Design Concept Evaluation in Digital Human Modelling Tools

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Abstract

In the design process of products and production systems, the activity to systematically evaluate initial alternative design concepts is an important step. The digital human modelling (DHM) tools include several different types of assessment methods in order to evaluate product and production systems. Despite this, and the fact that a DHM tool in essence is a computer supported design and analysis tool, none of the DHM tools provide the functionality to, in a systematic way, use the results generated in the DHM tool to compare design concepts between each other. The aim of this paper is to illustrate how a systematic concept evaluation method is integrated in a DHM tool, and to exemplify how it can be used to systematically assess design alternatives. Pugh´s method was integrated into the IPS software with LUA scripting to systematically compare design concepts. Four workstation layout concepts were generated by four engineers. The four concepts were systematically evaluated with 2 methods focus on human well-being, 2 methods focus on system performance and cost. The result is very promising. The demonstrator illustrates that it is possible to perform a systematic concept evaluation based on both human well-being, overall system performance, and other parameters, where some of the data is automatically provided by the DHM tool and other manual. The demonstrator can also be used to evaluate only one design concept, where it provides the software user and the decision maker with an objective and visible overview of the success of the design proposal from the perspective of several evaluation methods

Keywords: IPS IMMA, ergonomics, simulation, design, evaluation

Introduction

Simulation and automation are elements in the Industry 4.0 transformation that affect manufacturing industries' production systems and way of working (Rosin et al., 2019). Industry 5.0 has been introduced, reinforcing the human-centric perspective onto Industry 4.0 (Nahavandi, 2019). Digital human modelling (DHM) tools is a human-centric category of simulation software that facilitates proactive consideration of ergonomics in computer-generated environments, hence requiring no physical prototypes (Scataglini &

Paul, 2019). DHM tools can for example be used at the early stages of the design process to create, visualize, assess, optimize, and verify workplace designs. In the design process of products and production systems, the activity to systematically evaluate initial alternative design solutions, often referred to as concepts, is an important step since the choice of concept has a strong impact on the subsequent steps of the design process. Several different methods for performing systematic concept assessments are available, e.g. Pugh's method for controlled convergence (Pugh, 1981), weighted concept scoring (Ulrich et al., 2020), analytical hierarchy process (Saaty, 1980), and the ELECTRE methods (Roy, 1991). Honkala et al. (2007) compare different concept selection methods, where they suggest that comparisons of concept alternatives should start with more simple methods, e.g. Pugh's method or weighted scoring methods, and if there is a reason to question the result from the more simple methods, the use of more detailed methods can be justified. Several DHM tools exist, e.g. EMA (Fritzsche et al., 2011), IPS IMMA (Högberg et al., 2016), Ramsis (Seidl, 1997), Santos (Yang et al., 2005), and Siemens Jack (Badler et al., 1993). DHM tools include several different types of assessment methods in order to evaluate the human-system interaction represented in the scenario modelled in the DHM tool, e.g. in regards to reach, vision, and risks for musculoskeletal disorders (MSDs). Despite this, and the fact that a DHM tool in essence is a computer supported design and analysis tool, none of the DHM tools provide the functionality to, in a systematic way, use the results generated in the DHM tool to compare design concepts between each other. The purpose of such a systematic comparison is to identify those design solutions that are superior compared to other design alternatives. Hence it is a convergent activity in the design process. The aim of this paper is to illustrate how a systematic concept evaluation method is integrated in a DHM tool, and to exemplify how it can be used to systematically assess design alternatives.

Methods

The DHM tool IPS IMMA was used as a software platform to demonstrate the integration. Pugh´s method was interpreted and then integrated into the software with LUA scripting to systematically compare design concepts. A graphical interface for comparing concepts was created. In order to test and illustrate the functionality of the demonstrator, four engineers were recruited as test subjects. The four engineers were familiar with DHM tools in general, and IPS IMMA in specific, and had overall knowledge about the work task represented in the test case, i.e. a pedal car assembly work. The task of the test subjects was to design a workstation layout for pedal car assembly. Four parts were to be mounted at the pedal car assembly in the station: a mud guard, a wheel, a bracket for the seat, and the seat itself. The four parts and the pedal car assembly were available with CAD models in an IPS IMMA scene. The given sequence and tasks only included manual efforts from an assembly operator and there are therefore no need for hand hold tools or other resources to mount the parts on the pedal car assembly. To simplify the test, anthropometric diversity was not considered, and therefore just one manikin was used, representing a Swedish 50th percentile male in stature.. The workstation area was not allowed to exceed 8 m2, i.e. the workstation the test subjects designed should fit inside a box in the scene. The test subjects were free to add any fixtures, logistic racks, primitives, etc. to make the workstation complete and functional before giving the manikin tasks. The subjects were creating one layout concept and were informed that four evaluation methods should be used to assess the design concepts:

1. Lundqvist OWAS index (the lower the better) (Lundqvist, 1988)

2. Arvidsson's action levels for preventing MSDs (Arvidsson et al., 2021)

3. Length of spaghetti diagram (total walking distance) (Kanaganayagam et al., 2015)

4. Percentage of time performing value adding tasks (Womack & Jones, 2003)

The design concepts were also evaluated from an "engineering cost perspective", represented by the time the test subjects spent on designing the workstation layout. The cost was measured in minutes. The clock for measuring the minutes started when the test subject received the written instruction. The subjects had accepted to participate in the test, and they were notified in advance that they would receive an email with instructions and access to software files on a specific day and time. The cost clock for a certain test subject was stopped when the IPS IMMA scene was sent back by email, i.e. representing the test subject's proposed design of the workstation layout. Three of the four subjects fulfilled the task and replied with an IPS IMMA file of the suggested workstation layout (example in Figure 1).

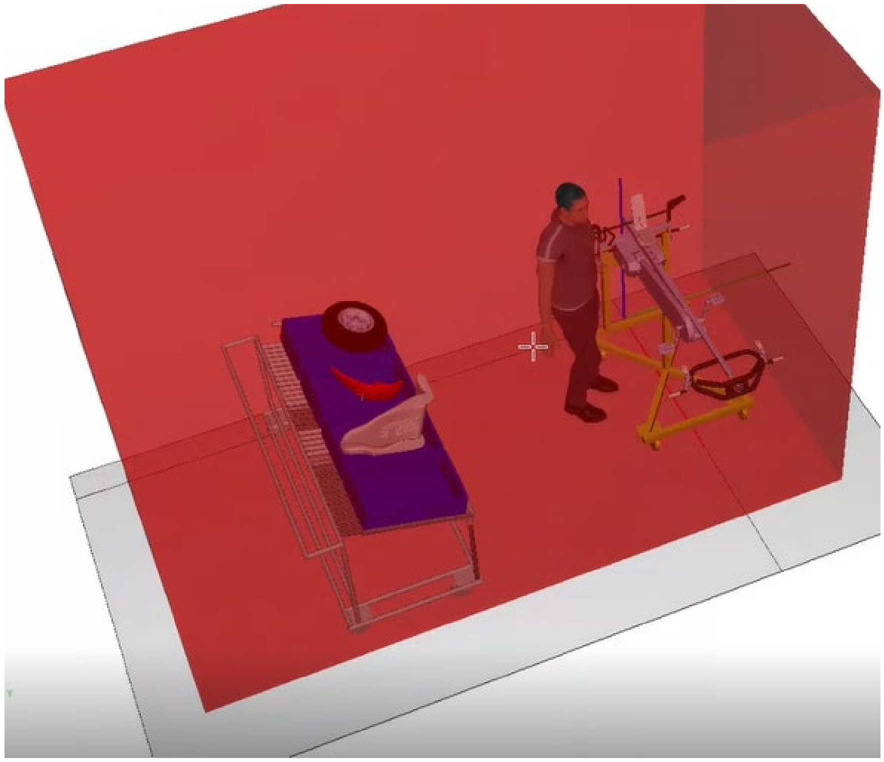

Figure 1. Example of one test subject's proposed design of the workstation layout.

Results

The result demonstrates an integrated solution where design concepts can be compared in a systematic way. The solution provides a demonstrator that provides objective design decision support, based on data automatically generated in the DHM software. When needed, data can also be manually added, as done for the "engineering cost" in this case. The demonstrator (Figure 2) includes two major steps: (1) to build up the Pugh matrix, and (2) to use the matrix for the design concept comparisons. The Pugh matrix build up phase is carried out using two major selectors: the concept alternatives selector (building the matrix horizontally), and the criterion selector (building the matrix vertically). In the first selector the design concepts, as described in unique IPS IMMA files, that are to be included in the design concept evaluation are selected. In accordance with Pugh's method for controlled convergence, one of the concepts selected will form the datum, i.e. the reference concept that all other concepts will be compared with. The second selector is the criterion selector, where the user selects the parameters to be considered in the concept evaluation. As ergonomics, per definition, regards the optimization of both human well-being and overall system performance (Wilson, 2000), the demonstrator enables adding criteria that are based on data on both human well-being and overall system performance. Here, the following two criteria were used to assess human well-being: Lundqvist OWAS index (Lundqvist, 1988) and one of the suggested action levels for preventing MSDs by Arvidsson et al. (2021), namely the right arm angular velocity. For the assessment of system performance, the following two criteria were used: length of spaghetti diagram (Kanaganayagam et al., 2015) and percentage of time spent on performing value adding tasks (Womack & Jones, 2003). The data for these four criteria came from the IPS IMMA simulation of the pedal car assembly tasks, performed by the manikin in the proposed workstation layout. Hence, objective data was retrieved automatically per design concept, based on the data provided by the DHM simulations of each concept. In the matrix it is highlighted in red if any criteria are outside the recommendation for the criteria, e.g. if an exposure exceeds the recommended action level. It is also possible for the user to add own criteria, as well as values that do not origin from the DHM simulation itself. In this case, cost based on time spend to carry out the design task was added as a criteria, and the time value per design concept was added manually. This step ends the first step to build up the Pugh matrix.

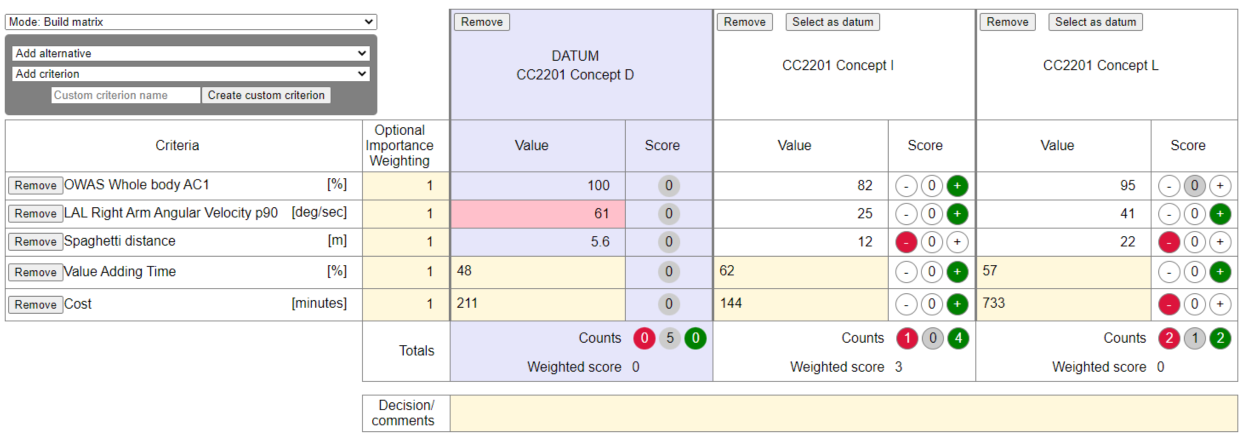

Figure 2. The Pugh concept evaluation matrix demonstrator in IPS IMMA.

The second step is the assessment step, which consist of comparing design concepts and making decisions on how to progress in the design process. In the demonstrator there is an option for the user to add weighting factors per criterion, if one or several criterions are more important than others. In accordance with Pugh's method for controlled convergence, the demonstrator provides the functionality for the user, or for a multi-disciplinary team when the concept evaluation is performed as a group activity, to rate concepts with consideration to each criterion, using the scale: worse than reference concept (-), equal to reference concept (0), or better than reference concept (+). In the summary section of Pugh's method, the numbers of -, 0 and + for each concept are automatically calculated, as well as the weighted sum of the scores. This to ease the user or the team to make decisions of how to progress in the design process, e.g.

to select a concept or several concepts to develop further, or possibly to iterate the design process in order to find even better design solutions or combine design concepts.

Discussion

The demonstrator illustrates that it is possible to perform a systematic concept evaluation based on both human well-being, overall system performance, and other parameters, where at least some of the data is automatically provided by the DHM tool. The result is very promising. A key feature of the presented approach, which is believed to be a large strength, is that the concept evaluation can be performed with support of objective data automatically generated from the simulation in the DHM tool. Thus, the potential of the DHM tool to provide objective data based on simulations of human-system interactions is used to find better design solutions. To use simulation tools to a high extent is one of the focus areas in Industry 4.0 (Nahavandi, 2019). Another focus area in Industry 4.0 is automation. The demonstrator is semi-automatic, which we believe is advantageous for concept evaluation activities, in order to facilitate transparency, dialogue in the design team, and to facilitate consideration of aspects that cannot be provided by the DHM simulation. Still, the criteria values are automatically filled in for the concepts, and quantities and sums are automatically calculated. The possibility to manually add criteria makes it possible for the user to customize the matrix. While such customized matrices most likely have been made before using tools such as spreadsheets, the demonstrator provides the functionality to make evaluations of multiple design concepts in a structured way in the DHM tool. The ability to perform the evaluation in the DHM tool will increase the efficiency as the user do not have to copy and paste information from one software to another. There is also less risk to make human errors, if information is kept within one software, or automatically transferred between different software, and do not have to be entered in another software. The ability to easily, quickly and objectively assess and compare different design concepts directly in the DHM tool is also believed to encourage the DHM tool user to find even better design solutions, hence assisting the design work being carried out in 'small loops' as discussed in Högberg (2009) as a way to enhance design process performance.

The demonstrator also facilitates method triangulation. There are several evaluation methods that have been developed to evaluate human well-being and system performance. Each of them has a unique set of advantages and disadvantages and using them in appropriate combinations is essential to get a representative evaluation that covers several relevant perspectives. The demonstrator can therefore also be used to evaluate only one design concept, where it provides the software user and the decision maker with an objective and visible overview of the success of the design proposal from the perspective of several evaluation methods. The objective and visual presentation will support the decision maker to compare the results of each evaluation method, and hence assist to make a well-founded decision. In summary, the demonstrator acts as a design decision support tool, utilizing the capability of the DHM tool to provide objective data, but also enables the user to enter additional data, and the design team to discuss and agree on decisions. The demonstrator that supports that data are transparent to the stakeholders, e.g. engineers, managers and ergonomists, and that arguments and conclusions regarding DHM simulations can be documented, stored and traced, which is in line with the guide and documentation system to support DHM tool usage proposed by Hanson et al. (2005). Even if the presented demonstrator is promising, more integration and usability work needs to be carried out based on user feedback.

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References

Arvidsson, I., Dahlqvist, C., Enquist, H., & Nordander, C. (2021). Action Levels for the Prevention of Work-Related Musculoskeletal Disorders in the Neck and Upper Extremities: A Proposal. Annals of Work Exposures and Health, 65(7), 741-747.

Badler, N.I., Phillips, C.B., & Webber, B.L. (1993). Simulating humans: Computer graphics animation and control. New York, USA, Oxford University Press.

Fritzsche, L., Jendrusch, R., Leidholdt, W., Bauer, S., Jäckel, T., & Pirger, A. (2011). Introducing ema (Editor for Manual Work Activities) – A New Tool for Enhancing Accuracy and Efficiency of Human Simulations in Digital Production Planning. Proceedings of International Conference on Digital Human Modeling, Orlando, USA, 272-281.

Hanson, L., Blomé, M., Dukic, T., & Högberg, D. (2006). Guide and documentation system to support digital human modeling applications. International Journal of Industrial Ergonomics, 36(1), 17-24.

Högberg, D. (2009). Digital human modelling for user-centred vehicle design and anthropometric analysis. International Journal of Vehicle Design, 51(3/4), 306-323.

Högberg, D., Hanson, L., Bohlin, R., & Carlson, J.S. (2016). Creating and shaping the DHM tool IMMA for ergonomic product and production design. International Journal of the Digital Human, 1(2), 132-152.

Honkala, S., Hämäläinen, M., & Salonen, M. (2007). Comparison of four existing concept selection methods. Proceedings of International Conference on Engineering Design, Paris, France, 1-11.
Kanaganayagam, K., Muthuswamy, S., & Damoran, P. (2015). Lean methodologies to improve assembly line efficiency: An industrial application. International Journal of Industrial and Systems Engineering, 20(1), 104-116.

Lundqvist, P. (1988). Psychosocial factors in the working environment of young Swedish farmers with milk production. Working environment in farm buildings. Diss. Rapport 58, Lund, Sweden, Swedish University of Agricultural Sciences, Department of Farm Buildings.

Nahavandi, S. (2019). Industry 5.0—A Human-Centric Solution. Sustainability, 11(16), 4371.

Pugh, S. (1981). Concept Selection: A Method That Works. Proceedings of the 1981 International Conference on Engineering Design, Rome, Italy, 497-506.

7th International Digital Human Modeling Symposium (DHM 2022) Rosin, F., Forget, P., Lamouri, S., & Pellerin, R. (2019). Impacts of Industry 4.0 technologies on Lean principles. International Journal of Production Research, 58(6), 1644-1661.

Roy, B. (1991). The Outranking Approach and the Foundation of ELECTRE Methods. Theory and Decision, 31, 49-73.

Saaty, T.L. (1980). The Analytical Hierarchy Process. McGraw-Hill, New York, USA.

Scataglini, S., & Paul, G. (Eds.). (2019). DHM and Posturography. Academic Press.

Seidl, A. (1997). RAMSIS, a new CAD tool for ergonomic analysis of vehicles developed for the German automotive industry. Automotive concurrent/simultaneous engineering, SAE Special Publications, 1233, 51-57.

Ulrich, K.T., Eppinger, S.D., & Yang, M.C. (2020). Product Design and Development (7th ed.). McGraw-Hill, New York, USA.

Wilson, J.R. (2000) Fundamentals of ergonomics in theory and practice, Applied Ergonomics, V31 (6), 557-567,

Womack, J.P., & Jones, D. (2003). Lean thinking. Banish waste and create wealth in your corporation. Free Press, New York, USA.

Yang, J., Marler, T., Kim, H., Farrell, K., Mathai, A., Beck, S., Abdel-Malek, K., Arora, J., & Nebel, K. (2005). Santos ™: A New Generation of Virtual Humans. SAE Technical Paper No 2005-01-1407, Warrendale, USA.