needed to make these tools more trustworthy and attractive to users. In regards to

the validity issue, developers may want to update the guidelines on which they base the calculations to reflect the current population size. Users with poor ergonomic knowledge, on the other hand, can resort to easy to get tools such as video and photographs to obtain the right postures. Software developers could add the capability of importing images to their products, so these images can be overlapped to the mannequin model, hence simplifying the process of getting the right posture.

One of the advantages of CDHM, it seems, is its graphic capabilities and the ability to mock-up different tasks in a 3D environment. The use of CAD drawings adds a sense of reality, and allows users to evaluate reach, space and fit. When it comes to the numerical evaluation of risks, loads and postures, the participants don't seem to perceive a difference between CDHM and SDHM beyond the cost. Participants suggested adding movement to fingers and the inclusion of some factors such as illuminations and sound levels.

To add a little more realism to the VR tools presented during the workshops, participants suggested the incorporation of haptics. This could be done by using some devices similar to the widely popular Wii, which adds weight and volume to virtual reality experiences. Complex VR systems equipped with this kind of devices are used today in some military training exercises.

Acknowledgements

The authors would like to recognize the financial support of NSERC, the Centre of Research Expertise for the Prevention of Musculoskeletal Disorders (CRE-MSD) and Ryerson University Department of Mechanical and Industrial Engineering, which made these workshops possible. Our gratitude to Dr. Jonas Laring and Dr. Jim Potvin, whose knowledge and expertise enriched these workshops. Many thanks to students and collaborators: Megan Mekitiak, Cecilia Berlin, Tizneem Nagdee, Thiago Feracini and Richard Wells for data collection assistance. The authors are also grateful to the participants for sharing their experiences and views in these workshop sessions.

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