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Age management in the context of Industry 4.0 and beyond

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Abstract: Keeping workers active and productive for a longer time is one of the key societal challenges of developed economies. Older workers have accumulated experiences and knowledge during their working lifetime, but due to declining functional capacities, many of them will not be able to work until the increased retirement age. Contemporary technological solutions supporting human-machine interactions such as smart working environment, production cells, exoskeletons, and others, in the context of Industry 4.0 technologies enable workers to stay productive longer. In the present study, we use a multiple decrement model. In the numerical example, we apply the model to the European industrial workforce. We modeled transitions among different productivity states of industrial workers, ranging from a potential employee to workforce exit, through retirement or death. The presented study shows the importance of appropriate age management practice applications that have the potential to substantially prolong the work-life of industrial workers in the European Union. The demographic model presented, allows measuring the influence that technological solutions in the context of Industry 4.0 have on the workers' entrance and exits. The model shows how leveraging the accumulated workers' knowledge and experience of older workers and automation of physically demanding tasks can not only improve the productivity of industrial systems but also decrease the costs of ill-health related expenditures.

Keywords: Industry 4.0, smart working environment, age management

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1. INTRODUCTION

As proposed by the Industrial Internet Consortium in the USA, and the Internet Plus Initiative within Made in China 2025 (Veile et al., 2019), Industry 4.0 has the potential to substantially improve the productivity of industrial systems. Industry 4.0 and modern technological solutions are supporting human-machine interactions such as smart working environment, production cells, exoskeletons, and others, which enable workers to stay productive longer and not to influence the led-time perturbations in a production and supply chain (Bogataj & Bogataj, 2004; 2007, Bogataj & Grubbström, 2012; Bogataj, Aver & Bogataj, 2016; Bogataj, Bogataj & Drobne, 2019; Bogataj et al., 2017; 2019a). In the future, Industry 4.0 and edge-based approaches will be essential to support appropriate age management practice applications that have the potential to substantially prolong the work-life of workers in the European Union. It will also influence location of activities and supply chains and environmental issues (Bogataj & Usenik, 2005; Kovačić & Bogataj, 2013; Kovačić et al., 2015; Kovačić, Usenik & Bogataj, 2017).

Nowadays, the industrial workforce is ageing across developed countries and affecting their national economies (Calzavara et al., 2019; Bogataj et al., 2019b). A challenge that exists is whether industrial workers will be able to work longer (Bogataj, Vodopivec & Bogataj, 2013). Due to the shrinking of the working-age population in the European Union, industrial organizations are concerned about human resource shortages and concerned about their competitiveness in global supply chains (Usenik & Bogataj, 2005; Bogataj & Bogataj, 2011). Our research question is focused on how to understand the patterns of industrial workforce exit in the context of age productivity and increasing retirement age in national pension schemes (Bogataj et al., 2017; Calzavara et al., 2019). One of the researched topics of age management is also inclusiveness and discrimination of older workers. Industry 4.0 will offer more inclusive workspaces for older workers due to the automation of physical tasks and leveraging the experiences of older workers (Singh, Mahanty & Kumar Tiwari, 2019). Manufacturing organizations will have the challenge to assure a sufficient number of industrial workers in their functional regions (Bogataj et al., 2019b) and stay or invest in the regional compiting areas (Usenik & Bogataj, 2005; Campuzano-Bolarin et al., 2019; Bogataj et al., 2019a; Drobne and Bogataj, 2017).

Active ageing is defined by The World Health Organization in Zacher, Kooij, and Beier (2018, p.37) as *"the process of optimizing opportunities for health, participation, and security in order to enhance the quality of life as people age."* As people are living longer, they will consequently have to work longer. The retirement age in countries with automatic adjustment mechanisms is increasing one year each decade and is expected to reach 70 years until 2060. Due to the development of musculoskeletal diseases and the decline of functional capacities, many industrial workers are not likely to work until the increased retirement age (Bogataj et al., 2019b). Due to the declining European population, there are only a few options, among them, prolonging of working life of existing workers or the immigration of workers from other regions (Bogataj, Bogataj, & Drobne, 2019). Investments in ergonomics can considerably prolong the working life of assembly line workers (Bogataj et al., 2017). Therefore, we examine the contribution of Industry 4.0 to longer working life tenure. Industry 4.0 uses different digital technologies that allow the transformation of how organizations operate, along with significant changes in manufacturing processes and business models (Trotta & Garengo, 2018). Digital transformation enables the development of intelligent products and production processes, which would allow for rapid product development, and flexible production in complex environments (Brettel et al., 2014). In addition, many existing industrial systems will become digital enterprises of tomorrow (Xu, Xu & Li, 2018). Older workers have accumulated practices and knowledge during their working lifetime. Still, due to declining functional capacities, many of them will not be able to work until increased retirement age. Therefore, it is an important question, how Industry 4.0 can empower older workers to stay active and productive for a longer time, also after meeting the current retirement age.

2. THEORETICAL BACKGROUND

Hope exists that physical production processes, combined with information and communication technologies, will improve the sustainability of future work (Gabriel & Pessl, 2016). Ageing factors are slowly incorporated in the design of workplaces, production processes, and some technological solutions that are related to the Industry 4.0 paradigms (Calzavara et al., 2019). Yang (2019) further argued that contemporary technological shifts require employees to have integrative skills combining technical, social, and analytic competencies in order to be connected to the challenges and opportunities in technological development according to the shifts in human resources due to ageing of the population. Several scholars have emphasized the importance of technological innovations that have contributed to the development of the health sector through smart health solutions (Dautov, Distefano & Buyya, 2019). Big data sensors and other information communication technologies are also expected to improve human resource management policies by supporting accurate decisions (Veile et al., 2019). Industry 4.0 requires employees who are both experienced and knowledgeable (Ras et al., 2017). Therefore, substantial re-education and continuous training of the workforce will be necessary to leverage the operational efficiency of cyber-physical systems (Bogataj et al., 2017). Bogataj et al., (2019b) claimed that for employees to remain competitive, they will have to acknowledge that they have to adapt to changes and to keep learning throughout their whole career.

In a recent study Ravina-Ripoll et al. (2019) identified that there would be three essential effects of automation on the society and the economy related to Industry 4.0 and the rise of the robots within. First, more significant acceleration of the pace of technological change; second more enormous scope of technological change; and third, the benefits of technological change will not be broadly shared in society because real average wages have lagged behind compared to the growth of productivity, resulting in increased economic and social inequalities. Not only productivity, but also equity and social justice have to be taken into consideration when developing industrial policies (Ravina-Ripoll et al., 2019).

Due to this fact, organizations will have to devote more time and other resources to stimulate learning on all organizational levels to help older workers to adapt and achieve new skills needed in addition to be future proof. Furthermore, Industry 4.0 will lead to increased automation of tasks, which means that workers should be prepared to perform new tasks. The same applies to the education of older employees, which hold immense potential due to tacit knowledge and experiences they embrace. Digital transformation will create new business models and have a substantial effect on global markets due to the increased competitiveness of companies adapting industry 4.0 (Maresova et al., 2018). Organizations that will not adopt digital transformation will not be competitive due to high labor costs (Bogataj et al., 2019a). Moreover, Industry 4.0 is a hot research topic as presented in Figure 1, showing the review of publication years of the concept Industry 4.0, as analysed in the Web of Knowledge database in the period of 2012-2019 (Clarivate Analytics, 2019a).

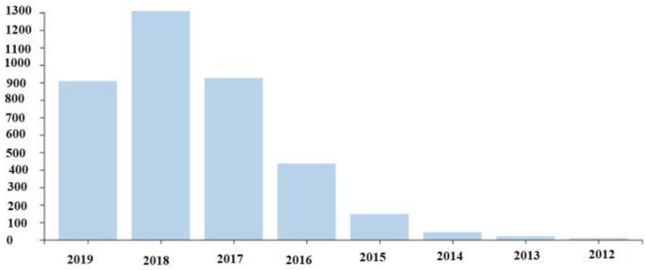

Fig. 1. Analytics of publication years of Industry 4.0 in the period of 2012-2019
Data source: Clarivate Analytics, 2019a.

Similarly, Figure 2 presents the analytics of the concept Industry 4.0 per publications areas (Clarivate Analytics, 2019a).

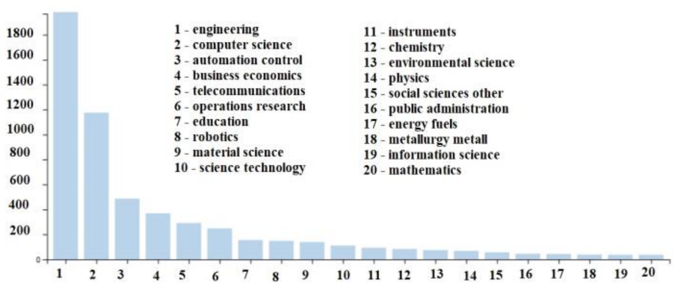

Fig. 2. Analytics of publication areas of the Industry 4.0 concept
Data source: Clarivate Analytics, 2019a.

Likewise, Figures 3 and 4 present the analytics of concept Age Management per publications areas (Clarivate Analytics, 2019b), as well as the analytics of the Age Management concept publication areas in the period of 2000-2019, which is also gaining in its importance to assure the required number of human resources (Bogataj & Bogataj, 2018).

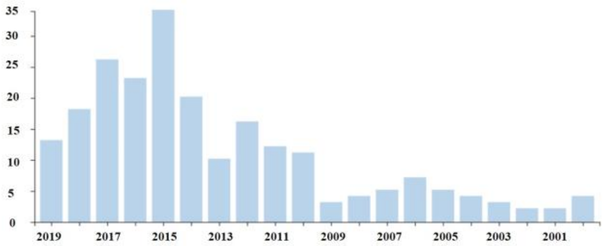

Fig. 3 Analytics of publication years of Age Management concept in the period of 2000-2019
Data source: Clarivate Analytics, 2019b.

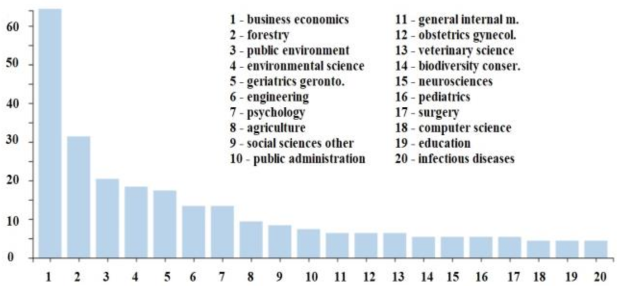

Fig. 4. Analytics of publication areas of the Age management concept
Data source: Clarivate Analytics, 2019b.

Muscle strength, sight, lung, kidney, and heart functioning, and many other biometric indicators deteriorate from an early age onwards, however, the experience and the ability to deal with human nature appear to increase with age (Boersch-Supan & Weiss, 2016). For modelling the functional capacities of older workers, we can look at the research in the field of long-term care, where the abilities to perform activities of daily life are associated with categories of functional capacities of older adults (Rogelj & Bogataj, 2019). The influence of these dynamics on productivity can be analyzed in a multiple decrement model using different categories of productivity (Dimovski et al., 2019) .

3. THE MODEL

3.1 Multiple decrement model

Actuary mathematics used for the development of the multiple decrement model is presented in Deshmukh (2012), Gerber (1997), and Promislow (2015) and is further developed by Bogataj, Ros-McDonnell and Bogataj (2015; 2016) and Rogelj and Bogataj (2018). The ageing of industrial workers has detrimental effects on their physical and cognitive capabilities (Lindberg et al., 2009; Prakash et al., 2009), which causes industrial workers to reach the threshold of functional capabilities earlier in their lifetime. By stimulating the usage of the available Industry 4.0 solutions and products that help industrial workers within their working process and therefore slow down the decline of their functional capabilities, the threshold is reached at a later stage, and the available pool of industrial workers stays larger. The described changes are presented in Figure 5.

The industrial workers may move among various states such as employed, fully productive classic industrial worker, employed, fully productive Industry 4.0 operator, unemployed, retired, or dead. The used multiple decrement model will be extended as a tool for evaluating the appropriateness of specific Industry 4.0. solutions. In multiple decrement models that have m different states for workers and retirees, there are m + 1 states for the transition from one state to another (the second usually being less productive) (Dimovski et al., 2019).

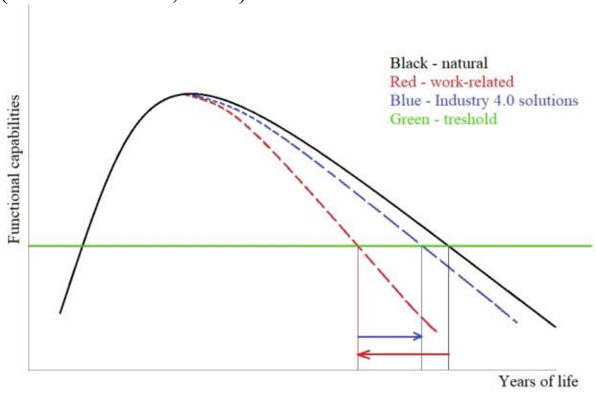

Fig. 5. Dynamics of functional capacities of industrial workers

In the model, we have different productivity states. Productivity states are labelled as j, j = 1, 2, 3, … m. Senior industrial workers can move among various states of productivity regarding their functional capacities, education, and skills to operate Industry 4.0 devices and skills to collaborate with robots as well as the willingness to work. We model the future work period of the industrial worker by random variable $T_i(x)$ by probability distribution function (Dimovski et al., 2019):

$$G_i(t) = Pr(T_i \leq t), t \geq 0 \quad (1).$$

The function $G_i(t)$ represents the probability that the industrial worker will die or transfer to a productive category of type j within t years (Dimovski et al., 2019):

$$g_i(t)\, dt = Pr(t < T_i < t + dt, i \in IW) \quad (2).$$

Where (2) describes the probability that the industrial worker will transfer from a state of type i in the infinitesimal time interval from t to t+dt. Therefore, the probability that a industrial worker aged x in state of productivity i will transfer into a state of productivity j within t years is denoted by the symbol ${}_t q_x(i, j)$ (Dimovski et al., 2019). We have thus the known relationship:

$${}_t q_x(i,j) = G(i,j{:}t) \quad (3).$$

Similarly, one can write:

$$ {}_tp_x(i) = 1 - G(i,j:t) \quad (4). $$

Which denotes the probability that an industrial worker x years old will remain in his or her current state at least t years.

We can forecast the future distribution of industrial workers S based on the current distribution of industrial workers according to productivity category and transition matrix ${}_tP_{x,\,t}$ (Dimovski et al., 2019):

$$ S_{x+1,\tau+1} = S_{x,\tau}P_{x,\tau} = $$
$$ [S_x^{(0)}S_x^{(1)}S_x^{(2)}S_x^{(3)}S_x^{(4)}S_x^{(5)}]_\tau \begin{bmatrix} p_x^{(0)} & q_x^{(0,1)} & q_x^{(0,2)} & q_x^{(0,3)} & q_x^{(0,4)} \\ 0 & p_x^{(1)} & q_x^{(1,2)} & q_x^{(1,3)} & q_x^{(1,4)} \\ 0 & 0 & p_x^{(2)} & q_x^{(2,3)} & q_x^{(2,4)} \\ 0 & 0 & 0 & p_x^{(3)} & q_x^{(3,4)} \\ 0 & 0 & 0 & 0 & p_x^{(4)} \end{bmatrix}_\tau \quad (5). $$
$$ = [S_{x+1}^{(0)}S_{x+1}^{(1)}S_{x+1}^{(2)}S_{x+1}^{(3)}S_{x+1}^{(4)}S_{x+1}^{(5)}]_{\tau+1} $$

4. NUMERICAL EXAMPLE

The presented numerical example is prepared for the EU-28 industrial workers. Table 1 shows the number of industrial workers aged 15-64 years in EU-28 member states as well as for some selected EU member states. Let us assume that in EU-28 there are 821,307 industrial workers aged 50 years, distributed in different states of productivity, as presented in Table 2.

Table 1. Number of industrial workers (IW) 15-64 years (in thousand)

Region	Number of IW
European Union - 28 countries	32,852.3
Germany	7,666.1
Ireland	234.3
Spain	2,225.3
France	2,940.3
Italy	3,803.6
Netherlands	720.0
Austria	669.1
Poland	3,214.8
United Kingdom	2,658.5

Data Source: Eurostat, 2019.

Table 2. Number of industrial workers aged 50 years in different states of productivity

EFPCIW	EFPIO	U	R	D
796,668	24,639	0,000	0,000	0,000

Legend: EFPCIW - Employed, fully productive classic industrial worker; EFPIO - Employed, fully productive Industry 4.0 operator, U – Unemployed, R – Retired, D – Dead

$$ S_x = [S_x^{(0)}S_x^{(1)}S_x^{(2)}S_x^{(3)}S_x^{(4)}] = [796{,}668\ 24{,}639\ 0\ 0\ 0] $$

$$ P_{50}^{2019} = \begin{bmatrix} p_x^{(0,t)} & q_x^{(0,1)} & q_x^{(0,2)} & q_x^{(0,3)} & q_x^{(0,4)} \\ 0 & p_x^{(1,t)} & q_x^{(1,2)} & q_x^{(1,3)} & q_x^{(1,4)} \\ 0 & 0 & p_x^{(2,t)} & q_x^{(2,3)} & q_x^{(2,4)} \\ 0 & 0 & 0 & p_x^{(3,t)} & q_x^{(3,4)} \\ 0 & 0 & 0 & 0 & p_x^{(4,t)} \end{bmatrix}_{2019} $$

$$ \begin{bmatrix} 0.75 & 0.1 & 0.04 & 0.1 & 0.01 \\ 0 & 0.95 & 0.01 & 0.03 & 0.01 \\ 0 & 0 & 0.95 & 0.03 & 0.02 \\ 0 & 0 & 0 & 0.98 & 0.02 \\ 0 & 0 & 0 & 0 & 1 \end{bmatrix} $$

$$ S_{51}^{2019} = S_{50}^{2018}P_{50}^{2018} = [S_{51}^{(0)}S_{51}^{(1)}S_{51}^{(2)}S_{51}^{(3)}S_{51}^{(4)}]_{2019} $$

Table 3. Results of the numerical example

Time/ State	EFPCMW	EFPIO	U	R	D
2019	796,668	24,639	0	0	0
2020	597,501	103,074	32,113	80,406	8,213
2021	448,126	157,670	55,438	142,604	17,469
2022	336,094	194,600	72,168	190,957	27,488
2023	252,071	218,479	83,949	228,751	38,057
2024	189,053	232,762	92,020	258,455	49,017
2025	141,790	240,029	97,308	281,935	60,245
2026	106,342	242,207	100,515	300,595	71,648
2027	79,757	240,731	102,165	315,499	83,155
2028	59,818	236,670	102,654	327,452	94,713
2029	44,863	230,818	102,281	337,065	106,280
2030	33,647	223,763	101,270	344,803	117,824
2031	25,235	215,940	99,790	351,022	129,320
2032	18,927	207,666	97,969	355,997	140,748
2033	14,195	199,176	95,904	359,939	152,093
2034	10,646	190,636	93,669	363,012	163,344
2035	7,985	182,169	91,317	365,346	174,490
2036	5,988	173,859	88,893	367,042	185,525
2037	4,492	165,765	86,426	368,182	196,442
2038	3,368	157,926	83,942	368,834	207,237
2039	2,526	150,367	81,459	369,050	217,905

The results of the numerical illustration of EU-28 industrial workers are presented in Table 3. The given numerical example shows how it is possible to model the influence of investments in the Industry 4.0 on industrial workforce transitions and exit by using an adapted multiple decrement model in order for economies to be able to ensure sustainable manufacturing by assuring the sufficient number of industrial workers in their functional regions.

5. CONCLUSIONS

Our study was motivated by the increasing retirement age of industrial workers in national pension schemes and how Industry 4.0 can contribute to solving this challenge. In the literature review, we found that there does not yet exist a model that would show the connection between an age productivity profile and workforce exit. It is possible to model productivity states, and we presented the model of workforce transitions and exits that has different productivity states of industrial workers, ranging from employed, fully productive classic industrial worker, employed, fully productive Industry 4.0 operator, to workforce exit, through unemployment, retirement or death. The current theory on Industry 4.0 contributes to the solutions in the context of a combination of deploying Industry 4.0 technologies and age management practice applications that have the potential to substantially prolong the work-life of industrial workers in the European Union.

Our theoretical and empirical contributions address three crucial issues. First, the demographic model presented shows how leveraging the accumulated workers' knowledge and experience of older workers and automation of physically demanding tasks can not only improve the productivity of industrial systems but also mitigate the development of occupational diseases and decrease the costs of ill-health related expenditures. Second, we use the theory of Industry 4.0 to develop an empirical measurement that can be used to identify transitions between different states of the productivity of industrial workers. Based on the national demographic statistics, one can calculate the expected labor supply of varying productivity and the age management tools needed for such transitions. Third, we have applied the model to the European industrial workforce and made upper echelons predictions by observing all the possible paths from the initial state through transition age - productivity states and finally to workforce exit. Theoretically, this means that we connected the theory of Industry 4.0, where 4.0 technologies enable workers to stay productive longer, and the multiple decrement model, which let us examine the workforce ageing phenomenon. Further development of the multiple decrement model is proposed, linking decision making processes and decision outcomes regarding assuring social equality, longevity and healthier lifestyle of industrial workers, in line with Europe 2020 strategy.

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