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The Sustainable Role of Human Factor in I4.0 scenarios

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Abstract

The ageing of working population is the byproduct of the global recognized trend of the general population ageing. The decline of elder human operators' capabilities is a main subject concerning industrial engineering and management in the ongoing 4th Industrial revolution and the introduced new technologies. In this paper, the concept of human factor sustainability inside manufacturing line is explored. It is discussing the theoretical fundamentals of a complexity based states loop to be tested inside 4.0 frame. This is pointing on advanced ICT technologies for ageing workforce management in manufacturing lines. The paper starts with a systematic literature review on the ageing workforce inside industries highlights the human capabilities deterioration, knowledge and experience management of ageing workers. The review is used as the key trace of the modified human factor sustainability concept including Physical, Behavioural, Mental and Psychosocial dimensions. Those are related with the age factor while discussing about traits and entropy based information probability. Furthermore, the proposed formula of Human Factor (HF) probability with a context based application is discussed. Finally, some conclusion remarks will be given, and the future agenda will be proposed based on the collaborative work scenarios.

Keywords: Ageing; Sustainability; Human Factor; Complexity.

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1. Workforce management in 4.0 era

Integration of robotics and cyber-physical systems (CPS) in workspaces can lead to increased productivity and improvement in the operation of an Industrial plant due to real-time monitoring and less downtime in the assembly

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and manufacturing line. This, however, demands a flawless cooperation with the human workforce which must evolve and learn new skills while keeping their level of productivity at the same level. Training simulations and real-time practice can be a consistent solution on how the workforce can adapt to the new situation, but how the human operators will respond in the new demands of his changed workspace environment is still an issue concerning several factors. Those factors can be grouped into three main categories conditioned by external behaviours: (i) Physical or HUMAN-SYSTEM related, (ii) Mental or HUMAN-KNOWLEDGE based and (iii) Psycho-Social or HUMAN-group based AGE formed. Age (and experience depending on the years working on a certain work position) is the linking factor to all these categories and is considered a growing concern due to population ageing. The ageing workforce is a global trend acknowledged by governments, institutions and economists [14]. It is mainly attributed to the low birth rates and is estimated that the workforces' age will rise dramatically by 2060 if the circumstances remain as it is [13, 47].

Elder workers are valuable in terms of their skills and experience. They are a source of knowledge that can be transferred to the newer generation [19, 33]. A worker that is ageing, gradually deteriorate in term of his physical skills (such in dexterity and physical abilities), mental skills (such in behaviour and mental abilities) and cognitive abilities (such in working memory, learning and reaction time). The impacts of those changes in the industrial plants of the present and future is a serious concern and is investigated by industrial engineering and research societies. The sustainability of human workforce must be considered in the decision making of Industrial business. Issues regarding the categories of human factor and their connection to the "new" workspace (collaborative robots, CPS) is a subject for further research.

This paper is divided into three sections. In the first section, the characteristics of an ageing worker are presented in industrial engineering. A short analysis of the current literature is presented on the issues of ageing human operators working on assembly lines. In the second section, the focus is the presentation of the human factor sustainability concept inside the Industry. The concepts of safety based behavioural, mental, physical and psychosocial sustainability are discussed regarding a human operator inside the Industry. In the third section, the initial formula of human factor calculation is presented along with a brief theory presentation of statistical mechanics that were used as the foundation for this part of the project. Figurative tests are performed based on industrial context as per previous published papers [16].

2. Ageing workforce assessment

To comprehend the ageing deterioration of a worker, in this section a brief literature review has been performed. The review has two goals; first one is on how industrial engineering research and decision making consider elder and/or ageing workers and the second goal is to present how the abilities (physical, mental and cognitive) of workers deteriorate through ageing. How many articles cover the area of human factor sustainability? What type of contribution (type of research) is being conducted in this area? What class of human factor management is covering? Are some of the principal research questions we are addressing. So, we analysed, and selected, a large Scopus database search – with the intent to make a deep clusterization as per sustainability traits: "ageing/older", "human factor/workforce" and "Industry/manufacturing". The combination of these keywords have been used on the Scopus database resulting in a starting total of 239 papers. To refine the initial results we used the following criteria:

- Language: English
- Source Type: Journal
- Area of Interest: Engineering/Ergonomics and Social Science-Cognitive Science

The resulting number of papers through this process (Figure 1) were 75. With further added restriction on date (2005-today) and a second screening based on content, title and abstract reading, the final derived number of selected papers was 49. In the second screening, the main criteria for inclusion into the list of selected paper was relation with industrial engineering and management, and information on ageing workforce and knowledge/experience management.

The selected papers were categorized into three main categories (Table 1): the "Human-System" capabilities referring to the physical, mental and cognitive abilities, the "Human- Knowledge" based issues referring to the management and exploitation of ageing workers experience and knowledge, and the "Human-Ageing" factors in the hierarchy of industrial modelling and management.

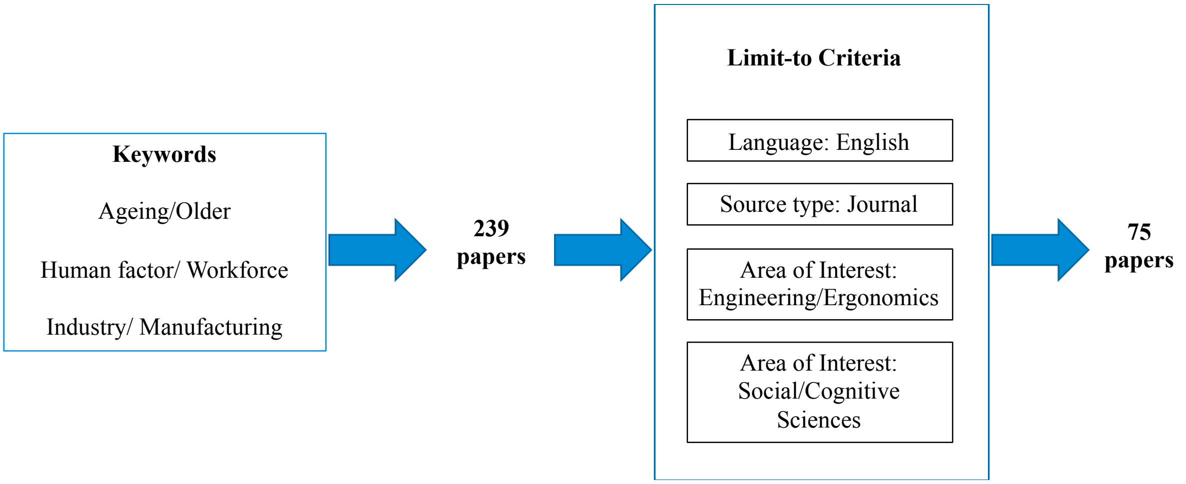


Fig. 1. Systematic literature review and resulting number of papers for each step.

2.1. Human-System Management

The productivity of a human operator inside a manufacturing/industrial workplace is related to his capabilities, be it physical, mental or cognitive. As the human operator age, part of his functional characteristics starts to diminish as demonstrated in several publications [12, 46] but has not been considered a concern to the overall system productivity as the experience of an older worker could bridge the gap those diminished abilities created [5, 54]. The ongoing advancement of robotics and CPS systems inside manufacturing, in preparation of the Industry 4.0 age, and the need for the human operators to evolve into smart operators capable of interacting and working with those systems, is raising some concerns on older workers capacity to adapt to the new environment [4].

Older workers tend to develop muscle fatigue faster, as was reported by Qin *et al* [38] by using electromyography sensors (EMG) when they are assigned with a heavy task that needs to be repeated throughout their working day, risking continuous muscular injuries. Chen *et al* [10] and Kowalski *et al* [24] studied the psychological profile by limit setting maximum weightlifting for older workers in contrast to their younger counterparts. Neuman et al [35] studied musculoskeletal disorders and injuries on manufacturing workers. Landau *et al* [26-27] researched how musculoskeletal disorders can affect the workers long-term; even when their working routine changes to low demand lifting, older workers suffer from previous trauma in their neck, spine, shoulder and upper limbs. Verma *et al* [50] observed that trauma from injuries become more frequent and more sever the older the worker is.

Moreover, there are studies that showcase the impact of environment inside the workspace has on ageing workers. Ongoing noise exposure can affect the workers fatigue levels even on shift work as was reported by Saremi *et al* [40]. Cold exposure can have impact on older workers; Development of back pains on workers through ongoing exposure in cold workspaces was studied by Thetkathuek *et al* [48]. Nardolillo *et al* [34] studied the differences of how workspace environment affects workers of varied ages; concluding that management decision making should include age-classification when assigning tasks and workspaces.

Several studies have reported that older group of workers needs more time or more trials to learn a new task or a new soft skill than their younger counterparts [41, 53]; Fritzsche e*t al* [15] and Gilles *et al* [18] reported lower performance on movement and decision process of older workers. The issue of shift work has been studied as well [6]. Rouch *et al* [39] studied the possible difficulties ageing workers may face with shift work; their work reported no clear indication of interaction between age and shift work. On the other hand, Van de Ven *et al* [49] in his work, reported sleep problems (disturbed sleep, short duration and negative mood when waking up) of the older workers of shift work assignments. The relationship of work ability and quality of life with the age group of workers was the focus of Sorensen *et al* [43]. Neupane *et al* [36] reported on the linkage between different age groups and their work satisfaction with the work environment and its arrangements.

Table 1. Categories arranged as per papers selected for literature analysis. Main connection (references) with Categories and Traits of figure 2 is here reported. Acronyms (in grey colour) as per legend of figure 2.

HUMAN-SYSTEM Management		**HUMAN- KNOWLEDGE** management		**HUMAN-AGEING** management	
Rouch et al (2005)	B_SRK; PH_E; PH_TE	Lombardi et al (2009)	B_SRK; M_C; PS_P	Olstein et al (2005)	PH_TE; M_C; PS_P
Kowalski-Trakofler et al (2005)	B_SRK; B_M; M_C	Puevo et al (2011)	PH_TE	Kawakami et al (2006)	M_F; M_C; PS_I
Schwerba et al (2007)	B_SRK; PH_MR; PH_TE	Arezes et al (2013)	B_SRK; PH_E; PS_P	Weichel et al (2010)	B_SRK; M_F; PS_I
Landau et al (2008)	B_SRK; PH_E; M_C; PS_E	Massingham et al (2014)	B_SRK; PH_MR	Becker et al (2012)	B_SRK; PH_TE
Saremi et al (2008)	PH_E; PH_MR; M_F	Massingham (2018)	B_SRK	Kumashiro et al (2014)	PH_E; PH_MR; M_F
Sorensen et al (2008)	B_SRK; PH_MR; M_F	Volberg et al (2017)	B_SRK; PH_MR; PH_TE	Boenzi et al (2015)	M_F; M_C
Verma et al (2008)	PH_MR; M_F	Srilakshmi et al (2018)	B_SRK; PH_MR; PS_E	Jeon et al (2016)	B_SRK; PH_TE; M_F; M_C
Wilker et al (2009)	PH_MR; M_C	Massingham et al (2018)	PH_TE; PS_E	Botti et al (2017)	B_SRK; PH_TE
Kawakami et al (2009)	PH_MR	Strasser (2018)	B_SRK; B_M; M_C	Sokas et al (2019)	PH_TE; PS_I
Blok et al (2011)	PH_MR; M_F	Battini et al (2018)	PH_E; M_F	Calzavara et al (2020)	B_SRK; PH_E
Landau et al (2011)	PH_E	Abubakar et al (2019)	B_SRK; B_M; PH_MR; PH_TE		
Stamov-Roßagnel et al (2012)	B_M; PS_E	Guvernator et al (2020)			
Fritzsche et al (2014)	PH_E; PS_I; PS_P				
Neupane et al (2014)	PH_MR; PS_P				
Qin et al (2014)	B_M; PH_MR; M_F				
Xu et al (2014)	B_SRK; PH_TE; PS_I				
Thetkathuek et al (2015)	PH_MR; PH_TE; M_F				
Van de Ven et al (2016)	B_M; M_C; PS_P				
Binoosh et al (2017)	PH_TE				
Chen et al (2017)	PH_MR; M_C				
Gilles et al (2017)	PH_MR; PH_TE; M_F				
Nardolillo et all (2017)	PH_MR; PH_TE; M_F				
Neumann et al (2018)	B_SRK; PH_E				
Di Pasquale et al (2020)	B_SRK; M_C; PS_E				

2.2. *Human-Knowledge Management*

The experience that older worker possess is an important resource for management, despite their diminishing physical and cognitive abilities. Srilakshmi *et al* [44] reported that older workers, with the experience and knowledge they possess on their workspace, can compensate the disadvantages they have in terms of physical abilities and energy. Abubakar *et al* [1] showed that experience is considered more important in the skillset of human factor than younger age, cognitive abilities and individual performance. Volberg *et al* [51] reported that decrease in certain type of injuries is related to experience of older workers since they have better knowledge of their working environment. Furthermore, older experienced worker are more conscious of using their protective gear while working [2-3, 28]. Strasser [46] stated that experienced workers avoid injuries by planning their tasks ahead of time and quickly, are highly autonomous and can identify when situations can become critical. Massingham [30-32] in his experimental tests demonstrated that knowledge management can be an effective tool in transferring the knowledge and experience from older workers to younger workers.

2.3. *Human-Ageing Management*

Knowing the capabilities (physical, mental and cognitive) of older workers and how relevant is the experience in terms of strategies and transferred knowledge, the issue, now, is how the decision making of industries can use them to properly manage and support the ageing workforce. One proposal is alternating the job rotation scheduling by age group differences and how high- or low- physically demanding is the work task as reported by four different research papers [7-8, 20, 52]). Retirement policies and new ICT technology should be an open issue for management as suggested by Olstein [37]. Kawakami *et al* [22-23] demonstrated how effective use of work tasks by older workers and the use of automation can benefit the manufacturing line. Kumashiro [25] studied long-term system designs by enabling and using ergonomic support systems. Sokas *et al* [42] proposed that older workers should be provided with career training for management positions and mentoring newer workers. Calzavara *et al* [9] proposed new ergonomics and human factor management research paths for the Industry 4.0 age.

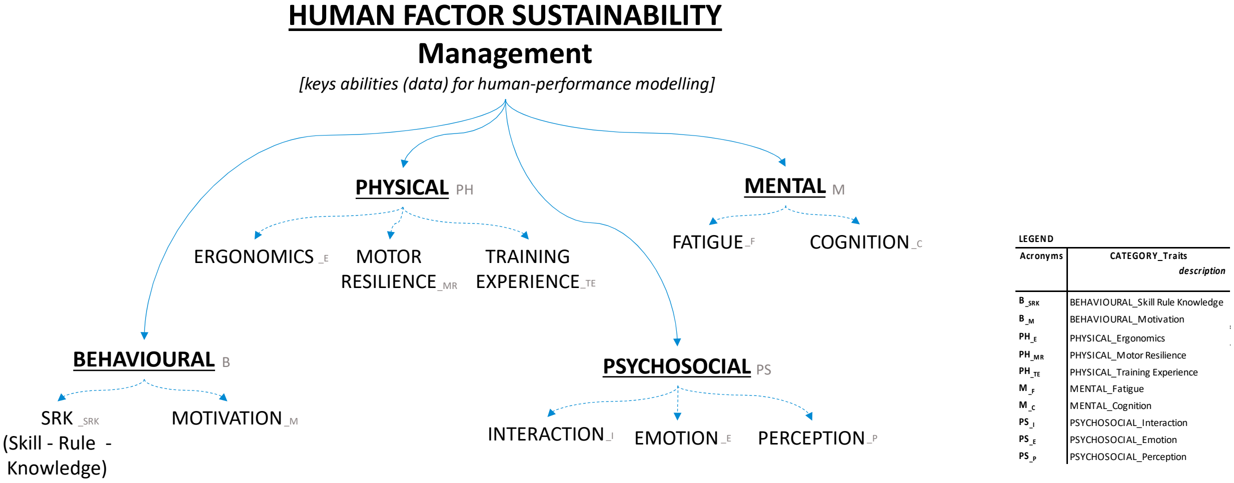
3. The Sustainability of Human Workforce in Industry 4.0 context

The fourth Industrial revolution (I4.0) basic concept is the integration of advanced technologies into manufacturing. Here, Cyber-Physical Systems (CPS), those can provide real time data on the state of production, aided by the Internet of Things (IoT), which include cloud and cognitive computing, collected data and trend exports; machine to machine collaboration, advanced collaborative robotics, 3d printing and mobile technologies (e.g. augmented reality tools) performs work with the utmost productivity. All of the new technologies require and produce a large streamline of data, making the big data analytics an essential part of the new era.

The benefit of combining those advanced technologies for industrial management and decision-making can lead to increased productivity and real-time monitoring of potential critical issues subject to maintenance. Thus, the workforce is required to evolve into smart operators capable of handling the new equipment and able to process the influx of data and react in real time; while keeping the same level of production. In other words, the process of manufacturing and keeping the same level of production while having to deal with big data must be sustainable.

The concept of sustainability has a different definition based on the main streamline viewed upon. It is a combination of the words “sustain” and “able”. The word “sustain” is used to describe something that can be given support, helped to keep up or that it is able to keep up in time. Sustainability can be used to describe that something (e.g environment, production, product, economics) can be kept at the same level over time. There are a lot of research papers dealing with sustainable manufacturing and sustainable supply chains in Industry 4.0; Kamble *et al* [21] in his systematic literature review analysed trends and perspectives of sustainable frameworks in I4.0, Stock *et al* [45] studied sustainable manufacturing for I4.0 and Luthra *et al* [29] studied supply chains sustainability in emerging economies.

In this work, the aim is to present our initial study and ideas on a modified concept of human factor sustainability in the I4.0 scenarios. Human factor inside the workplace needs to achieve sustainability in four categories: *(i)* Behavioural, *(ii)* Physical, *(iii)* Mental and *(iv)* Psychosocial (figure 2).



LEGEND

Acronyms	CATEGORY_Traits *description*
$B_{\_SRK}$	BEHAVIOURAL_Skill Rule Knowledge
$B_{\_M}$	BEHAVIOURAL_Motivation
$PH_{\_E}$	PHYSICAL_Ergonomics
$PH_{\_MR}$	PHYSICAL_Motor Resilience
$PH_{\_TE}$	PHYSICAL_Training Experience
$M_{\_F}$	MENTAL_Fatigue
$M_{\_C}$	MENTAL_Cognition
$PS_{\_I}$	PSYCHOSOCIAL_Interaction
$PS_{\_E}$	PSYCHOSOCIAL_Emotion
$PS_{\_P}$	PSYCHOSOCIAL_Perception

Fig. 2. Human Factor Sustainability Categories and Traits. Acronyms as per legend

i. **BEHAVIOURAL** sustainability (mainly related to safety issue, and procedural based actions) is important for management and worker both; management needs to provide a safe workplace to its human workforce to avoid losing its resources (production and workforce) and the human operators need be cautious to avoid any injury as it will cost them physically and mentally. For the I4.0 era where collaborative robots are part of the manufacturing line, human operators need to be able to co-exist in the same environment without fearing of their safety. In this context, *"Skills and Rules and Knowledge"* (i.e., SRK) acts on the controllability of the process. To achieve safety sustainability, the workers need to have sufficient knowledge of new technologies. Standards for Human-System interfaces are required and have to be differentiated according to personal skills and attitudes. Workforce reactions to contingences changes over time. Personal *"Motivation"* engrave human reaction to new technologies and arrangement in the workplace environment.

ii. **MENTAL** sustainability is linked with the physical stress and subsequently with *"Fatigue"*. It is also connected with the cognitive, and *"Cognition"* based, abilities of the human factor and is dependent on the age group of workers. To maintain sustainability in this category, management need to ensure that workers are not overloaded with information and knowledge as to avoid mental stress and eliminate wasteful activity during their work shift.

iii. **PHYSICAL** sustainability relates to the physical abilities of workers and is connected with the age group. Ageing workers need to avoid heavy loads as to avoid injuries and younger workers need not to be overloaded as to avoid chronic injuries. Sustainability can be achieved by *"Training Experience"* workers in the new ergonomic designs and advanced *"Ergonomics"* robotic designs, which will assist in heavy workloads and preserve their physical *"Motor Resilience"* both short-term (work shift) and long-term (avoiding physical load will help in avoiding chronic pains).

iv. **PSYCHOSOCIAL** sustainability is dependent both on groups of workers and individuals. With the integration of robotics and CPS, a human operator can possibly be alone in his workplace alongside collaborative robots and augmented reality tools losing communication with co-workers. The *"Interaction"* factor, based on HMI assessment, reports product and process quality outcomes. It can affect his *"Emotion"*, depending on the personality of the operator, which may lead him to have an identity crisis on his position inside his work and potentially lead him to leave his position or develop mental fatigue even quicker than normal. Promoting human Interactions inside the working environment and reassuring human operators of their values inside manufacturing can assist in sustainability of their psychological and social profile. In this context, the *"Perception"* workload work-context is the first bias to external stimulus and, consequent, reactions.

4. The Human Factor Probability of action

The working environment of Industry 4.0 can be considered complex as it stands in the regime between a regular working motion and chaotic motion; interactions and work tasks ruled by some disorder of strong chaos while maintaining the order required to work. The human operator in this environment will be required to perform his work task by collaborating with robots and interacting with cyber systems (e.g. AR/VR tools) and maintain his productivity to high levels. However, from the literature analysis we derived that the workforce population overall is ageing and that the capabilities of those workers deteriorate in some regards, bringing into attention the need to have a mean of measuring the human operator at work based on his capabilities.

As discussed in previous sections, the human factor and its sustainability represent a concept of complex factors: behavioral, mental, physical and psychosocial. These factors can be described, as macro-states of the human state and, as seen in the literature review, are dependent on the age group of the human operator. Non-extensive statistical mechanics (complexity theorem) can be used to study a possible formulation of the human factor probability of action. It must be noted that further research into which parameters of those macro-states may or may not affect the human operator at work or may affect him before starting his work tasks is required.

4.1. The Boltzmann-Gibbs and Tsallis Entropy

Statistical mechanics are used to identify the nature and laws of a given system. The process of defining a system requires the use of microscopic laws and with the help of probability theory through which we can identify the connection between micro- and macro- states by using the concept of entropy. The most recognizable form of entropy is the classical one, which was proposed by Ludwig Boltzmann:

$$S_B = k\ln(\Omega) \tag{1}$$

where k is the Boltzmann's constant and Ω represents the total number of microstates of the system. The equation is used for equal probabilities microstates. The generalized Boltzmann-Gibbs (BG) entropy is given by:

$$S_{BG} = -k\sum_{i=1}^{\Omega} p_i \ln(p_i) \tag{2}$$

With the normalization condition for each i and p as the probability of a microstate:

$$\sum_{i=1}^{\Omega} p_i = 1 \tag{3}$$

Tsallis in 1988 proposed a generalized theory for entropy, which can describe non-extensive systems. This new entropy is defined by the following equations:

$$S_q = \frac{k}{q-1}\left(1-\sum_{i=1}^{\Omega} p_i^q\right), \tag{4}$$

The q parameter of the equation defines the degree of non-extensivity of the system, where for $q=1$, the equation gives the classical entropy theory of BG. The Ω represents the total number of micro-states, each with a probability of p_i, and the sum of probabilities satisfy equation 3. Tsallis proposed entropy can be used in Shannon's Information theory, where the entropy S_S is replaced by S_q.

$$S_q = -\sum_{i=1}^{\Omega} p_i \log p_i \tag{5}$$

A higher content of information (probability amount) about micro-states limits the entropy amount. We can limiting the complexity (avoid uniform probability) of human reaction while controlling endogenous factors and making continuous steady state snapshots of working system. A higher entropy is after "free choice". The Operator Choice Complexity is linked with the theoretical entropy of information. The higher is the entropy thus the lower is information thus the lower is reliability as unpredictability fixed outcomes (i.e., magnitude) of actions.

4.2. Model Conceptualization

To enable the use of complexity theory in our problem we make two consensus:

1. The general state of operator is defined as a natural state,
2. Human is defined by four macro-states: Physical, Mental, Behavioural and Psychosocial.

With those two consensus, we now can lay the similarities of our system with the foundation of a system that can be described by statistical mechanics:

i. The dynamic interaction inside the workplace (and the effect on human operator) are considered as the microscopic dynamics of our system (similar to N-body/elements/fields systems microscopic dynamics). Time in this system can be measured as the time of a work shift or the time set by the management (week, month, year, etc.).
ii. Initial conditions of this system are the operator state and the state of the cyber systems and entities in the systems (e.g., agents in system are governed by Operational rule in need of effectiveness).
iii. For long evolution time, the system will reach a stationary state or quasi-stationary state.
iv. Initial conditions for the human operator state that we are examining are non-consequential to our measurements, thus the use of complexity theory
v. The entropy function, which we correlate with the human factor in our system, can be defined since, we can measure the probabilities of our macro-states.

The above points cover the basic foundations for a system described by statistical mechanics and thus, the formulation of our model along with results from its testing are presented below.

4.3. Measuring the Human Factor Probability of error

The dynamic workplace of I4.0 era is comprised by technologies such as collaborative robots (cobots), CPS systems and virtual and/or augmented reality tools along with IoT technology. The human operator in this working environment is subjected to a lot of information and data; some of those information and data may be redundant. The overload of information and environmental workplace conditions can lead to decrease in productivity for the human operator and may lead to injuries or accidents due to stressful conditions. Thus, we need a way to calculate the state of human operator in the dynamic workplace environment. The research questions we tried to answer is how the human operator reacts and how his capabilities are stressed by the dynamic interactions in his environment and the influx of real-time data stream towards workers. From the literature review we can derive that the major contributing factor for reactions and capabilities is the age of the human operator. For example, younger workers have higher capacity of learning new technologies and their physical capabilities are still on their prime. On the other hand, older workers are more experienced and have better mental fortitude and behaviour towards their working tasks.

Assuming same working conditions, information received and the same dynamic working environment for younger and older workers, the human factor can be defined as a complex equation that is dependent by age groups and, as seen in Figure 2, is comprised from the following macro-states (groups), (i) the mental state (*M*), (ii) the physical state (*PH*), (iii) the behavioural state (*B*) and (iv) the psychosocial state (*PS*):

$$HF_I = f(M, PH, B, PS)^a \tag{6}$$

The *HF* represents a probabilistic function for a human operator at work (with a fixed *I*nformation based behaviour) and can be represented in a general form by the following gaussian function:

$$HF_I = exp\left[-\left(\frac{PH\times M}{PS\times B}\right)^a\right] \tag{7}$$

where α factor is dependent on the age group and ranges from -1 to 1 [-1, 1]. Younger workers have the α factor equal to -1 and for older workers the α factor is equal to 1.

The formulation of equation 7 has been tested over common weekly arrangements for an automotive (we used virtual and real environment) cobot system. We used smartwatch to measure heartbeat frequency, and blood pressure. We implemented video recording to capture pupil dilation and eyes movement. We simulated a virtual scenarios to create the ergonomics indexes and to elaborate fatigue using standards equations from literature (as per Fruggiero *et al.* [16]). Breaks and work-shift load were measured according to the Human Error probability simulator (SHERPA) scenarios [11]. Questionnaires and AHP decision based approach were used to capture personal work attitude and main psychosocial factors (as per Fruggiero *et al.* [17]). Correlation between data over weekly task was measured, in experimental approach, with a discrete time based control for smartwatch data recording. We selected worker basing on age (2 categories) and sex (2 categories); we tested scenarios basing on noise (2 levels) and light arrangements (2 levels); we arranged task on 3 levels of difficulties. Experimental data reports correlation between pupil dilation and heartbeat frequency (consequently fatigue). They increase under growing task complexity while does not report remarkable differences over age level (figure 3a., 3b., 3c.).

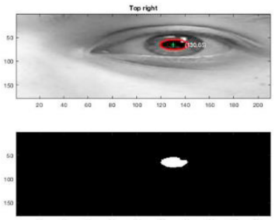


Fig. 3. (a) The pupil dilation [snap] capture

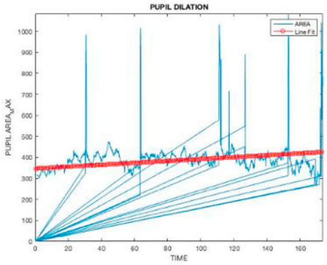


Fig 3. (b) The pupila delation [snap] measurement over time stamp (second). Peaks as per eyes closure/opening

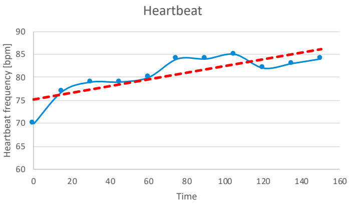


Fig 3. (c) The Heartbeat frequency [bpm] snap over time stamp

The analysis of HF_I revealed that Aged workers reports the higher, even though stable, error probability under different works arrangement/conditions when working in robot collaboration. The lowest error probability can be gained with young workers where variability in control remains the sticking point (fig.4(a) e 4(b)). In this case the behavioral sustainability gains role in system. It is a remarkable note that such results represent preliminary data and They require major investigation for further conclusions. They confirm the expected shape and the validity in formulation.

5. Conclusion

In this work, the current view of industrial engineering and social sciences on ageing workforce, and how management can identify and use the experience of those workers in the manufacturing process, is presented. Furthermore, it showcased that current research is focused on how to maximize human productivity on the new industrial era, but does so by the scope of industrial management and not by the scope of the human operators; how the human workforce will react and is reacting on the integration of I4.0 technologies inside the industry is not studied in any great length. Moreover, the sustainability concept of human factor inside the manufacturing lines of I4.0 based on the concepts of safety, mental, physical and psychosocial capabilities of human operators is presented. Author proposed a complexity based analysis while presenting a Human Factor Probability analysis based on main shaping factors and error monitoring. They, consistently with the literature analysis [12], reported the effect of ageing in the new implemented scenarios; large scale validation of the proposal is the focus of the future agenda of this work.

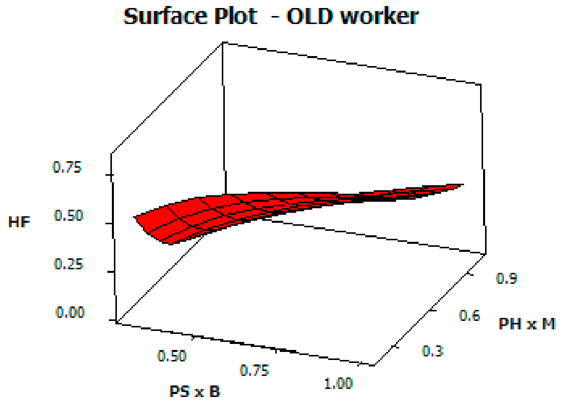


Fig.4. (a) The HF_I analysis for AGED worker (α =1) over different Behavioural, Mental, Physical and Psychosocial conditions (range from 0,1 to 1)

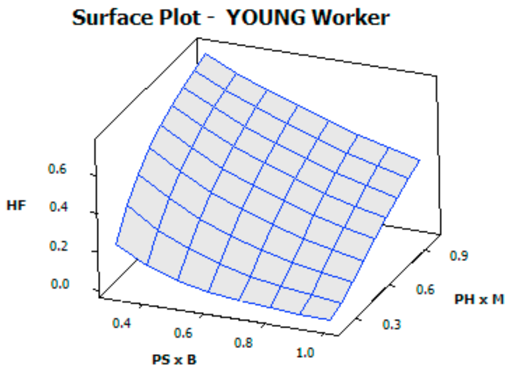


Fig.4. (b) The HF_I analysis for YOUNG worker (α =-1) over different Behavioural, Mental, Physical and Psychosocial conditions (range from 0,1 to 1)

References

[1] Abubakar, M. I., and Q. Wang. 2019. "Key Human Factors and Their Effects on Human Centered Assembly Performance." *International Journal of Industrial Ergonomics* 69: 48–57.

[2] Arezes, P. M., and A. S. Miguel. 2013. "Assessing the use of Hearing Protection in Industrial Settings: A Comparison Between Methods." *International Journal of Industrial Ergonomics* 43 (6): 518–525.

[3] Battini, D., M. Calzavara, A. Persona, F. Sgarbossa, V. Visentin, and I. Zennaro. 2018. "Ergonomics and Human Factors in Waste Collection: Analysis and Suggestions for the Door-to-Door Method." *IFAC-PapersOnLine* 51 (11): 838–843.

[4] Becker K., Fleming J., Keijsers W., 2012. "E-learning: Ageing workforce versus technology-savvy generation." *Education and Training* 54(5): 385-400.

[5] Binoosh, S. A., G. M. Mohan, and D. Bijulal. 2017. "Assessment and Prediction of IndustrialWorkers' Fatigue in an Overhead Assembly job." *South African Journal of Industrial Engineering* 28 (1): 164–175.

[6] Blok, M. M., and M. P. de Looze. 2011. "What is the Evidence for Less Shift Work Tolerance in Older Workers?" *Ergonomics* 54 (3): 221–232.

[7] Boenzi, F., S. Digiesi, G. Mossa, G. Mummolo, and V. A. Romano. 2015. "Modelling Workforce Aging in job Rotation Problems." *IFAC-PapersOnLine* 48 (3): 604–609.

[8] Botti, L., C. Mora, and M. Calzavara. 2017. "Design of job Rotation Schedules Managing the Exposure to age-Related Risk Factors." *IFAC-PapersOnLine* 50 (1): 13993–13997.

[9] Calzavara M., Battini D., Bogataj D., Sgarbossa F., Zennaro I., 2020. "Ageing workforce management in manufacturing systems: state of the art and future research agenda." *International Journal of Production Research* 58(3): 729-747.

[10] Chen, J. A., C. R. Dickerson, R. P. Wells, and A. C. Laing. 2017. "Older Females in the Workforce–the Effects of age on Psychophysical Estimates of Maximum Acceptable Lifting Loads." *Ergonomics* 60 (12): 1708–1717.

[11] Di Pasquale V., Fruggiero F., Iannone R., Miranda S. A model for break scheduling assessment in manufacturing systems Computers and Industrial Engineering, 111 (2017), pp. 563-580

[12] Di Pasquale V., Miranda S., Neuman P.W., 2020. "Ageing and human-system errors in manufacturing: a scoping review." International Journal of Production Research., Vol 58, Issue 15, pages 4716-4740.

[13] EU-OSHA. 2017. "Joint Report on Towards Age-friendly Work in Europe: A life-course Perspective on Work and Ageing from EU Agencies." *Publications Office of the European Union*, Luxembourg.

[14] EU-OSHA. 2019. "Third European Survey of Enterprises on New and Emerging Risks." *Publications Office of the European Union*, Luxembourg.

[15] Fritzsche, L., J. Wegge, M. Schmauder, M. Kliegel, and K.-H. Schmidt. 2014. "Good Ergonomics and Team Diversity Reduce Absenteeism and Errors in car Manufacturing." *Ergonomics* 57 (2): 148–161.

[16] Fruggiero, F., Fera, M Iannone, R., Lambiase, A., 2018 Revealing a frame to incorporate safe human behaviour in assembly processes, IFAC-PapersOnLine, vol. 51, Issue 11, Pages 661-668.

[17] Fruggiero F., Fera M., Lambiase A., Di Pasquale V. (2020) Linking Human Factors to Assess Human Reliability. In: Ferraguti F., Villani V., Sabattini L., Bonfè M. (eds) Human-Friendly Robotics 2019. HFR 2019. Springer Proceedings in Advanced Robotics, vol 12. Springer, Cham.

[18] Gilles, M. A., J.-C. Guélin, K. Desbrosses, and P. Wild. 2017. "Motor Adaptation Capacity as a Function of age in Carrying out a Repetitive Assembly Task at Imposed Work Paces." *Applied Ergonomics* 64: 47–55.

[19] Guvernator IV G.C., Landaeta R.E., 2020. "Knowledge Transfer in Municipal Water and Wastewater Organizations." *EMJ – Engineering Management Journal*.

[20] Jeon, I. S., B. Y. Jeong, and J. H. Jeong. 2016. "Preferred 11 Different job Rotation Types in Automotive Company and Their Effects on Productivity, Quality and Musculoskeletal Disorders: Comparison Between Subjective and Actual Scores by Workers' age." *Ergonomics* 59 (10): 1318–1326.

[21] Kamble S. S., Gunasekaran A., Gawankar S. A., 2018. "Sustainable Industry 4.0 framework: A systematic literature review identifying the current trends and future perspectives." *Process Safety and Environmental Protection* 117: 408-425.

[22] Kawakami, M., Y. Kajihara, T. Ukai, H. Izumi, and Y. Sanbayashi. 2006. "IT-based Job Enlargement System for AgingWorkers." *Journal of Japan Industrial Management Association* 56 (6): 460–470.

[23] Kawakami, M., and K. Yamanaka. 2009. ""A Study on Energy-Efficient Temperature Control".World Academy of Science." *Engineering and Technology* 58: 1098–1101.

[24] Kowalski-Trakofler K.M., Steiner L.J., Schwerha D.J., 2005. "Safety considerations for the aging workforce." *Safety Science* 43(10): 779-793.

[25] Kumashiro, M. 2014. "An Approach of Ergonomics and Management in Occupational Health for a Society of Aging Workers." *Journal of Japan Industrial Management Association* 65 (2): 124–130.

[26] Landau, K., H. Rademacher, H. Meschke, G. Winter, K. Schaub, M. Grasmueck, I. Moelbert, M. Sommer, and J. Schulze. 2008. "Musculoskeletal Disorders in Assembly Jobs in the Automotive Industry with Special Reference to age Management Aspects." *International Journal of Industrial Ergonomics* 38: 561–576.

[27] Landau, K., R. Brauchler, M. Diaz-Meyer, J. Kiesel, A. Lenz, H. Meschke, and A. Presl. 2011. "Occupational Stress Factors and Musculo-Skeletal Disease in Patients at a Rehabilitation Center." *Occupational Ergonomics* 10 (4): 139–153.

[28] Lombardi, D. A., S. K. Verma, M. J. Brennan, and M. J. Perry. 2009. "Factors Influencing Worker use of Personal Protective Eyewear." *Accident Analysis and Prevention* 41 (4): 755–762.

[29] Luthra S., Mangla S. K., 2018. "Evaluating challenges to Industry 4.0 initiatives for supply chain sustainability in emerging economies." *Process Safety and Environmental Protection* 117: 168-179.

[30] Massingham P., 2014. "An evaluation of knowledge management tools: Part 1 – managing knowledge resources." *Journal of Knowledge Management* 18(6): 1075-1100.

[31] Massingham P., 2014. "An evaluation of knowledge management tools: Part 2 – managing knowledge resources." *Journal of Knowledge Management* 18(6): 1101-1126.

[32] Massingham P., 2018. "Measuring the impact of knowledge loss: a longitudinal study." *Journal of Knowledge Management* 22(4): 721-758.

[33] Massingham P.R., Massingham R.K., 2014. "Does knowledge management produce practical outcomes?" *Journal of Knowledge Management* 18(2): 221-254.

[34] Nardolillo, A. M., A. Baghdadi, and L. A. Cavuoto. 2017. "Heart Rate Variability during a Simulated Assembly Task: Influence of Age and Gender". Proceedings of the Human Factors and Ergonomics Society. 2017-October,, 1853–1857.

[35] Neuman P.W., Winkel J., Palmerud G., Forsman M., 2018. "Innovation and Employee Injury Risk in Automotive Disassembly Operations." *International Journal of Production Research* 56(9): 3188-3203.

[36] Neupane, S., P. Virtanen, T. Luukkaala, A. Siukola, and C.-H. Nygård. 2014. "A Four-Year Follow-up Study of Physical Working Conditions and Perceived Mental and Physical Strain among Food Industry Workers." *Applied Ergonomics* 45 (3): 586–591.

[37] Olstein, M. A. 2005. “Managing the Coming Brain Drain.” *Journal / American Water Works Association* 97 (6): 60–67. + 12.

[38] Qin, J., J.-H. Lin, B. Buchholz, and X. Xu. 2014. “Shoulder Muscle Fatigue Development in Young and Older Female Adults During a Repetitive Manual Task.” *Ergonomics* 57 (8): 1201–1212.

[39] Rouch, I., P. Wild, D. Ansiau, and J.-C. Marquie. 2005. “Shiftwork Experience, age and Cognitive Performance.” *Ergonomics* 48 (10): 1282–1293.

[40] Saremi, M., O. Rohmer, A. Bonnefond, A. Muzet, P. Tassi, and A. Burgmeier. 2008. “Combined Effects of Noise and Shift Work on Fatigue as a Function of age.” *International Journal of Occupational Safety and Ergonomics* 14 (4): 387–394.

[41] Schwerha, D. J., S. F.Wiker, and M. Jaraiedi. 2007. “Effect of Distractors, age, and Level of Education upon Psychomotor Task Learning.” *International Journal of Industrial Ergonomics* 37 (43382): 801–809.

[42] Sokas R.K., Dong X.S., Cain C.T., 2019. “Building a sustainable construction workforce.” *International Journal of Environmental Research and Public Health* 16(21): 4202.

[43] Sörensen, L. E., M. M. Pekkonen, K. H. Männikkö, V. A. Louhevaara, J. Smolander, and M. J. Alén. 2008. “Associations Between Work Ability, Health-Related Quality of Life, Physical Activity and Fitness among Middle-Aged men.” *Applied Ergonomics* 39 (6): 786–791.

[44] Srilakshmi, K., and R. Kulkarni. 2018. “Productivity of Senior Employees - A Case Study with Reference to Selected Pharmaceutical Industries.” *International Journal of Mechanical Engineering and Technology* 9 (1): 680–686.

[45] Stock T., Seliger G., 2016. “Opportunities of Sustainable Manufacturing in Industry 4.0.” *Procedia CIRP* 40: 536-541.

[46] Strasser, H. 2018. “The “art of Aging” From an Ergonomics Viewpoint - Wisdoms on age.” *Occupational Ergonomics* 13 (S1): 1–24.

[47] The Economist. 2017. “As Japan Ages, so too does its Workforce.” The Economist Group Limited, 7 January 2017.

[48] Thetkathuek, A., T. Yingratanasuk, W. Jaidee, and W. Ekburanawat. 2015. “Cold Exposure and Health Effects among Frozen Food Processing Workers in Eastern Thailand.” *Safety and Health at Work* 6 (1): 56–61.

[49] Van de Ven, H. A., J. J. L. van der Klink, C. Vetter, T. Roenneberg, M. Gordijn, W. Koolhaas, M. P. de Looze, S. Brouwer, and U. Bültmann. 2016. “Sleep and Need for Recovery in Shift Workers: Do Chronotype and age Matter?” *Ergonomics* 59 (2): 310–324.

[50] Verma, S. K., D. A. Lombardi,W.-R. Chang, T. K. Courtney, and M. J. Brennan. 2008. “A Matched Case-Control Study of Circumstances of Occupational Same-Level Falls and Risk of Wrist, Ankle and hip Fracture in Women Over 45 Years of age.” *Ergonomics* 51 (12): 1960–1972.

[51] Volberg, V., T. Fordyce, M. Leonhard, G. Mezei, X. Vergara, and L. Krishen. 2017. “Injuries among Electric Power Industry Workers, 1995–2013.” *Journal of Safety Research* 60: 9–16.

[52] Weichel, J., S. Stanic, J. A. Enriquez Diaz, and E. Frieling. 2010. “Job Rotation - Implications for old and Impaired Assembly Line Workers.” *Occupational Ergonomics* 9 (2): 67–74.

[53] Wiker, S. F., D. J. Schwerha, and M. Jaraiedi. 2009. “Auditory and Visual Distractor Decrement in Older Worker Manual Assembly Task Learning: Impact of Spatial Reasoning, Field Independence, and Level of Education.” *Human Factors and Ergonomics in Manufacturing* 19 (4): 300–317.

[54] Xu, X., J. Qin, T. Zhang, and J.-H. Lin. 2014. “The Effect of age on the Hand Movement Time During Machine Paced Assembly Tasks for Female Workers.” *International Journal of Industrial Ergonomics* 44 (1): 148–152.