Available online at www.sciencedirect.com

ScienceDirect

Procedia Manufacturing 11 (2017) 1413 – 1420

Procedia MANUFACTURING

27th International Conference on Flexible Automation and Intelligent Manufacturing, FAIM2017, 27-30 June 2017, Modena, Italy

Virtual maintenance simulation for socially sustainable serviceability

Margherita Peruzzini[a,]* , Fabio Grandi[a], Marcello Pellicciari[a], Claudia Campanella[b]

[a]*Dept. of Engineering "Enzo Ferrari", University of Modena and Reggio Emilia, via Vivarelli 10, 41125 Modena, Italy*
[b]*CNH Industrial, Ergonomics – HMI, Design Analysis & Simulations, Viale delle Nazioni 55, 41100 Modena, Italy*

Abstract

In order to achieve more sustainable development processes, industries need not only to improve energy efficiency and reduce costs, but also to increase the operators' wellbeing to promote social sustainability. In this context, the present research focuses on the definition of a methodology based on human-centred virtual simulation to improve the social sustainability of maintenance tasks by enhancing system design and improving its serviceability. It is based on the operators' involvement and the analysis of their needs from the early design stages on virtual mock-ups. The methodology proposed merges a protocol analysis for human factors assessment and an immersive virtual simulation where immersive serviceability simulations can be used during design phases. To demonstrate the effectiveness of the proposed method, an industrial use case has been carried out in collaboration with CNH Industrial.

Keywords: Virtual simulation, Sustainability, Human-Centred Design (HCD), Ergonomics, Serviceability.

---

1. Introduction

Nowadays companies are pushed towards the creation of sustainable processes, based on the balance among environmental, economic, and social objectives [1]. Numerous examples recently demonstrated how the adoption of

---

* Corresponding author. Tel.: +39-059- 2056259; fax: +39-059-2056129
E-mail address: margherita.peruzzini@unimore.it

doi:10.1016/j.promfg.2017.07.271

sustainability principles could gain competitive advantages for companies [2]. However, real benefits can be achieved only when sustainability assessment is introduced during the early design stages, and sustainability is a real design driver that serves to optimize the sustainability performance before product creation and process definition. Only in this case, design solutions are optimized in short time, engineering changes are limited and late optimization loops are avoided [3]. According to the modern sustainability thinking, companies are asked to optimize the use of any kind of resources and consider the mutual impacts of their choices on three dimensions: profit, planet, and people [4]. In the automotive sector as well as in machining and production systems, products must guarantee high performances and reliability and must need short maintenance time, in order to make the operational costs competitive. In order to reach this goal, designers and engineers have to respect the so-called "serviceability requirement" considering also the social sustainability of the tasks to be executed. Indeed, the system design should guarantee an easy and safe operating experience, to have shorter execution times and safer tasks. In this context, human factors have to be analyzed in advance, since they affect task feasibility, operation time and costs too.

Today the application of sustainability assessment models in industry is mainly based on ex-post analyses to monitor the existing conditions by ad-hoc simulations created on monitoring the real processes [5]. As a consequence, actions are usually taken after the design stage, when products and/or processes are already developed [6][7]. Virtual Reality (VR) is commonly used throughout the design phase, starting from the conceptual design phase to digital mock-ups validation in the advanced stages of the design process. Indeed, design tasks can be successfully reviewed by full-scale stereoscopic visualization within an immersive virtual environment [8].

In this context, the paper aims at defining a design methodology to promote process sustainability by virtual simulation. The methodology consists of a structured protocol analysis to assess sustainability on both real and virtual environments, and an immersive virtual simulation to anticipate the human factors assessment during the design stage by involving real users. Indeed, in order to design human-centred systems, the operators' needs and responses have to be assessed during the early design stages and both physical and cognitive workloads have to be considered to improve the assembly process quality. The paper applies the proposed method to maintenance and service tasks in order to improve the entire process sustainability by detecting the main human-related criticalities from the design stage and to improve the product and process design to benefit product serviceability.

2. The research background

The most well known approaches to sustainability assessment are based on the definition of a set of key indicators to assess process performances (e.g., functionality, manufacturability, serviceability, environmental impact). Numerous methodologies have been developed in the last ten years for different purposes: Life Cycle Assessment (LCA) that sums the environmental impacts generated during all phases of product lifecycle [9][10]; Life Cycle Cost Analysis (LCCA) that associates total cost to all lifecycle activities [11]; and Social Life Cycle Assessment (sLCA) addressing the social dimension [12]. Recently, some researches have coupled LCA, LCCA and sLCA analyses in different industrial sectors and faced different aspect, such as lifecycle cost or human-related aspects [13][14][15]. Recently, the importance of adopting a holistic approach including different areas of sustainability (i.e., plant, profit and people) to increase product quality, customers' satisfaction, and global competitiveness has been demonstrated by several research works [16][17]. In particular, it has been proved that the social dimension of sustainability, related to human factors, highly affects the global efficiency and costs of industrial processes, from material handling to assembly, order picking, and manufacturing and maintenance operations in general [18][19]. Indeed, low attention to human factors brings to unnatural positions and dangerous actions executed by operators during their jobs, with consequent lower performances, higher production time, greater absence from work, and a general increase of Musculoskeletal Disorders (MSDs), with a great economic impact on both companies and societies. The effects of bad workplace ergonomics on productivity, quality of production, safety and costs have been demonstrated also on real case studies [20]. Such evidences are pushing companies to pay increasing attention to the evaluation of ergonomic performances. The most widely adopted methods refer to: NIOSH equation [21], Ovako Working posture Analysis System (OWAS) [22], Occupational Repetitive Actions (OCRA)[23], Rapid Upper Limb Analysis (RULA) [24], Rapid Entire Body Assessment (REBA) [25] or Workplace Ergonomic Risk Assessment (WERA) [26]. More recently several subjective methods have been introduced to better evaluate the human efforts and discomfort in task execution. However, all these methods generally require high level of detail, real process monitoring, and long data processing from direct operators' observation. This fact impedes their application during the design stages and make them applicable on physical prototypes or, usually, on the final workspace. As a consequence, such methods are used to assess ergonomics are usually time-consuming and provide validation results rather then design specification.

More conveniently, a proactive ergonomic workplace design can be adopted to prevent MSD and optimize the design of industrial systems before their creation to save money and time for late optimization [27]. It is based on the preventive evaluation of human factors to have an early ergonomic design of the workstations and tasks to be executed on digital prototypes. In this direction, some computer-aided technologies can support simulation-based engineering for preventive ergonomic analysis before the facilities are physically in place. Such tools allow workplaces and tasks to be simulated on digital mock-ups, and human actions and behaviors to be reproduced by digital human models (DHMs) [28]. A lot of different models have been developed: Siemens JACK [29], Dassault Systèmes CATIA/DELMIA HUMAN [30], RAMSIS [31], SANTOS [32], 3D Static Strength Prediction Program[33], or Anybody Modeling System [34]. Using these tools, the biomechanical attributes of specific postures, the visual scope and the reach envelope of users representing specific populations can be analyzed. Some tools also include ergonomic observational methods like RULA, OWAS or REBA, and provide a quick, virtual representation of human beings in a simulated working environment to identify the main ergonomic issues. The use of VR for validating digital mock-ups has been proved to play an important role in specific sectors, such as automotive and manufacturing [35][36].

In the context of serviceability analyses, virtual maintenance simulations are becoming an important tool to check the feasibility of maintenance tasks during the early design stages and to properly plan the maintenance operations as ell as the system design to facilitate its serviceability [37]. Process simulation on virtual mock-ups allows anticipating the analyses and avoiding late changes. However, digital simulations are not usually able to assure a robust estimation of the human workload since simulations are generally referred to discrete analysis on static positions, instead of a dynamic process simulation. As a consequence, simulations provide specific results for a certain analyzed condition, without any indication about corrective actions; they focus on physical ergonomics mainly, without considering the cognitive aspects as well as the mental workload, the effective human behaviors, and the lived experience. Furthermore, analyses are not related to the other aspects of sustainability (i.e., environmental can cost impacts).

In order to overcome such limitations, virtual simulation within immersive virtual environments could be coupled with the analysis of human factors by users' physiological parameters monitoring. The investigation of humans' behaviours by physiological data measurement such as heart rate (HR), electrocardiogram (ECG), electroencephalogram (EEG), electro-dermal activity (EDA), has been widely used in medical research to investigate diseases or other disorders and could be moved also to industrial contexts [38]. Indeed, thanks to the improved system miniaturization, the greater system usability, and the reduced technology costs, human parameters' monitoring could be adopted in addition to traditional methods to carry out a more detailed and precise behavioural analysis and stress monitoring.

3. The methodology for human factors assessment for socially sustainable serviceability

3.1. Protocol for human factor assessment for serviceability

A protocol analysis was defined to effectively measure ergonomics during maintenance tasks. It considers both physical and cognitive aspects, because both of them contribute to the operators' wellbeing and stress, which highly affect the performance (i.e., productivity, absence from work). The proposed protocol is defined on the basis of the Norman's models of perception and human-machine interaction [39]. It is assumed that the "system" determines the user actions, reactions and feedback. As a consequence, the quality perceived by the user during the user-system interaction can be measured by actions and generated feelings during task execution. From their analysis, the physical response and other aspects affecting the task execution, such as visibility and accessibility, can be inferred. However, such analysis has to be adopted quickly and easily.

For these purposes, two types of analysis are defined, referring respectively to the physical workload and the cognitive workload. For each of them, a set of metrics, measures and collecting data techniques have been defined. Physical workload is measured by two different analyses: risk assessment based on SAE J817 [40] and postural analysis based on the combination of Dreyfuss 3D [41] and OWAS analysis [22]. The SAE index is one of the most comprehensive attempts to quality the maintenance occupation in terms of equipment design, and is used to assess the risk of each analysed tasks. It is based on a set of scores, assigned to each task features related to the assumed positions, the supporting tools, the accessibility issues, and more. It is a synthetic index of the task complexity and risk for the operators. In the present case, it is adopted in a simplified way also within the virtual environments, on both digital manikins and real users during the interactive virtual simulation. Postural analysis is based on Dreyfuss 3D and OWAS. Dryfuss 3D is useful for comfort assessment for seated-posture work and for upper limbs assessment during task execution. OWAS provides a general postural assessment of the entire body posture during maintenance task. Cognitive workload is measured by visibility and accessibility analyses, which considers the visible and reachable areas respectively from the users' viewpoint. Such analyses can be carried out on both virtual manikins and interactive virtual simulation environments involving real users. Both visibility and accessibility are also monitored by eye tracking mapping. An additional metric refers to the execution time, which has been considered as an important variable: in maintenance tasks, usually duration is connected to task complexity and it has been experimentally found that longest tasks generate higher cognitive stress. For all metrics, users' observation is carried out both during simulations and on real operators' at the shop floor for simulation validation. Table 1 shows the protocol overview and describes the protocol metrics, measures, and related collecting data techniques. Among the collecting data techniques, the physiological parameters' monitoring depends on the specific adopted set-up. In the present research, the set-up includes a multi-parametric sensor to monitor different human parameters in order to objectify the human conditions in term of postural and cognitive stress.

Table 1. Protocol analysis for human factors analysis serviceability

Analysis	Metrics	Measures	Collecting data techniques
Physical workload	Risk assessment	SAE J817 (combined score)	Interactive virtual simulation Heuristic evaluation Users' observation
	Postural analysis	Dreyfuss 3D (-60; +60) OWAS score (1-7 for different indicators)	Interactive virtual simulation Heuristic evaluation Interview Users' observation Physiological parameters' monitoring
Cognitive workload	Visibility	Visibility condition (view cones' amplitude) Visibility subjective score (no.1-10) Eye tracking mapping	Interactive virtual simulation Heuristic evaluation Interview Users' observation Eye tracking Physiological parameters' monitoring
	Accessibility	Accessibility condition (reach envelopes' amplitude) Accessibility subjective score (no.1-10) Eye tracking mapping	
	Time of execution	Time of task execution	Interactive virtual simulation Users' observation

3.2. Human-centred virtual simulation set-up

The human-centred simulation set-up was arranged to carry out the maintenance tasks on mixed prototypes, combining virtual environments with physical objects. Indeed, in order to simulate a real interaction, the supporting devices (e.g., screws, pliers) as well as some components to be handled (e.g., tubes, valves, covers) are represented by real objects that the operators can directly grasp and move. Diversely, other features representative of the system layout and the product assembly where the maintenance actions are taken are virtualized and the operators interact with them virtually. In this way, the features of the virtual objects will be easily modified to test different scenarios and to optimize the product design towards serviceability. Furthermore, the operators' moving into the virtual scene was tracked to replicate its action by a personalized virtual manikin and carry out specific postural analysis on it. The arranged set-up adopted an optical tracking system made up of eight infrared cameras (Bonita by Vicon), properly configured according to the tasks to be captured. In the meanwhile, an external video camera recorded the user actions. In order to monitor the human parameters, the set-up was equipped with an eye tracking system (Glasses 2 by Tobii) to analyse the user eye movement, and a multi-parametric biosensor (BioHarness 3.0 by Zephyr) able to monitor in real time the user heart rate (HR and heart rate variability (HRV), the breathing rate (BR), the skin temperature (ST), as well as the body activity (BA) and the body posture (P) by means of accelerometers and gyroscopes. Proper software tools were used to create the virtual scene and to process the collected data. Digital mock-ups were created by JACK (by Siemens), which imports different CAD models. Mock-ups visualization is allowed by a 3D stereoscopic large volume display (6-2 meter) and interaction is simulated by motion capture and real object tracking. Data from motion capture were analysed by Tracker software (by Vicon) and integrated with JACK software in order to create personalized manikins from motion capture. For full body motion capture, a set of rigid bodies were ad-hoc created and tracked data interfaced within JACK. Eye tracking data and human monitoring data were processed by dedicated software respectively, and properly synchronized.

4. The industrial use case

4.1. Use case description

The use case has been developed in collaboration with CNH Industrial, a global manufacturer of agriculture and industrial vehicles, with more than 64 manufacturing plants and 50 research and development centers in 180 countries. It designs and produces tractors, trucks, buses, on-road and off-road powertrain solutions, and marine vehicles. The use case focused on the application of the proposed methodology for maintenance and service tasks optimization, in order to achieve socially sustainable product serviceability. The agricultural market was selected for the research. The first step was the analysis of the actual maintenance tasks on one of the most widespread tractors produced by the company, and the selection of the more critical tasks on the basis of two main indicators: frequency of intervention and related costs (derived by the maintenance time). The second step consisted of the task analysis of the most critical tasks in order to find out the human-system interaction flow and the interaction modalities. The third step referred to the task virtualization and the virtual simulation on digital mockups. The fourth step was the human-system interaction simulation within a virtual interactive environment, where operators were monitored by the above-mention human-centred virtual simulation set-up. The use of digital mock-ups allowed simulating the selected tasks on a variety of design alternative in a quick and easy way, in order to define the more sustainable design. Contemporarily, the operators' physical and mental workload was inferred by human parameters' monitoring in order to understand how comfortable they are working and how stressful the interaction was.

4.2. Tasks analysis and experimental results

The selection of the tasks to be analyzed and optimized was based on the analysis of their frequency and the related costs. Among all tasks, four tasks were selected as the most critical:

- replacement of the engine oil filter: it requires the disassembly of a huge quantity of components, it takes a long time and it is affected by limited accessibility;
- cleaning of the air cabin filters: it requires a ladder and operators' movements are complex, a huge quantity of components are involved, and it take a long time;
- cleaning of the transmission oil cooler: limited accessibility and long disassembly;
- replacement of the DEF/AdBlue® in line filter: it requires the disassembly of a huge quantity of components and the use of a not-usable pincer.

In particular, the first one is particularly expensive due to the high frequency of the task (the filter has to be replaced every 600 hours, which means about 2-3 months according to the tractors' usage). As a consequence, the research focused on the serviceability improvement of this specific task.

4.3. Simulation within virtual immersive environment

Real operators' were monitored to define the list of tasks to be simulated and the digital workplace to be reproduced. The list of sub-tasks is represented in Fig. 1 and the workflow can be synthetized as follows: 1) disassembling the toolbox; 2) removing the motor hood support; 3) removing the support bracket; 4) removing the engine electrical wiring; 5) unscrewing the engine oil filter with the key and manually (lastly); 6) screwing the engine oil filter with hands and the key. Finally actions are repeated inversely for re-assembling.

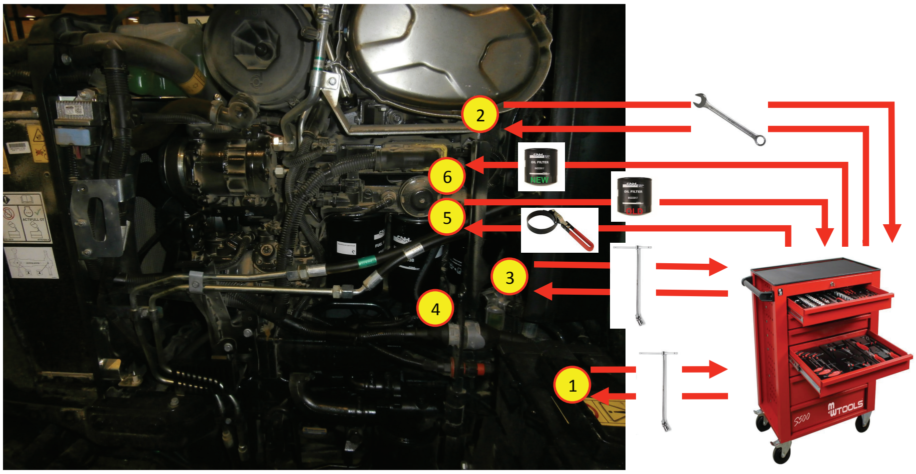

Fig. 1. Task workflow for the use case (replacement of the engine oil filter) on the real product

After task analysis, the workplace was virtually reproduced and operators' involved in task execution of both real product and virtual mock-up to validate the virtual set-up. Each action was replicated into the virtual immersive environment by real operators' and moved into the virtual scene. According to protocol analysis, Drayfuss 3D and OWAS were calculated on virtual manikins, while visibility and accessibility were analyzed on virtual manikins as well as by users' observation and direct interview during task execution. On the basis of the experimental results, different workflows were tested to define the best one in relation to the execution time. Time analysis is shown in Fig. 2. Fig. 3 shows an example of data analysis carried out for a specific task to identify the main critical factors.

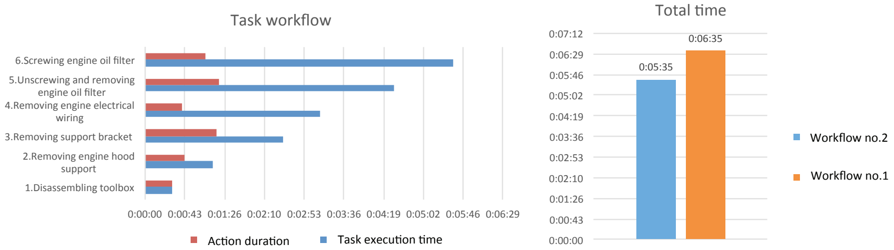

Fig. 2. Execution time analysis for the analyzed task (replace of the engine oil filter) and improvement by a new product layout

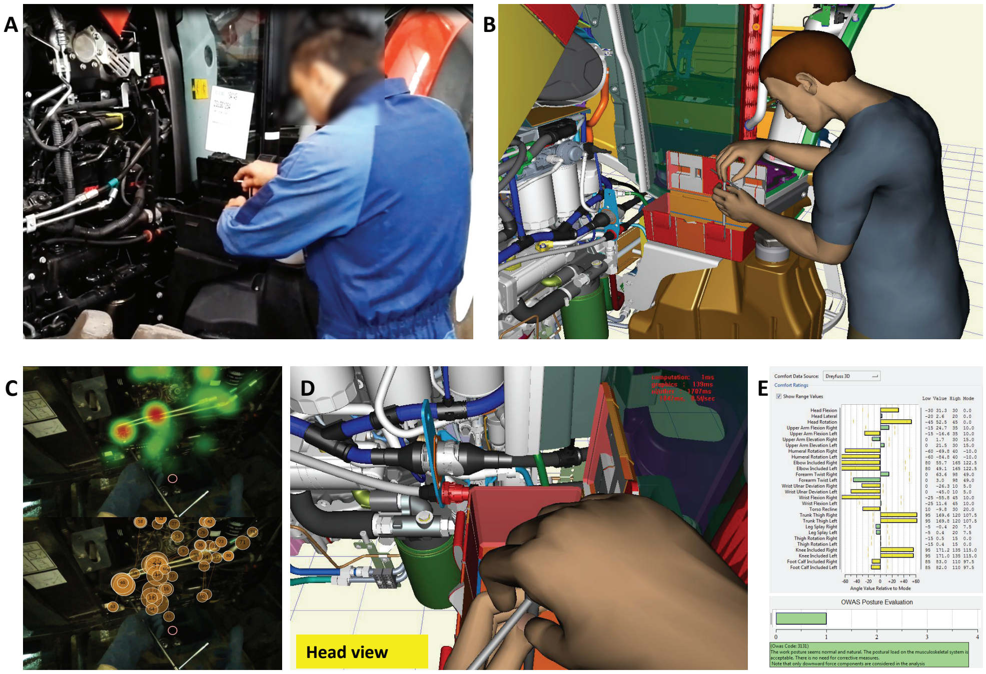

Fig. 3. Human factor analysis for the use case: the real operator (A), the virtualized operator (B), the eye tracking results (C), the visibility and accessibility analysis on virtual mock-ups (D), and the postural analysis results (E)

5. Conclusions

The paper proposed a human-centred methodology to improve serviceability considering social sustainability. The method is based on a protocol analysis to assess the operators' physical and cognitive workload, and an immersive virtual set-up were tasks are virtualized and real operators are involved to investigate their requirements and needs from the early design stages on virtual mock-ups. Human factor assessment was useful to optimize the product serviceability and to improve the operator's wellbeing and quality of work. To demonstrate the effectiveness of the proposed method, a preliminary industrial use case focused on tractors' maintenance is presented. Future works will be focused on the set-up improvement to realize a more intuitive virtual interaction (by gloves or other interactive devices).

Acknowledgements

Authors want to acknowledge CNH Industrial (http://www.cnhindustrial.com), in particular the Modena site, for its precious collaboration in the set-up definition and the preliminary tests on real industrial cases.

References

[1] T.F. Slaper and T.J. Hall, The Triple Bottom Line: What Is It and How Does It Work?, Indiana Business Review, 86 (1) (2011).
[2] M. Peruzzini, A. Luzi and E. Marilungo, Assessing sustainability and supporting compliance to standards in continuous industrial processes, Int. J. Product Lifecycle Management, 7 (2/3) (2014).
[3] A.M. Conteras, E. Rosa, M. Prez, H.V. Langenhove and J. Dewulf, Comparative Life Cycle Assessment of Four Alternatives for Using By-Products of Cane Sugar Production, Journal of Cleaner Production, 17 (2009) 772-779.
[4] M. Fisk, People, Planet, Profit: how to embrace sustainability for innovation and business growth, Kogan Page Limited, London (2010).
[5] J. Heilala, S. Vatanen, H. Tonteri, J. Montonen, S. Lind, B. Johansson and J. Stahr, Simulation-based sustainable manufacturing system design, in Proc. 2008 Winter Simulation Conference (2008) 1922-1930.
[6] E. Amrina and A.L. Vilsi, KPIs for sustainable manufacturing evaluation in cement industry, Procedia CIRP, 26 (2015) 19-23.

[7] S. Gupta, G.S. Dangayach and A.K. Singh, Key Determinants of Sustainable Product Design and Manufacturing, Procedia CIRP, 26 (2015) 99-102.

[8] G. Monacelli, VR Applications for reducing time and cost of Vehicle Development Process, Proc. 8th International Conference & Exhibition Florence ATA 2003. Florence May 14-16 (2003).

[9] ISO 14040: Environmental Management - Life Cycle Assessment - Principles and Framework, International Standard Organization (2006).

[10] ISO 14044: Environmental Management - Life Cycle Assessment - Requirements and Guidelines, International Standard Organization (2006).

[11] S. Nakamura and Y. Kondo, Hybrid LCC of appliances with different energy efficiency, Int. J. Life Cycle Assess, 11 (5) (2006) 305-314.

[12] B. Weidema, The integration of economic and social aspects in life cycle impact assessment, Int. J. Life Cycle Assess, 11 (1) (2006) 89-96.

[13] J. Parent, C. Cucuzzella and J.P. Revéret, Impact assessment in SLCA: sorting the sLCIA methods according to their outcomes, Int. J. Life Cycle Assessment, 15 (2) (2010) 164-171.

[14] A. Dobon, P. Cordero, F. Kreft, S.R. Østergaard, H. Antvorskov, M. Robertsson, M Smolander and M. Hortal, The sustainability of communicative packaging concepts in the food supply chain. A case study: part 2. Life cycle costing and sustainability assessment, Int. J. Life Cycle Assessment, 16 (6) (2011) 537-547.

[15] M. Peruzzini and M. Germani, Design for sustainability of product-service systems, Int. J. Agile Systems and Management, 7 (3/4) (2014) 206-219.

[16] V. Nappi and H. Rozenfeld, The Incorporation of Sustainability Indicators into a Performance Measurement System, Procedia CIRP, 26 (2015) 7-12.

[17] M. Peruzzini, R. Raffaeli and M. Mandolini, Towards a design-to-sustainability platform based on functional representations and simplified geometric layouts, Computer-Aided Design & Applications (2016).

[18] D. Battini, M. Faccio, A. Persona and F. Sgarbossa, New methodological framework to improve productivity and ergonomics in assembly system design, International Journal of Industrial Ergonomics, 41 (2011) 30-42.

[19] E.H. Grosse, C.H. Glock, M.Y. Jaber and W.P. Neumann, Incorporating human factors in order picking planning models: Framework and research opportunities, International Journal of Production Research, 53 (3) (2015) 695-717.

[20] A.C. Falck and M. Rosenqvist, A model for calculations of the costs of poor assembly ergonomics, Int. J. Industrial Ergonomics, 44 (1) (2014) 140-147.

[21] P.G. Dempsey, Usability of the revised NIOSH lifting equation, Ergonomics, 45 (12) (2002) 817-828.

[22] O. Karhu, R. Harkonen, P. Sorvali and P. Vepsalainen, Observing working posture in industry: Examples of OWAS application, Applied Ergonomics, 12 (1981) 13-17.

[23] E. Occhipinti, OCRA: a concise index for the assessment of exposure to repetitive movements of the upper limbs, Ergonomics, 41 (9) (1998) 1290-1311.

[24] L. McAtamney and E.N. Corlett, RULA: a survey method for the investigation of work-related upper limb disorders, Applied Ergonomics, 24 (2) (1993) 91-99.

[25] S. Hignett and L. McAtamney, Rapid entire body assessment (REBA), Applied Ergonomics, 31 (2) (2000) 201-205.

[26] M.N.A. Rahman, M.R.A. Rani and M.J. Rohani, WERA: An Observational Tool Develop to Assess the Physical Risk Factor associated with WRMDs, Journal of Human Ergology, 40 (2) (2011) 19-36.

[27] J. Dul and P. Neumann, Ergonomics contributions to company strategies, Applied Ergonomics, 40 (2009) 745-752.

[28] H.O. Demirel and V.G. Duffy, Applications of digital human modeling in industry, in V.G. Duffy (Ed.) Digital human modeling, HCII 2007, LNCS 4561, Berlin, Heidelberg, Springer (2007) 824-832.

[29] JACK, 2017, accessed in January 2017: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/manufacturing-simulation/human-ergonomics/jack.shtml

[30] DELMIA ERGONOMICS, 2017, accessed in January 2017: http://www.3ds.com/products-services/delmia/disciplines/ergonomics/

[31] RAMSIS, 2017, accessed in January 2017: http://www.intrinsys.com/software/ramsis

[32] SANTOS, 2017, accessed in January 2017: http://www.santoshumaninc.com

[33] 3DSSPP, 2017, accessed in January 2017: http://c4e.engin.umich.edu/tools-services/3dsspp-software/

[34] ANYBODY, 2017, accessed in January 2017: http://www.anybodytech.com

[35] U. Jayaram, Y. Kim, S. Jayaram, V.K. Jandhyala and T. Mitsui, Reorganizing CAD Assembly Models (as-Designed) for Manufacturing Simulations and Planning (as-Built). Journal of Computing and Information Science in Engineering, 4 (2004) 98-108.

[36] M. Peruzzini, S. Carassai, M. Pellicciari, A.O. Andrisano, Human-centred design of ergonomic workstations on interactive digital mock-ups, in Advances on Mechanics, Design Engineering and Manufacturing (2016) 1187-1195.

[37] F. Bruno, M.L. Lucchi, A. Milite, G. Monacelli, M. Pina and F. Sessa, Serviceability analyses in virtual environment for the automotive industry, Proc. Design2016 conference (2016) 447-454.

[38] N. Stanton, A. Hedge, H.W. Hendrick, K.A. Brookhuis, E. Salas, Handbook of Ergonomics and Human Factors Methods, Taylor & Francis, London (2004) 201-208.

[39] D.A. Norman, The Design of Everyday Things, New York, Doubleday (2008).

[40] SAE J817: Engineering Design Serviceability Guidelines - Construction and Industrial Machinery - Maintainability Index - Off-Road Work Machines, SAE International (2009).

[41] A.R.Tilley, The measure of men and women: human factors in design, Henry Dreyfuss Assiciates, Wiley, USA (2002).