TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 64, Issue Special I, January, 2021

ERGONOMICS IN INDUSTRY 4.0

Dorian STEF

Abstract: *In recent years, the industrial sector has been facing fierce competition in the market, imposed by the process of globalization. This paper will present a state of the art of Industry 4.0 system, review based on recent research and practice. The research approach that we propose to design a more viable architecture of the methodology for developing the activity of ergonomic modeling starts from modeling the life cycle of a product. By using, the proposed architecture using IDEF0 diagrams for the development of the ergonomic modeling activity (by immersing a real human operator into a virtual reality) it led to a simulation with a high degree of realism.*
Key words: *Industry 4.0, Ergonomic, Virtual Reality, IDEF0, Methodology.*

1. INTRODUCTION

In recent years, the industrial sector has been facing fierce competition in the market, imposed by the process of globalization. The Industry 4.0 system has grown with a high degree of expectation, due to the current IT infrastructure, which allows the industry to quick and efficiently implement the principles that stand at the base of this system. A challenge, in the Industry 4.0 systems, will be finding the human factor that has the talent and ability to develop and implement algorithms necessary for artificial intelligence, but also for the way of implementing human resource learning systems, taking advantage of the current infrastructure.

The evolution of industrial production to an Industry 4.0 offers enormous opportunities for sustainable production, using the omnipresent infrastructure in the field of information and communication technology (IT) [15].

This paper will present a state of the art of Industry 4.0 system, review based on recent research and practice. In this case, the macro and micro perspectives of Industry 4.0 will viewed and analyzed. Subsequently, sustainable production approaches combined with Industry 4.0 requirements and an overview of sustainable production opportunities will presented in the macro and micro perspective. Finally, a case of using the equipment as a specific opportunity for sustainable production in Industry 4.0 will exemplified. The studies concluded that it is important to integrate the real human operator in the virtual environments, in order to implement the Industry 4.0 system

2. THE MAIN IDEAS OF INDUSTRY 4.0

The main ideas of Industry 4.0 were initially published by KAGERMANN in 2011 [4] and created the foundation for the Industry 4.0 manifesto published in 2013 by the German National Academy of Science and Engineering [1]. At European level, the public-private partnership (PPP) for Factories of the Future (FoF) addresses and develops topics related to industry [5]. The content of Industry 4.0, in the US is promoted by the Consortium for Industrial Internet [6].

The paradigm of Industry 4.0 is essentially underlined by three dimensions [3, 7, 8] (Figure 1): (1) horizontal integration across the entire value creation network, (2) end-to-end engineering throughout the product life cycle, as well as and (3) vertical integration and network manufacturing systems:

1. Horizontal integration: represents a complex relationship between the strategic and

operational objectives at the different levels of the manufacturing systems that requires the modeling of an intelligent manufacturing system. Thus, the Stevens model used to identify different elements of the manufacturing system that require strategic planning; using standardized techniques and different scenarios as operational objectives [14].

2. Vertical integration of manufacturing systems in the network describes the cross-linking and intelligent digitization in the different levels of hierarchy of a value creation module. Vertical integration or internal integration has the role of evaluating the system, to identify the crucial areas. Regarding the vertical integration study, two components considered and presented separately for review. However, in the analysis, these components will be combined because they contain similar elements [2,3].
   a. Socio-technical system: This is a key system for organizations. Analysis of the vertical structure is crucial; aimed at providing support to the company and carrying out the activities in the program. The socio-technical system must contain three main elements: the technological system, the organizational system and the human operating system [14].
   b. Value creation modules: these are like the socio-technical system. These differ in that the value creation modules require two other elements (the product and the process) to complete the activities, which leads to a deeper analysis, especially in the field of value creation modules [7].

An Industry 4.0 paradigm will be a step towards creating a more sustainable industrial value. In the current literature, this stage mainly characterized as a contribution to the ecological dimension of sustainability. The allocation of resources, products, materials, and energy can be done more efficiently, based on intelligent modules for creating cross-linked values [2].

In addition to these environmental contributions, the Industry 4.0 has a great opportunity to achieve sustainable industrial growth on all three dimensions of sustainability: economic, social and environmental. The concepts that will presented combine the most important approaches to sustainable production in the current literature with trends and developments related to Industry 4.0.

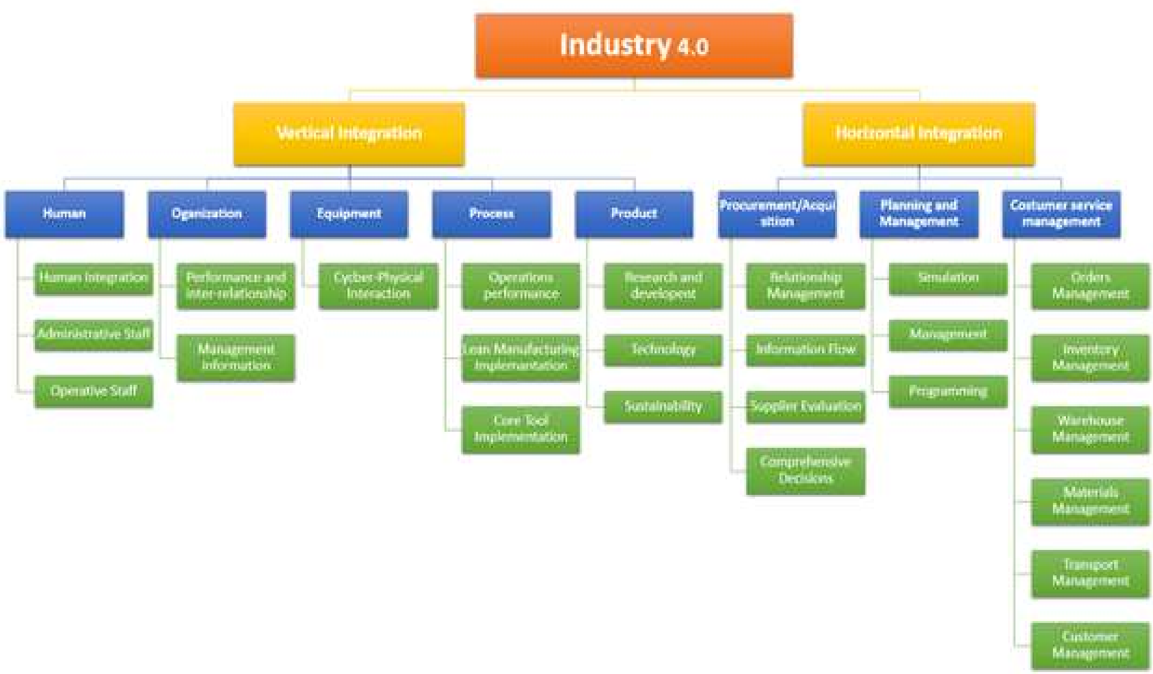

Fig. 1. The paradigm of Industry 4.0 (adapted from [15])

The macro perspective of Industry 4.0 is summarized as the sustainable production opportunities, and they are: Business Models and the Value Creation Network. For the micro perspective, to provide an overview of the opportunities, the values underlying this perspective are presented in the following.

Product - The approach for the sustainable design of products in Industry 4.0 focuses on achieving closed-loop life cycles for products, allowing the re-use and re-manufacture of the specific product or by applying the principles of product life cycle management. Different approaches to product design, in this approach, can include the customer-oriented design. These approaches can be supported by the application of identification and recognizing customer needs systems, e.g. for recognizing the needs of redesign and remanufacturing, or by applying new additional services and features to the product to achieve a higher level of customer satisfaction [19].

Process - These are the activities that give life to the product, so they considered to be a sustainable process and to have a key role in the value chain of creation, as the means to achieve the objective. The holistic approach to resource efficiency in Industry 4.0 is designing appropriate manufacturing process chains by using new technologies and through the implementation of communications systems between different equipment [18] [19].

Equipment - The equipment in the factory floor is often a capital asset whit a long depreciation period (a long-life cycle), up to 20 years or in some cases more. Retrofitting allows an easy and efficient way to modernize existing production equipment with sensor and drive systems, as well as the related control logic to overcome the heterogeneity of factory equipment [10]. Retrofitting can thus use as an approach to achieve a CPS within a value creation module, such as a factory with existing production equipment. It extends the use phase or facilitates the application in a new stage of production equipment use and can contribute to the economic and environmental dimensions of sustainability. It is especially suitable for small and medium-sized companies, being a cheap alternative to the new purchase of production equipment [9].

Human - In Industry 4.0 the people will continue to be considerate the creators in the value chain of creation [8]. Three different sustainable approaches can used to meet the social challenge in Industry 4.0:

- Increasing the efficiency of vocational training of workers by combining new IT technologies, e.g. using virtual reality glasses and augmented reality like a Learning Tools;
- Increasing intrinsic motivation and encouraging creativity by establishing new approaches based on CPS of work organization and design, e.g. by implementing flow theory concepts [17] or by using new IT technologies to implement gamification concepts (using video game to support learning) to support decentralized decision making;
- Increased extrinsic motivation by implementing individual stimulation systems for the worker, e.g. using intelligent dates from the product life cycle for providing individual feedback mechanisms.

Organization - A decentralized organization with a sustainable orientation in a smart factory is focused on the efficient allocation of products, materials, energy and considering the dynamic constraints of the CPS, e.g. of smart logistics, smart grid, self-sufficient supply or customer. This concept leads to a global resource efficiency and is described as one of the essential benefits of Industry 4.0 [2] [3].

3. THE PARADIGM OF ERGONOMIC SIMULATION

Manufacturing operations are typical cases where the involvement of the human operator is critical and influences the feasibility, duration of the operations cycle, work comfort and safety. Thus, the development of physical prototypes, for researching the factors of human mode of action, has positive effects on the working cycle and on the cost of workmanship in such operations. These considerations determine the need to integrate human factors into the design and simulation of industrial processes using advanced simulation techniques.

Modeling and simulating the movements of the different human segments (elements) of the body is a very complex task, for this purpose specialists often recourse to using preliminary studies for the movement by studying movements made by the real human operator. Capturing the intuitive movements of the human operator, but also the interaction between human and machine carried out in the actual process on the manufacturing flow, requires detailed knowledge of the mode of action and the mobility of the human factor [9].

In the last period, different virtual reality techniques have been studied, in view of the potential applicability in the simulation of real industrial processes. The studies concluded that it is important to integrate the real human operator in the virtual environments, to implement the Industry 4.0. Several systems have been developed that are based on virtual reality, largely focused on simulation on manual assembly processes.

The virtual reality techniques conceived do not yet provide clear and justifiable results (economically) for quantitative and ambiguous evaluation of the characteristics of the work processes in which human operators are involved. Support for human factor verification is limited to qualitative assessments of performance characteristics, without detailed quantitative analysis [12] [13].

Furthermore, the virtual reality technique, the 3D modelling environment and powerful computers have been used in excess for the modeling and simulation of human movement, especially to investigate the interaction of the human operator with the work environment or with complex products [16].

Several commercial software tools using digital mannequins have been available to facilitate human modeling and ergonomic analysis, in product, processes and workplaces design. They have used to verify human interactions in digital and/or virtual environments; these means replace the human operator with anthropometric representations of human joints, resulting a digital dummy. It provides a clear and useful path for ergonomic analysis, while the virtual reality technology ensures the machine's explicit programming ability to perform multiple tasks, such as: moving, lifting, firing, etc. However, this may be too complex or may result in incorrect results because it cannot accurately reproduce the natural movements of the human operator. Therefore, the means of simulation used today have a lack of realism.[20]

4. RESEARCH DEVELOPMENT FRAMEWORK

A consequence of the ones presented above, the analysis of the implementation mode of Industry 4.0, the ergonomic analysis of the manufacturing tasks that involve the intervention of the human operator achieved by modeling and analyzing a particular workload, with the help of a real human operator. To accomplish this task, a valid and reliable alternative is a user immersion system, which can make representations with high accuracy of the human body, achieved by capturing the movement, which would transferred and implemented within a virtual environment [11].

The objectives proposed for this initiative are oriented on:

- Creating an environment for implementing the immersion mode of the human operator;
- To allow a human operator immersed in the virtual environment, to perform different work tasks, in a realistic way;
- Realization of a database with the spatial path determined by the actions of the submerged human operator;
- Collecting best practices and developing guides for future trainings;
- Performing the immersion process of the operator in the virtual environment.

Because the product design, cycle is characterized by a multitude of loops, iterations, necessary adaptations in all its activities, and it is imposing special data maintenance and version management. It must be ensured that the update of the resulting data is continuous and immediately available to all interested parties, especially in case of changes.

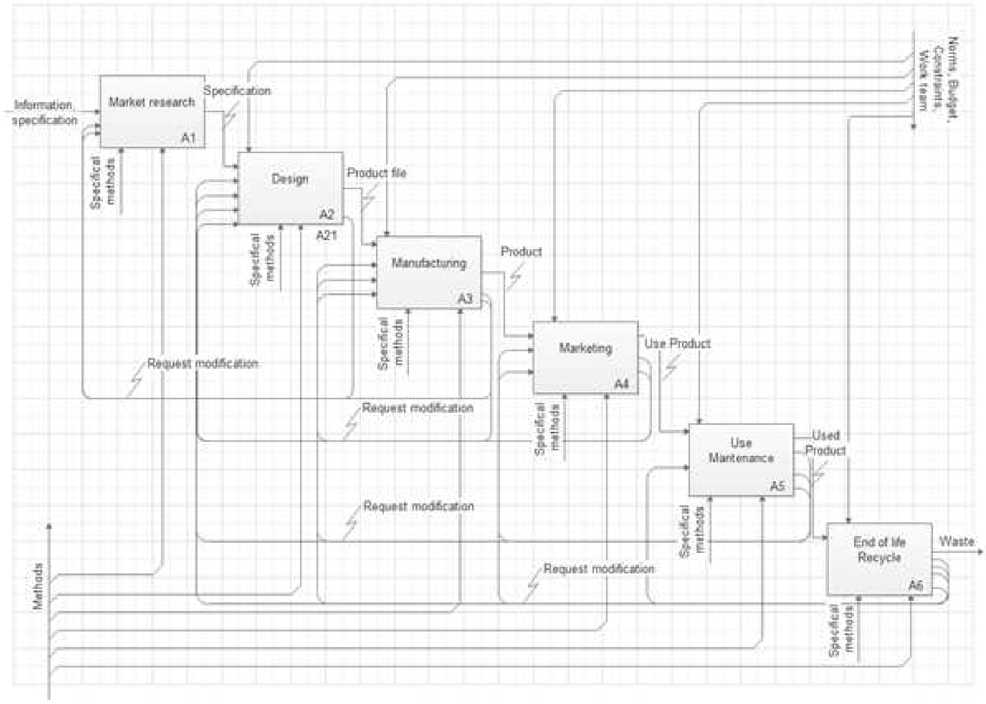

Fig. 2. Modeling the life cycle of a product using IDEF0

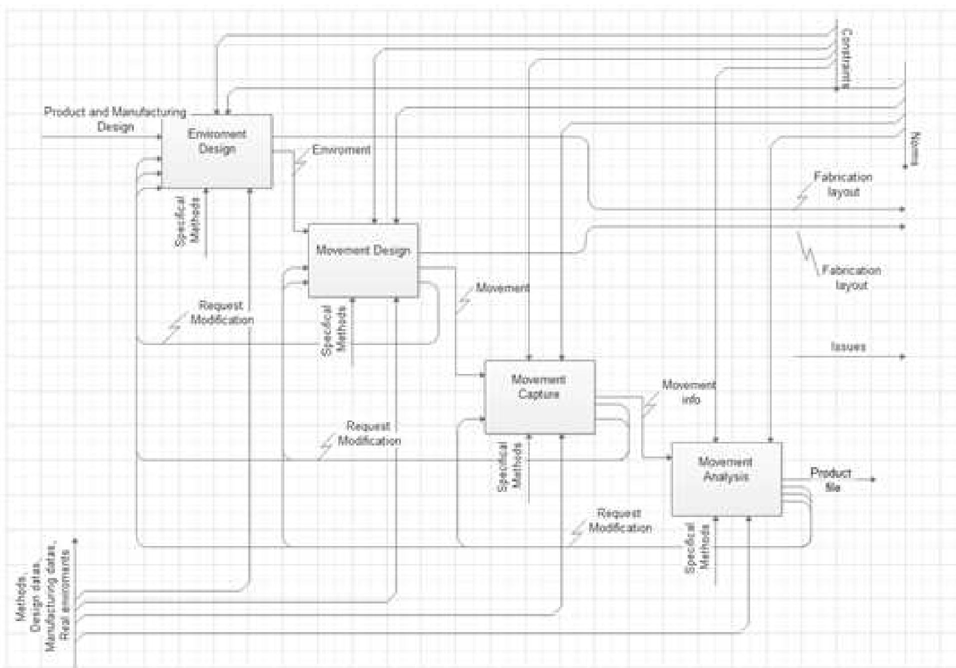

Fig. 3. Process of Ergonomic activity

The research approach that we propose to design a more viable architecture of the methodology for developing the activity of ergonomic modeling starts from modeling the life cycle of a product. For this, the product life cycle considered as a set of activities. To decompose the product life cycle, the iGrafx 2011 program was used, which contains the IDEF0 (Integration Definition Function) module [21].

To reach the design process modeling, it started with modeling the product life cycle.

Thus, the upper-level diagram, called A0, contains the activities of the life cycle, considering the inputs, outputs, methods/means of assistance and the constraints of each activity as shown in Figure 2.

The reduction of time until the launch of a product on the market influenced by the frequency of reconfiguration of the manufacturing system. Each time a product is changed or modified, in terms of its essential components (subassemblies) or just the addition of new components, the manufacturing process is modified, as a result, it is necessary to create a new ergonomically analysis (similar with the approaches described in [22; 23; 24; 25]). Thus, defining the environment for implementing the immersion mode of the human operator, the first step suggested in the proposed objectives, based on the virtual reality, involves the design of the immersion environment of the operator.

The concept of the environment leads to the generation of the simulation characteristics of the interaction of the human operator, this activity facilitates the realistic manipulation of the objects in the virtual environment. This provides means for defining the connection relation of the components, as well as the manufacturing or assembly parameters (in the immersion process) relative to the exact position of the components relative to their position.

The activity of movement design takes into account the virtual environment designed in the previous activity and allows the drawing an adequate map of the actions for the human operator according to the ergonomic regulations, whit the plan of the activity that it is going to carry out and whit the process floor layout dimensions (Figure 3).

This activity of movement designing, more precisely of the movement map, based on the desire to position and move properly and as naturally as possible the human body of the user that will be immersed in the virtual environment.

After developing the design of the motion map, the next activity purpose in the research approach is to immerse the human operator in the virtual environment. To fulfill this activity will be using virtual reality equipment (virtual reality glasses) and capturing the movements of the real human that immersed in the virtual environment by using kinetic cameras that can capture all the movement makes. The results of this activity are the acquisition data from the kinetic cameras that are with high fidelity of the movement of the human body that immersed in the virtual environment and accomplishes the designed movement.

The last proposed activity in the decomposed of the ergonomic activity is that of analyzing the data acquired from the kinetic cameras of the movements performed by the human operator immersed in the virtual environment (as supported by the research presented in [22; 23]). This activity facilitates the necessary adjustments for the virtual model (design of the product), the virtual environment (design of the floor layout), but especially of the position and orientations (movement map) of the human operator in context whit all the elements from the designed environment whit the purpose of generating collision detections and to create an appropriate global positioning map.

5. CONCLUSIONS

Through the research undertaken in this paper and following of the analysis of the paradigm and especially the essential elements of the three dimensions for the integration of Industry 4.0. It was observed that for the implementation of the Industry 4.0 system it is needed a lot of time because the equipment currently in the industrial environment has a long life cycle, so the human operators intervention in the manufacturing chain is still necessary. Additionally, it has observed that, within the Industry 4.0 paradigm, it desired to increase the professional training efficiency of human operators by combining new IT technologies, increasing intrinsic motivation and encouraging creativity, increasing extrinsic motivation by implementing individual incentive systems for the worker.

At present, in the process of modeling the ergonomic simulation of the human movement, the computing resources for the 3D modeling used in excess, but also the necessity of increasingly powerful computers to create the interaction of the human operator with the working environment or the complex products that are going to be manufactured. These means lead to the replacement of the human operator with a 3D anthropometric representation, providing a clear path and used for ergonomic analysis, but this approach can provide incorrect results. Based on the conclusions drawn so far, we will be proceeded to model the design process, having as a starting point the modeling of the product life cycle, developing the structural model using the IDEF0 language. Following the modeling of the product life cycle using the IDEF0 diagrams, the activities that will be needed to develop the product was identified, but more precisely the activity of the ergonomic simulation of the manufacturing process. A preliminary set of constraints appear during the design cycle, were identified the methods and the means of conception and a form of the architecture of the methodology development was drawn.

By using, the proposed architecture using IDEF0 diagrams for the development of the ergonomic simulation activity and by immersing a real human operator and using virtual reality techniques, it will be led to a simulation with a high degree of realism. This simulation performed can will respond to one of the desires noted in the analysis of the Industry 4.0 system, namely the increase of the efficiency of the professional training of the human operators by carrying out interactive simulation/training sets using the systems and equipment of virtual and augmented reality (similar to [24; 25]).

Future work will consist of the development of the infrastructure based on the proposed architecture that uses IDEF0, needed to have the possibility to immerse the real human in the virtual reality and to create the simulation environment as real as possible. To a good immersing of the real human into the virtual environment will try to use the virtual reality glasses (for that we will start to develop new forms of virtual glasses, that are easier to use) and to develop a methodology (architecture) for creating easily various virtual environment

6. REFERENCES

[1] Acatech, *Umsetzungsempfehlungen für das Zukunftsprojekt Industrie 4.0 – Abschlussbericht des Arbeitskreises Industrie 4.0*. Acatech, 2013.

[2] Kagermann, H., Lukas, W., Wahlster, W., *Abschotten ist keine Alternative*. In: VDI Nachrichten, Issue 16, 2015.

[3] Plattform Industrie 4.0, *Industrie 4.0 Whitepaper FuE-Themen*. Plattform Industrie 4.0, 2015.

[4] Kagermann, H., Lukas, W., Wahlster, W., *Industrie 4.0 - Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution*. In: VDI Nachrichten, Issue 13, 2011.

[5] European Commission, *Factories of the Future*. http://ec.europa.eu/research/industrial_technologies/factories-of-the_future_en.html

[6] Industrial Internet Consortium, *Manufacturing*, http://www.iiconsortium.org/vertical-markets/manufacturing.htm.

[7] Acatech, *Umsetzungsstrategie Industrie 4.0 Ergebnisbericht der Plattform Industrie 4.0*. acatech, 2015.

[8] VDI/VDE-GMA: *Statusreport Referenzarchitekturmodell* Industrie 4.0. VDI/VDE-GMA, 2015.

[9] Drăghici, A., *Ergonomie – Aspecte novatoare ale cercetării ergonomice*, Vol.2, Editura Politehnica, Timisoara, 2007.

[10] Spath, D., Ganschar, O., Gerlach, S., Hämmerle, M., Krause, T., Schlund, S., *Produktionsarbeit der Zukunft – Industrie 4.0*. Fraunhofer IAO, Fraunhofer Verlag, 2013.

[11] Mavrikios, D., Karabatosu, V., Alexopoulos, K., Chryssolouris, G., *Tehnici avansate de concepţie centrate pe utilizator – Paradigma bazată pe realitate virtuală*, Ergonomie – Aspecte novatoare de cercetării ergonomice, Vol.2, Editura Politehnica, Timisoara, 2007.

[12] Chryssolouris, G., Mavrikios, D., Fragos, D., Karabatosu, V., *A Virtual Reality based experimentation environment for the verification of human related factors in assembly processes*, Robotics & Computer Integrated Manufacturing, Vol. 16, pp. 267-276, 2000.

[13] Chryssolouris, G., Mavrikios, D., Fragos, D., Karabatosu, V., Alexopoulos, K., *A hybrid approach to the verification and analysis of assembly and maintenance*

process using Virtual Reality and Digital Mannequin technologies, in: Nee A.Y.C. and Ong S.K. (Eds.) Virtual Reality and Augmented Reality Applications in Manufacturing, London, Springer-Verlag, pp. 97-110, 2004.

[14] Stock, T., Seliger, G., *Opportunities of Sustainable Manufacturing in Industry 4.0* 13Th Global conference on Sustainable Manufacturing – Decoupling Growth form Resource Use, Procedia CIRP, pp. 536-541, 2016.

[15] Perez-Lara, M., Saucedo-Martinez, J., Marmolejo-Sacedo, J.A., Salaris-Fierro, T., Vasant, P., *Vertical and horizontal integration systems in Industry 4.0*, Springer Nature, https://doi.org/10.1007/s11276-018-1873-2, 2018.

[16] Stock, T., & Seliger, G., *Opportunities of sustainable manufacturing in Industry 4.0*. Procedia CIRP, 40(Icc), 536. https://doi.org/10.1016/j.procir.2016.01.129. 2016.

[17] Engeser, S., Vollmeyer, R., *Tätigkeitsanreize und Flow-Erleben*. In: Vollmeyer, R.; Brunstein, J.C. (Hrsg.), Motivationspsychologie und ihre Anwendungen, 2005.

[18] Swat, M., Brünnet, H., Bähre, D., *Selecting manufacturing process chains in the early stage of the product engineering process with focus on energy consumption*. In: Technology and Manufacturing Process Selection: The Product Life Cycle Perspective, Springer, 2014.

[19] Uhlmann, E., Fürstmann, P., Rosenau, B., Gebhard, S., Gerstenberger, R., Müller, G., *The Potential of Reducing the Energy Consumption for Machining TiAl6V4 by Using Innovative Metal Cutting* Processes. In: Proceedings of the 11th Global Conference on Sustainable Manufacturing GCSM2013, 2014.

[20] Larsson, T., Larsson, A., Leifer, L., Kobayashi, H., *Design for Wellbeing*. www.designforwellbeing.org, 2015.

[21] Stef, D., *Dezvoltarea produsului in contextual fabricii digitale*, Ed. Politehnica, PhD. Thesis, Timisoara, 2012.

[22] Cirjaliu, B., & Draghici, A. *Ergonomic issues in lean manufacturing*. Procedia-Social and Behavioral Sciences, 221, 105-110, 2016.

[23] Neag, P. N., et al. *Ergonomic intervention combined with an occupational and organizational psychology and sociology perspectives in production systems*. MATEC Web of Conferences. Vol. 305. EDP Sciences, 2020.

[24] Riel, A., Draghici, A., Draghici, G., Grajewski, D., & Messnarz, R., *Process and product innovation needs integrated engineering collaboration skills.* Journal of Software: Evolution and Process, 24(5), 551-560 (2012).

[25] Dragoi, G., Draghici, A., Rosu, S. M., & Cotet, C. E., *Virtual product development in university-enterprise partnership*. Information Resources Management Journal (IRMJ), 23(3), 43-59 (2010).

Ergonomia în Revoluția Industrială 4.0

Rezumat: În ultimii ani, sectorul industrial se confruntă cu o concurență acerbă pe piață, impusă de procesul de globalizare. Această lucrare va prezenta o sinteză a fenomenului Revoluției Industriale 4.0 bazată pe cercetări și practici recente. Demersul pe cercetare pe care îl propunem pentru a concepe o arhitectură cât mai viabilă a metodologiei de dezvoltare a modelarii ergonomice a unui produs, pornește de la modelarea ciclului de viață al produsului. Prin utilizarea arhitecturii propuse, dezvoltată sub forma modelelor grafice de tipul diagramelor IDEF0, au fost dezvoltate activitătii de modelare ergonomică (prin imersia operatorului uman într-un mediul virtual, folosind tehnici de realitate virtuală) un grad ridicat de realism.

Dorian STEF, Lecturer, PhD. Politehnica University Timisoara, Material and Manufacturing Engineering Department, Bd. Mihai Viteazu No. 1, Timisoara, Romania, dorian.stef@upt.ro