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Proposal of a multidimensional risk assessment methodolgy to assess ageing workforce in a manufacturing industry: A pilot case study

Fabio De Felice [a,*], Francesco Longo [b], Antonio Padovano [b], Domenico Falcone [a], Ilaria Baffo [c]

[a] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, Via G. Di Biasio, 43, 03043 Cassino (FR), Italy
[b] DIMEG, University of Calabria, via P. Bucci, cube 44c, Arcavacata di Rende, Cosenza 87036, Italy
[c] Department of Economics Engineering Society and Business Organization (DEIM), University of Tuscia, Largo dell'Università s.n.c., Loc. Riello, Viterbo 01100, Italy

A R T I C L E I N F O

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A B S T R A C T

The demographic characteristics of the population are changing around the world. Although, the population ageing is a fairly slow and predictable phenomenon even today in the productive sectors there are no clear and shared strategies to take appropriate measures to reduce its impact on work. In fact, on one side the more "*mature*" workers represent a resource for their companies for their human and cultural heritage. But, on the other side, the ageing workers also have, in general, a lower adaptability to innovation, a lack of familiarity with information technology, less creativity, a relative loss of physical strength. In this scenario, many company are investigating how ageing workforce can impacts both operational and occupational safety and health (OSH) performance. Thus, the current debate is for the most part being focused on the safety and productivity implications of an ageing workforce. In this study, we first identified the aspects of safety, risks and operational affected by the ageing workforce (AW). The analysis showed that there is still little research dealing with the ageing of the workforce and how to evaluate risk in the workplace. Based on this, we then presented a multidimensional management approach for measuring performance within the ageing workforce in occupational safety contexts. The model wants to be an useful tool for policy and industrial decision-makers.

1. Introduction

The manufacturing industry is currently facing several challenges associated with the workforce ageing phenomenon as emerges from several studies (Calzavara et al., 2020; Varianou-Mikellidou et al., 2021). The phenomenon is linked to the demographic ageing of the population. The change in the demographic structure of productive organizations and of the workforce as a whole risks exposing the business system to an extensive phenomenon of *skills shortage*, with the loss of a vast wealth of knowledge and experience (Rego et al., 2017). In this context it is necessary to develop specific actions to manage ageing workforce in all in all production sectors. Exactly for this reasons, the **United Nations** has proclaimed 2021–2030 the decade of healthy ageing to promote global action to improve the lives of the elderly. Applying the provisions of the **WHO** strategy also means making an important contribution to achieving the United Nations Sustainable Development Goals (SDGs), one among all the GOAL 3 "*Ensure healthy lives and promote well-being for all at all ages*". The ageing and shrinking workforce represents a great challenge also for all countries (Ciulli, 2022; Graf et al., 2022). The assessment of ageing at work is an important aspect in manufacturing companies. In fact, all risks can increase with advancing age, also due to the ageing of the population in the working age which has been prolonged considerably in the last (Vives et al, 2018). Some data emerging from a recent European survey show that the active population over 45 has a mediocre and poor level of work skills at risk of increasing with age (Botti et al., 2022). It should be noted that in Western countries the ageing of the elderly population of working age has been increasingly evident for some time (Quinn et al., 2021; Young, 2013). In the European Union it is estimated that in 2025 workers aged between 50 and 64 will be 35%, posing problems of economic sustainability also in terms of health and pensions, with an increase in the duration of working life (Ball and Flynn, 2021). However, it is ialso important to note that digitization is rapidly changing the world of work. It offers the potential for innovative developments in the workplace while ensuring the safety of the workplace (Brynn, 2021). It means that the *digitalization* of production processes could represent an

* Corresponding author.
E-mail addresses: defelice@unicas.it (F. De Felice), francesco.longo@unical.it (F. Longo), antonio.padovano@unical.it (A. Padovano), falcone@unicas.it (D. Falcone), ilaria.baffo@unitus.it (I. Baffo).

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opportunity to manage the ageing of workforce and to support the performance of specific tasks in the productive sectors (Belchik, 2022). The introduction of new technologies is almost certainly destined to lead to a problem of job retention in perspective, but no one hopes for an industrial production process without employment (Cioffi et al., 2020; Diefenbach et al., 2020). In the field of ageing of the workforce, most of the research admits AW's safety vulnerability and agrees on the need for adopting novel safety frameworks that permit the development of age-friendly working environments (Varianou-Mikellidou et al., 2019; Bogataj et al, 2019). The question is twofold: how to assess the risks associated with an ageing workforce? How digital technologies could improve the safety at workplace supporting the ageing workforce? In this study, we first identified the aspects of safety, risks and operational affected by the ageing workforce (AW). The analysis showed that there is still little research dealing with the ageing of the workforce and how to evaluate risk in the workplace. Based on this, we then presented a multidimensional management approach for measuring performance within the ageing workforce in occupational safety contexts. The model wants to be an useful tool for policy and industrial decision-makers. Our main assumption is that technology should be not replace the human being, but enters into synergy with human beings thanks to an approach that we define "*Human Technology*" in order to improve the health and safety conditions of all workers with a view to an ageing workforce. (Guizzi, et al., 2019; Aleksy et al., 2018; Luo and Yu, 2021). In the next future, in all production sectors should be to increase human skills and qualities. Thus, for economically developed nations, the current digital and technological innovation processes could represent a very important tool to counterbalance the risks associated ageing workforce (Bottani et al., 2021).

The rest of the paper is organized as follows: Section 2 outlines the state of art on ageing workforce; research design is presented and explained in Section 3; while, a case study is analyzed in Section 4. Finally, the main conclusions and future developments are summarized in Section 5 and Section 6.

2. Safety and risk assessment in an AW context

The research on the ageing workforce in the manufacturing industry is divided between acknowledging their *physical* and *cognitive* limitations and developing supporting technologies that aid AW in meeting their demanding roles (Boenzi et al., 2015). But there is a lack of absolute consensus around the characteristics of AW (e.g., age range, physical & cognitive capacity baseline, etc.). Conventionally, according to the WHO, the definition of "*ageing worker*" is that of an employee over the age of 45, while someone over 55 is called "*elderly worker*" (Cacchione, 2022; Eppler-Hattab et al., 2020). The work performance, however, depends not only on the age attained, but also on the type of work performed: this problem worsens significantly in the transition from **cognitive work** to **manual work** (Fisher et al., 2017; Micheli et al., 2018; Kroon et al., 2016). In addition, to the age factor, the reduction in working capacity still shows a large individual variable, determined above all by the presence or absence of **chronic diseases**. Another variable to consider is the **gender.** In other words, ageing is a multidimensional process of biological, psychological and social changes, characterized by **negative** effects (decline in functional abilities) partially offset by **positive** effects, as analyzed by several authors (Huang et al., 2019; Pahos and Galanaki, 2019; Lee et al., 2018). For example, many attributes, such as wisdom, strategic thinking, holistic perception and the ability to judge and the ability to make decisions, develop or manifest themselves for the first time with advancing age (De Merich et al., 2022). Work experience and skills also accumulate with age. Beyond the aspects analyzed above, it is necessary to specify that the ageing of workers can be correlated, depending on the activities performed, with an increase in **risk** both in terms of **probability** and **magnitude** and greater exposure to risk factors responsible for the onset of occupational diseases (Bauer et al., 2020; Longo et al., 2021). Among the various risks, the main ones are listed below (UNI ISO 31000:2018):

- **Risks related to physical work**, deriving from the handling of loads, intense physical exertion, and maintenance of incongruous postures. Added to these are the risks arising from the use of machines, such as sweepers, from slipping or from possible falls from tools such as ladders, in the case of the cleaning sector, or from the use of lathes and cutters, in the case of industry (Krishnan et al., 2021).
- **Risks related to the work environment**, such as adverse microclimatic conditions, or exposure to vibrations and noise. Among these risks, attention is paid to exposure to toxic and / or irritating substances, to which, for example, those who work in the cleaning sector are exposed on a daily basis (Burmeister et al, 2018).
- **Risk related to training and work organization**, use, transmission of skills, such as the lack of training, rigidly imposed working methods, the achievement of unexpected peaks of activity (Sambandan et al., 2020).
- **Risk related to psycho-social causes**, such as relationships with "difficult" audiences or clients, or lack of support and recognition from superiors or colleagues (Akalp et al., 2015).

It is important to highlight that the conventional risk assessment methods are mainly focused on safety incidents that would immediately cause acute injury effects, as opposed to long-term ageing issues (Park, et al., 2019). However, the importance to include these effects in health and safety assessments is evident (Bognár and Benedek, 2021). Thus, the fundamental steps to achieve the prevention and protection of the health of the worker throughout his entire working life start from the assessment and analysis of the risk factors most susceptible to the age factor up to the adoption of specific measures. Therefore, the assessment of the ageing of the workforce should also be included in the risk assessment. The literature analysis showed that there is still little research dealing with the ageing of the workforce and how to evaluate risk in the workplace. In addition, it should be understood how technologic innovations can improve Occupational Health and Safety Performance (OHSP). The literature analysis shows that the use of digital technologies is promising as well analyzed by several authors (Laciok et al, 2021; Nåfors et al., 2020). However, there is still little research dealing with the ageing of the workforce, on how to evaluate risk. Thus, the present research aims to fill this gap by proposing an new methodology that combines the risk assessment and the use of technologies with safety and productivity. Surely, this is a pilot study, not complete but with future perspectives. More details are provided in the following sections.

3. Research design

3.1. Conceptual assumptions

In any production context but mostly in manufacturing system, safety and productivity are inextricably linked. It is impossible to choose between the two, both aspects must be managed in a *win to win logic*. In general, small businesses underestimate the problem (Khan et al., 2019). While, large companies, public or private, know the problem but, with some exceptions, believe that little is possible do to fix it. In the light of the previous considerations it is clear that the problem of the ageing workforce is a complex and multifactorial issue (Micheli et al. 2021). Therefore, in our opinion, a **multidimensional approach** is required for its management. A multidimensional approach should be a strategy that best orientates towards management of a complex problem and its specific aspects: social security aspects; ergonomic approach; risk assessment taking into account age; health surveillance of elderly workers and health promotion.

3.2. A multidimensional approach as strategy to manage ageing at work

Companies need tools to analyze the requirements of their technology, their organization, as well as their workforce. We believe that in order to preserve and strengthen the employability of workers with age, it is necessary to develop a multiple analysis as depicted in Fig. 1. Fig. 1 depicts the proposed framework of a multidimensional management approach of ageing at work. The approach is based on the *Plan–Do–Check–Act* cycle (ISO 45001:2018). The development of the proposed method presupposes the definition and identification of an *expert team* with expertise in safety in the workplace as well as experts in manufacturing processes. The experts team is made up of 1 HSE Manager, 1 Production Manager, 1 Quality Manager, 2 Worker (man and woman), 1 External consultant with expertise in HSE.

The multidimensional approach is characterized by 3 different phases as detailed below.

Phase#1 - Context analysis and mapping. It consists of a preliminary analysis (analysis of company demographics) of one's own reality to detect age and gender groups with relative strengths and improvement points. This approach allows greater awareness of the problem and also identifies any critical issues on key company resources/positions and addressing the appropriate generational turnover. For example, companies with workers between the ages of 40 and 50, who represent an important part of the company population, will have to seriously consider strategic age management in the coming years, in order to promote knowledge transmission and intergenerational collaboration. To perform a preliminary analysis, the experts team have developed a specific questionnaire that aims to collect all the data deemed necessary for company mapping. A copy of questionnaire is shown in Appendix A. Questionnire contains questions concerning ability and health. In particular, the questionnaire consists of 20 questions. The first 10 questions aim to collect data on: gender, education, department of labor/work, type of work and main current diseases and ilness. The last 10 questions aim to collect data essentially on work capacities using the Likert scale (1–7). The maximum of points possible are 70.

Filling out all questions help the experts team at the final conclusion whether measures for improving safety have to be taken and if work ability must be improved. More in detail, the experts teams has defined a **Productivity Index** – PI according to Eq. (1). In other words each question is associated with a score that allows us to calculate the Productivity Index.

$$\begin{aligned}\text{Productivity Index (PI)} &= (\text{No points received/No points possible}) \\ &\quad \times \%\ \text{performance at work} \\ &= \%\ \text{PI}\end{aligned} \tag{1}$$

The formula is based on the assumption that as a general rule, the definition of labor productivity refers to the efficiency with which a worker generates goods or services in a certain amount of time with a certain volume of resources. Therefore, the experts team have assumed as % performance at work the number of days of absence from work. The fewer days of absence at work, the higher the productivity index as follows: max. 9 days absence = 70% performance, 10–24 days absence = 60% performance and 25–99 days absence = 50% performance.

Phase#2 - Risk assessment. According to the experts team it has been assumed that the ageing of workers can be correlated, depending on the activities performed, with an increase in risk both in terms of *probability* and *demage* and greater exposure to risk factors responsible for the onset of occupational diseases. The fundamental steps to achieve the prevention and protection of the health of the worker throughout his/her entire working life start from the assessment and analysis of the

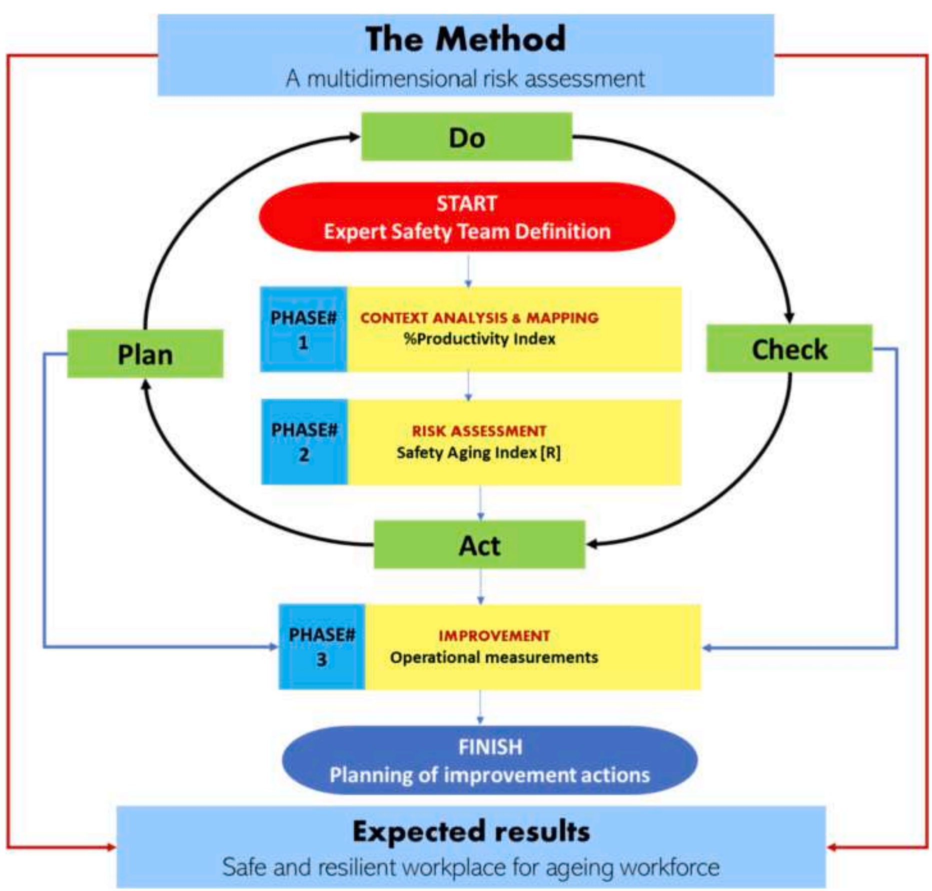

Fig. 1. Framework of a multidimensional management approach of ageing at work (author's proposal in agreement with the experts team).

risk factors most susceptible to the age factor up to the adoption of specific measures. Thus, this phase consists of a risk analysis to carry out a first summary of the risk estimate with respect to age and provides preventive guidelines for each risk investigated. The risk assessment matrix system is currently the most widely used analytical tool to generate and quantify residual risk and establish intervention priorities (Lo and Liou, 2018). In order to evaluate the ageing of the workforce, expert team proposed a variant to the traditional risk matrix which involves the classification of the risk according to the three variables. The method is based on a classification of risk levels according to a **P × D × A matrix** where **P** is the probability of occurrence, **D** is the potential damage deriving from coronavirus infection, **A** is an adjustment coefficient that takes into account the ageing of the workforce, as shown in Fig. 2. The ageing component is more difficult to assess. It is due to both consequences and the likelihood of ageing issues, which may be indeterminate (Ji et al., 2021). Thus, there has been needed to develop a quantitative risk assessment with better representation for chronic ageing issues. The experts team deveoloped the following method that proposes a procedure for identifying the level of risk and the adoption of prevention and protection measures. The investigation should be conducted acquiring the necessary information directly from the workers.

Traditionally, the meaning of P and D factors is described as below (Palega, 2021; Sudarsana, 2021; Lopez et al., 2015).

Probability (**P**) that a certain event will happen to come (e.g. ergonomic risk, VDT, etc.). P can take the value equal to:

– 0 = low probability;
– 1 = low-medium probability;
– 2 = average probability;
– 3 = medium–high probability;
– 4 = high probability.

Damage (**D**) depends on the possible consequences that the event can bring to the subject and also in this case it was carried out using a scale of values ranging from 1 to 4

– 0 = low demage;
– 1 = low-medium demage;
– 2 = average demage;
– 3 = medium–high demage;
– 4 = high demage.

The score resulting from the combination (P × D) is corrected with a factor that takes into account the third aggregation scale (**A**) understood as the **Ageing** of the worker. As described before, it is impractical to quantify the probabilities of many outcomes associated to ageing workforce with any precision. Hence, it was decided to take a more holistic approach, by focusing on the overall effects of occupational exposure rather than the specific causes. As stated by several authors (Fuentes-Bargues et al., 2016; Pinto et al., 2011; Aneziris et al., 2017; Cantley et al., 2015) commonly used ordered scale is 6: Almost certain 100%, 5: Likely 60%, 4: Possible 40%, 3: Unlikely 20%, 2: Rare 10%, and 1: Almost Incredible 1%. Many studies show that after the age range between 20 and 30, a slow but progressive state of decay begins, which weakens the body and slows down physiological functions. Thus, expert team developed a new scale based on the following principles:

– needs to be consistent and progressive;
– needs to use simple numbers to be used easily.

The parameter A is between 0.50 and 1 and can have a value equal to (see Table 1):

The final result is the calculation of Risk or Safety Ageing Index = [R]

Table 1
Scale for A.

Likelihood Description	Likelihood Scale	Age of workers
Almost Incredible	1.00	18–24 years
Rare	1.05 (+0.5)	25–34 years
Unilikely	1.10 (+10%)	35–44 years
Possible	1.15 (+15%)	45–54 years
Likely	1.30 (+30%)	55–64 years
Almost certain	1.50 (+50%)	65 + years

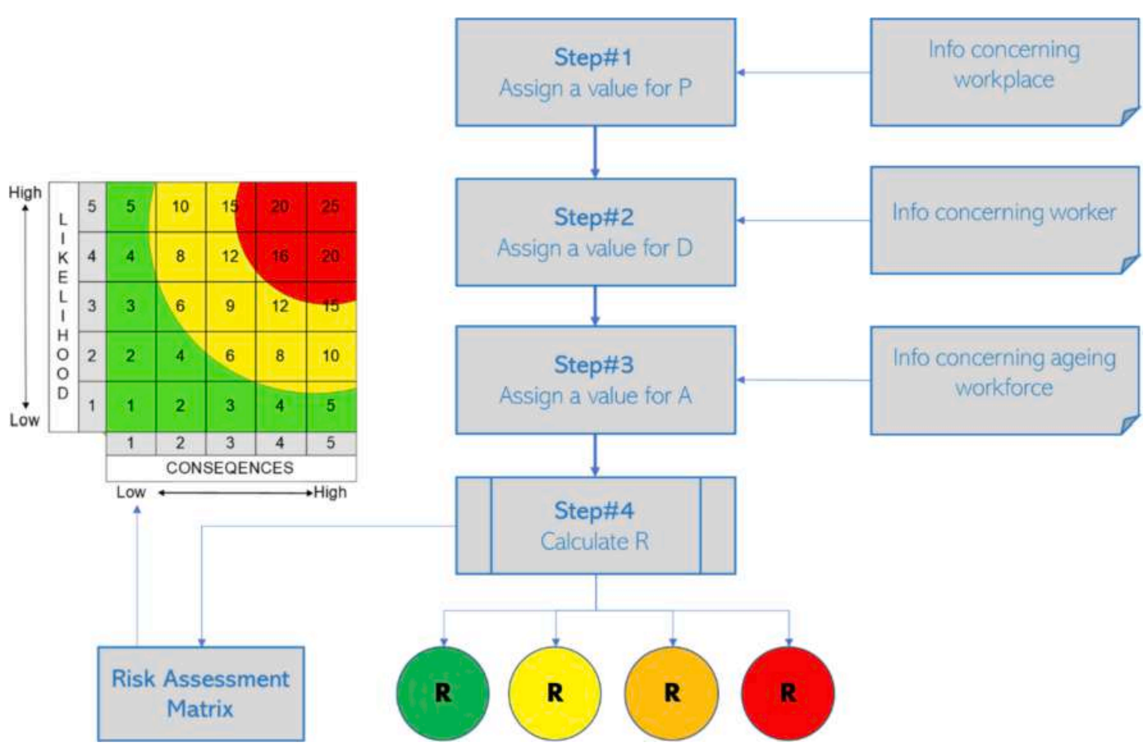

Fig. 2. Procedure for risk assessment(author's proposal).

= (P × D × A).

The assessment is carried out by differentiating by task and/or by department or by considering individual cases if these have significant peculiarities for the purposes of the assessment. Based on the results (P × D × A), four different scenarios will be defined according to Table 2.

Phase#3 - Improvement measures. It consists of an assessment of age-related measurement and, with reference to the tasks performed, can lead to the adoption of specific improvement measures, such as: *organizational measures* (shifts, timetables, breaks, rotations …); *management measures* (values and attitudes, training, specific health surveillance …); *technical measures* (automation, ergonomics, lighting, acoustics…) and *training* of the adult worker.

4. A case study: Ageing workforce management solutions following a multidimensional approach

As case study a pilot study within a manufacturing company operating in the field of mechanical and electromechanical processing (as shown in Fig. 3) has been considered. Since 1994, the company has been running a health protection and safety for worker. Therefore, the CEO's strategic policy foresees safety management as a priority for the next 3 years.

The company's organization consists of the following main departments: Production; Quality control, Maintenance, Research and Development (R&D); Purchasing; Marketing; Human Resource Management (HR); Accounting and Finance. Here below is the description of each phases of the multidimensional method defining with the experts team.

Phase#1 - Context analysis (mapping). The company decided to develop a pilot study involving workers belonging to the departments of Production, Quality control, Maintenance. A questionnaire was administered (the detail of the questionnaire is shown in Appendix A**)**. The questionnaire was administered through *Microsoft forms*. The questionnaire was sent by email. In addition, a *qrcode* was provided to the participants to access to the form using phone or tablet. In particular, **66 workers** were involved in the survey. After a mapping of workers and safety conditions, relevant information emerged. Here below is a summary:

- Most of the work is employed in the Production department and they are man (68%);
- The age of the respondents is distributed as follows: Production (35–44; 42%), Maintenance (45–54; 38%), Quality (45–54; 33%);
- The education of the respondents is characterized by specialist training distributed as follows: Production (42%), Maintenance (38%), Quality (33%);
- The type of work is essentially manual: Production (45%), Maintenance (44%), Quality (40%);
- Based on the type of work, the following technologies are considered important: Production (Robot 35%), Maintenance (AR/VR 44%), Quality (IoT 33%).

A detail of all the data collected is shown in Table 3 showing all characteristics of all respondents.

Based on the data collected in Table 3 the experts team analyzed in detail the questionnaire for the three main departments: Production, Maintenance and Quality. It emerged that workers up to 44 years of age have fewer days of absence at the workplace than workers aged 45 and over. In more detail, the age range 55–64 has a percentage of absence in the workplace equal to 24% for 25–99 days of absence. While, the over 65 + reach 38% as shown in Fig. 4. It means that in terms of working days their performance is lower than other workers.

Analyzing the data concerning the main current diseases and ilness it ermerged that diseases cardiovascular system and musculoskeletal disorders are the two most common health conditions affecting ageing workers, impacting 30% and 27%, respectively, of workers over the age of 65, as shown in Fig. 5. The frequency of these conditions and others in ageing adults has important implications for how and when workers can physically perform their duties.

Fig. 6 represents a detail of the questionnaire for age groups. It emerges that the more the age increases, the more critical issues arise in terms of efficiency in the workplace.

While, Fig. 7 highlights the comparison between age groups.

Fig. 8 shows that the productivity index is typically above 50% up to age 54. The highest value is noted for the age range 18–24 years (with a value equal to 70%). The result does not surprise us because in this age group the days of absence at the workplace are a maximum of 9 days. Another fact that we note is that from a point of view of "*N ° points received*" there is no substantial difference between very young and older workers. The reason is due to the fact that in the first case, productivity is influenced by less experience, in the second case health problems can affect productivity and efficiency. In any case, in every age group, health and safety conditions are of fundamental importance in order to avoid accidents or deaths at work. For this reason, from a safety point of view, it is important to estimate the risks and dangers present in your workplaces, as will be discussed later.

Phase#2 - Risk assessment. Based on the previous analysis, in this phase the risk assessment was carried out. According to several authors (Diefenbach et al., 2020), in general, the main risks characterized a typical production departmens are: highly repetitive work, manual handling of loads, shift and night work and noise. Table 4 shows the calculation of Safety Ageing Index [R] for age groups and risk factors analyzed.

The results made it possible to better understand the improvement actions to be implemented. The company has decided to implement specific actions. For the company it is essential to rely on the experience of its workers but at the same time it considers vital to rethink working methods in order to ensure the health of more mature workers. Thus, the company has been promoting specific health and safety actions to manage the ageing of the workforce. The aim is to develop smart, personalized and adaptive ICT solutions for active, healthy and productive ageingwith enhanced workability. Novel solutions are needed so as to help ageingworkers maintain workability and productivity, along

Table 2
Classification of scenarios according to [R] = Safety Ageing Index = (P × D × A).

SCENARIOS	Risk (PxDxA)	DESCRIPTION	ACTIONS
Scenario #1	**Low 0-2**	Negligible risk	Voluntary improvement actions
Scenario #2	**Medium 3-4**	Low risk	Recommended improvement actions
Scenario #3	**High 5-9**	High risk	Care to ageing workers
Scenario #4	**Very High 10-24**	Very High risk	Urgent improvement actions

Fig. 3. Example of mechanical and electromechanical Processing.

Table 3
Descriptive characteristics of respondents.

		Departments					
		Production		Maintenance		Quality	
		N°	%	N°	%	N°	%
Total sample	**66**						
Gender	Woman	21	0,32	4	0,04	6	0,06
	Man	45	0,68	12	0,12	9	0,09
	Prefer not to say	0	0,00	0	0,00	0	0,00
Ages of respondents	18-24	8	0,21	1	0,06	1	0,07
	25-34	15	0,36	2	0,13	3	0,20
	35-44	12	0,42	5	0,31	2	0,13
	45-54	15	0,27	6	0,38	5	0,33
	55-64	8	0,15	1	0,06	2	0,13
	65+	8	0,05	1	0,06	2	0,13
Education	Less than a High school	8	0,12	2	0,13	1	0,07
	Specialist training	28	0,42	6	0,38	5	0,33
	High school degree	14	0,21	4	0,25	3	0,20
	Bechelor degree	11	0,17	3	0,19	4	0,27
	Master degree	5	0,08	1	0,06	2	0,13
Type of work	Cognitive	20	0,30	5	0,31	4	0,27
	Manual	30	0,45	7	0,44	6	0,40
	Cognitive and Manual Work	16	0,24	4	0,25	5	0,33
Technologies considered most useful for their work	IoT	10	0,15	5	0,31	5	0,33
	AR/VR	7	0,11	7	0,44	4	0,27
	Robot	23	0,35	2	0,13	2	0,13
	Additive manufacturing	14	0,21	1	0,06	3	0,20
	Simulation/digital twin	12	0,18	1	0,06	1	0,07

with a balance between work and personal life, which supports them into good quality of life, active and healthy ageing. In this regard, the company in collaboration with the experts team has launched many actions. Some of the main ones are shown below.

Phase#3 - Improvement measures. In this section experts team defined specific improvement actions for safety in the workplace. Specific strategies have been identified, as summarized below and in Fig. 9. Obviously, the improvement actions will be accompanied by continuous and permanent training for all workers. Training is a safety measure like a protective device and must be effective and efficient.

The details of the improvement actions are shown below.

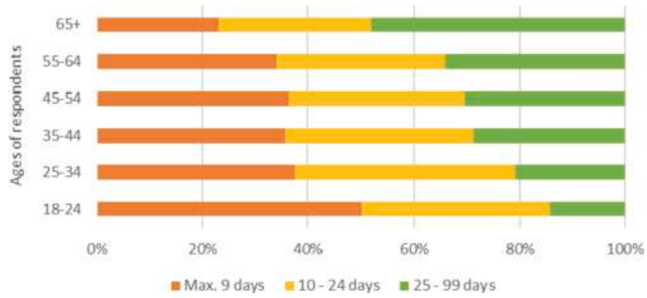

Fig. 4. % Performance at work (days of absence).

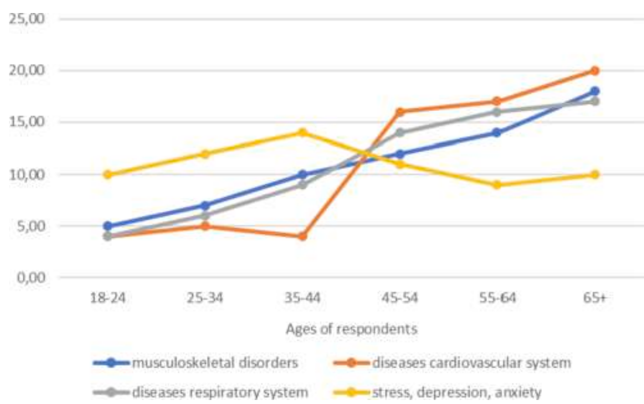

Fig. 5. Main current diseases and ilness.

Action #1 - Work Redesign Interventions: Prototyping an AR tool

The Company has decided to use mixed reality and AR through the *HoloLens* as a tool for the prevention of individual, collective and environmental risk. The technology meets the quality and safety standards required within a production scenario, ensuring a reduction in training times and an improvement in the quality of training. The new solution allows:

- support operators in real time during the performance of their work activities, detecting potential risks for the health and safety of workers linked to the presence of incompatible physical fields and environmental contamination or to the incorrect or dangerous reciprocal positions between workers and work equipment;
- promote a learning by doing approach to train skills;
- manage of critical issues on site with the help of information provided in real time;
- promote a direct integration with smart tools to collect data without interrupting the work flow;
- manage in the cloud and traceability of interventions and ex-post data analysis.

In this way it is possible to have even complex operations carried out by elderly operators in complete safety and guaranteeing operational continuity. In fact, the perception of the surrounding context is enriched with digital data generated thanks to technologies that allow the superimposition of contents (such as texts, images, live action or animated films) perceived as part of the real environment in which the worker finds himself/herself. Fig. 10 shows an example of worker collaboration based on AR.

Action#2 - Work Redesign Interventions: Cobot

Another improvement in terms of safety and productivity is the use of cobots which, instead of replacing the human capital of a company, collaborate with workers to increase efficiency. Cobots are designed to increase the safety of workers inside a factory. Current technologies are

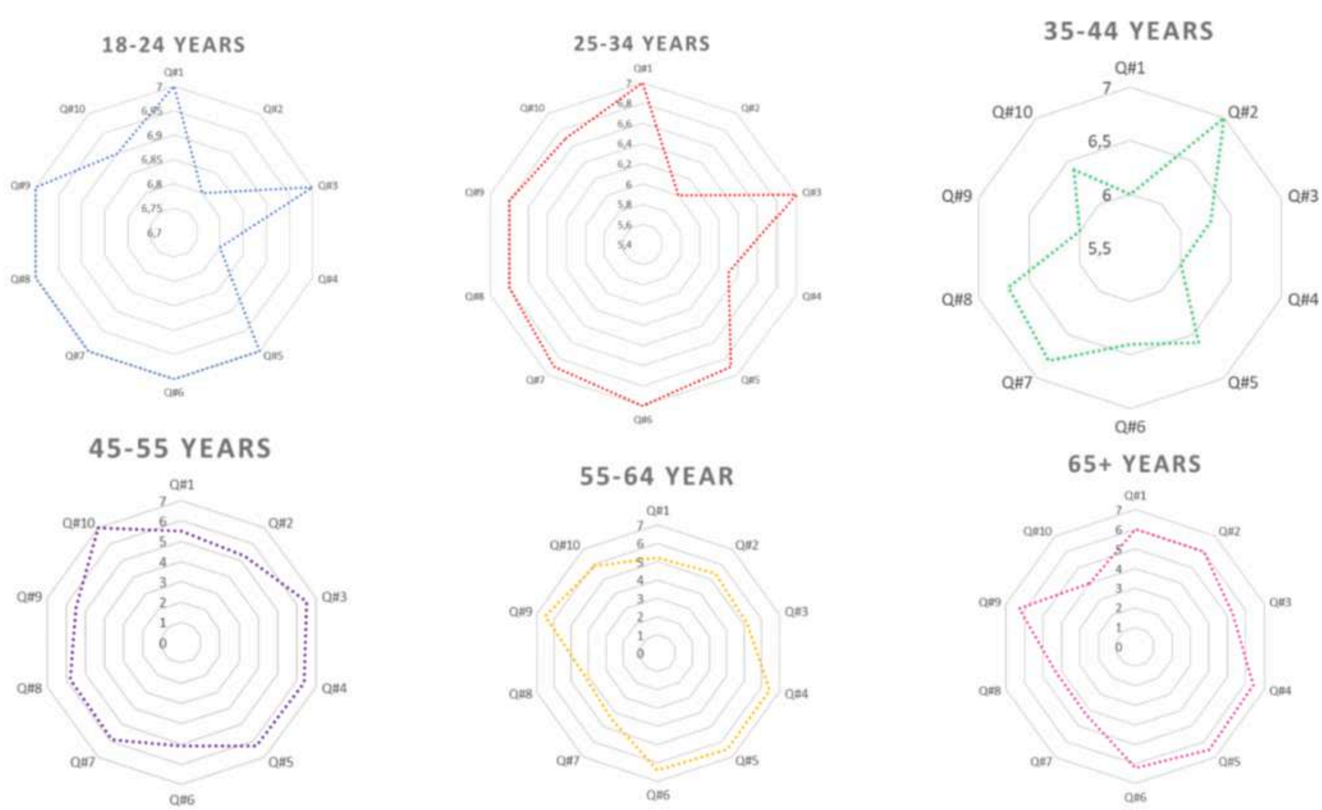

Fig. 6. Results of the questionnaire by age group.

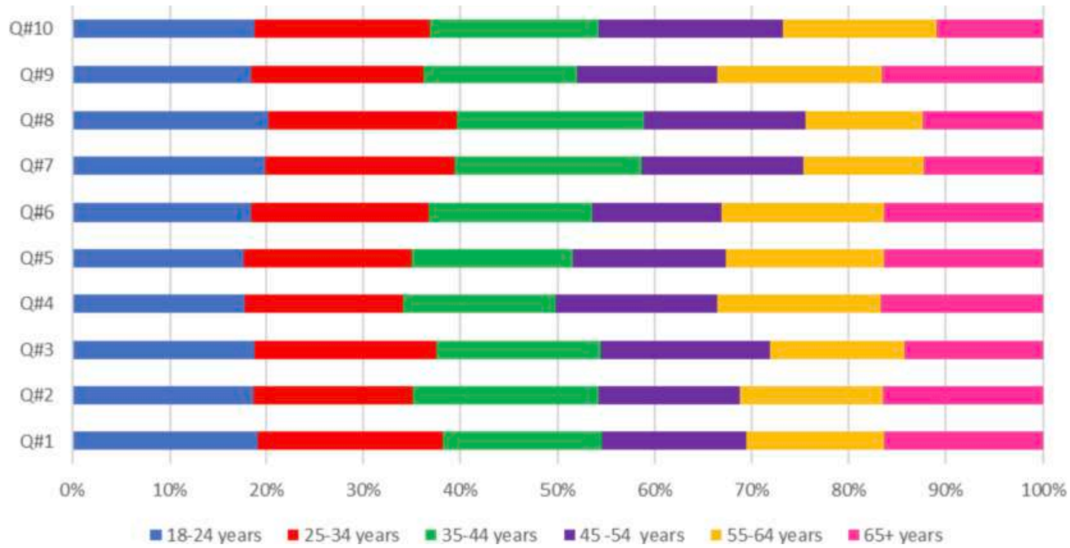

Fig. 7. Results of the questionnaire – comparison.

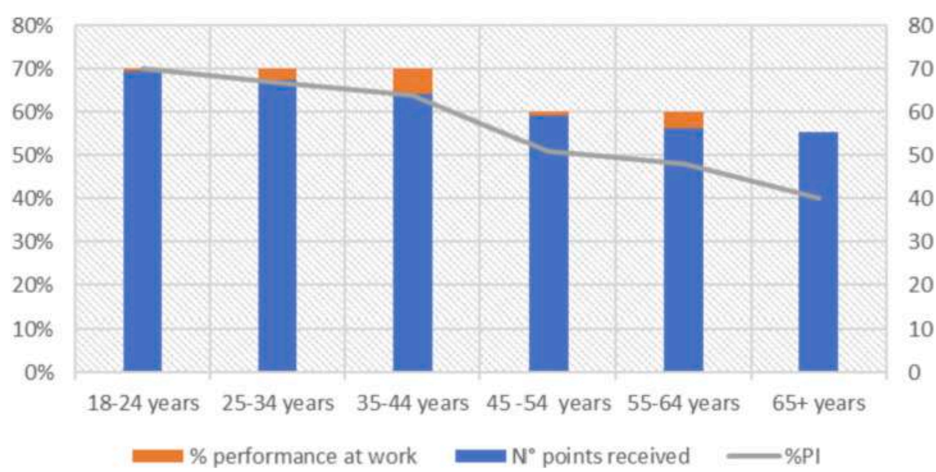

Fig. 8. Results for Productivity Index.

Table 4
Safety Ageing Index [R].

Risk assessment Safety Ageing Index [R]		Risk 1 Highly repetitive work				Risk2 Manual handling				Risk3 Shift and night work				Risk4 Noise			
		P	D	A	R	P	D	A	R	P	D	A	R	P	D	A	R
Ages of respondents	18-24	1	1	1,00	1,00	2	1	1,00	2,00	1	1	1,00	1,00	2	2	1,00	4,00
	25-34	1	1	1,05	1,05	2	1	1,05	2,10	1	1	1,05	1,05	2	2	1,05	4,20
	35-44	2	2	1,10	4,40	2	2	1,10	4,40	1	1	1,10	1,10	2	2	1,10	4,40
	45-54	2	2	1,15	4,60	2	2	1,15	4,60	3	2	1,15	6,90	2	3	1,15	6,90
	55-64	2	2	1,30	5,20	3	3	1,30	11,70	3	2	1,30	7,80	3	4	1,30	15,60
	65+	2	2	1,50	6,00	3	4	1,50	18,00	4	2	1,50	12,00	4	4	1,50	24,00

being improved in order to find the right channel to overcome the main criticality or the communication between man and machine also in terms of visuals and facial expressions. Cobots can be used for some particularly repetitive, severe, and low value-added tasks. One of these consists in cutting a series of electrical cables from the components produced: an activity that in the long run was causing injuries to operators, including widespread carpal tunnel syndrome. It is estimated that the cobots applied in this phase of the process cut over 16 thousand cables a day, could increase productivity by over 20%. Fig. 11 shows an example of application of a cobot.

Action#3 - Work Redesign Interventions: Technological solutions based on wearable and biometrics

The company intends to implement technological solutions based on wearable devices. In fact, especially for manufacturing facilities with

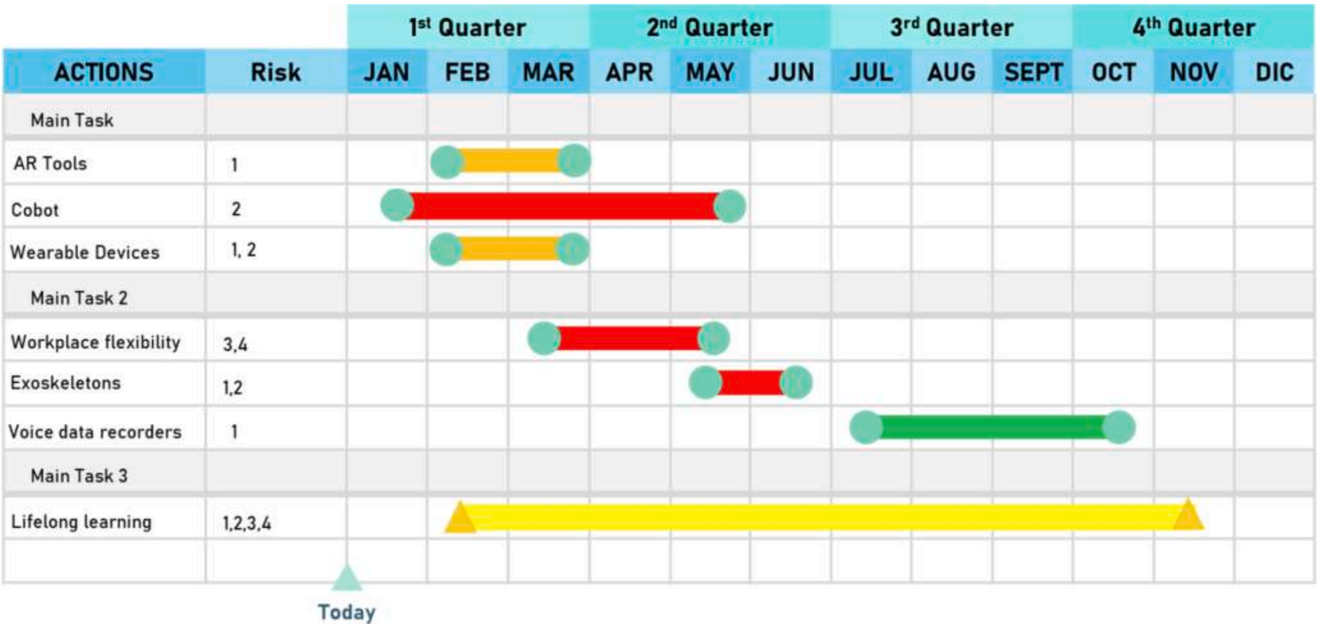

Fig. 9. Example of a prototype of worker collaboration based on AR.

Fig. 10. Example of a prototype of worker collaboration based on AR.

complex operations and a large area to cover, wearable devices for safetycan be very helpful to monitor the safety of the employees. For example, the use of panic buttons in manufacturing facilities can be a great way to provide lone workers with a tool that will help them ask for assistance in an emergency situation. In addition, in an industrial environment it is not appropriate to use consumer smart speakers (such as Alexa, Google, Siri …). Thus, the great challenge for ageing workers is to develop algorithms for natural language understanding (NLU) to allow tasks to be delegated to machines more quickly and precisely. In fact, if it is true that physical forces can decrease with time, it is also true that in good health conditions cognitive functions persist over time with great efficiency. The use of voice could represent a challenge for the future in smart factories in the perspective of ageing of the workforce. An example of technological solutions based on wearable and biometrics is shown in Fig. 12.

Action#4 - Prioritize workplace flexibility

Ageing workers prefer jobs that provide more flexibility over those that offer more vacation days. To the extent possible, give workers a say in their schedule, work conditions, work organization, work location, and work tasks. Thus, the company will introduce a smart working policy for possible tasks. Promoting flexibility at work will also help to control certain risks that characterize manufacturing activities such as *noise risk* and *shift and night work*. In fact, it will be possible to encourage a better organization of tasks.

Action#5 - Provide and design ergo-friendly work environments: Exoskeletons

The company intends to invest in exoskeletons to help workers perform manual handling tasks while reducing the load on the muscular system. In fact, exoskeletons are devices that can affect the physical load in the workplace. They are able to offer a solution where other technical, organizational or ergonomic design measures are not enough. An example of application of exoskeletons is shown in Fig. 13.

Action#6 - Provide a new work environments: Voice data recorders

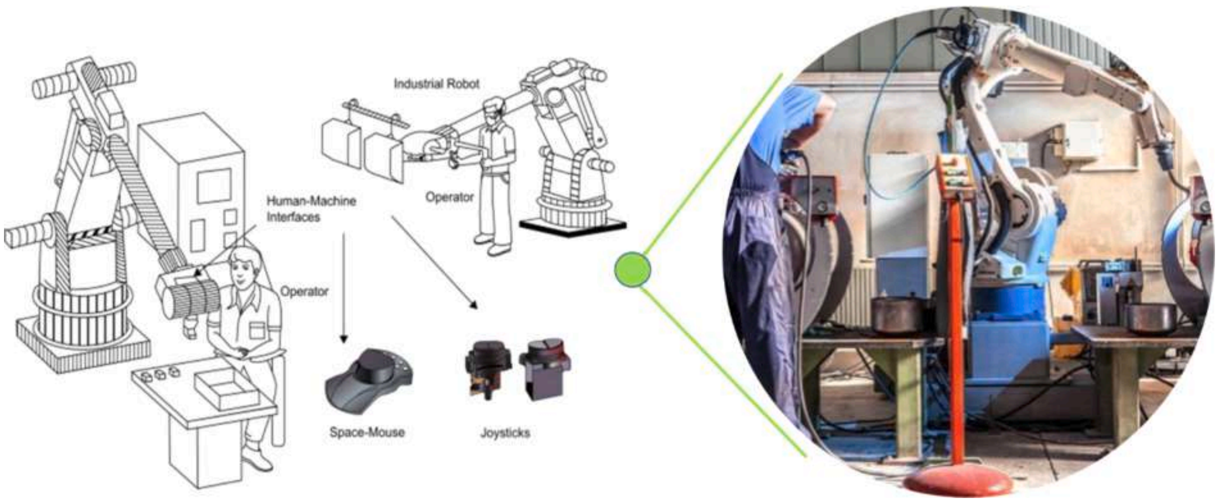

Fig. 11. Example of Cobot.

Fig. 12. Example of technological solutions based on wearable and biometrics.

Fig. 13. Example of exoskeletons.

Fig. 14. Example of a voice data recorders.

Another technological innovation on which the company intends to invest is the use of voice data recorders (or two-way radios). This technology is certainly not the most sophisticated technological elements but they can eliminate the need to carry around notepads, pens or iPads to jot down data and information. The combined use of a voice recorder with a headset or a similar device that allows you to have your hands free, can be used to provide real-time reports during inspections and other important safety checks and procedures. It goes without saying how important it is, in terms of safety, to have your hands free. Using the smartphone to take photos during a survey or inspection is not as safe and rather tends to distract attention. An example of a voice data recorders I shown in Fig. 14.

5. Conclusions

The most widespread stereotypes about the ageing of the workforce reinforce the idea that age has a negative impact on performance. In our opinion, in general, individual performance is compensated by experience. In any case, advancing age should be taken into account to protect workers by including a corrective factor in the risk assessment. This approach does not want to penalize older workers but to ensure their greater safety in the workplace. The relationship between age and productivity remains a complex issue. Therefore, a multidimensional approach is required. The present research shows that a multidimensional management approach of ageing at work could certainly improve working conditions for all workers, especially ageing ones. As in all processes of change, work and society face risks but also great opportunities. In conclusion, we can say that taking into account the age factor means having a far-sighted vision for the management of safety in the workplace. In this way it is possible to enhance the human resources of a company considering the ageing of the workforce. A multidimensional approach could also represent an important step to adequately respond to the problems concerning the safety and ageing of workers from both a legal and a social perspective. In addition, there is a clear awareness that the ways in which the digital revolution will permeate the national and global production system will depend on the interaction between demographic dynamics and the actual availability of human capital of sufficiently high quality. From this point of view, it will become crucial to ensure that the **education** and **training** system, especially at the higher level, is able to make adequate skills available, counterbalancing the decline of younger cohorts and the potential depopulation of some territories, on the one hand. Another fundamental theme is that relating to the **training** of **adults**. In this perspective, **lifelong learning** is certainly important as a possible tool to be used to induce mature workers to continue training in order to protect health and safety in the workplace. On the other hand, it will take on strategic importance to continue to use the typical skills of mature cohorts of workers, for the time necessary to adapt production systems and to transfer their know-how and their culture to the younger generations. Definitely, although the present study is a pilot study, it provides useful insights for future developments.

6. Recommendations for future research

The workplace of the future will see **integration** between humans and machines: objects smart (smart printers and smart TVs), autonomous objects (robots and vehicles autonomous), proximity-based sensors, virtual assistants and many other technologies to increase and improve the employee experience. Even ageing workers will be able to work more comfortably (if necessary) remotely, while continuing to feel "useful". Therefore, work will increasingly assume a social function for those who have the right physical and cognitive conditions. Research developments will provide for the more detailed definition of digital technologies for each specific production sector. Future research developments will be twofold. On the one hand, a broader type of risk characterizing the manufacturing sector will be analyzed. On the other hand, other productive sectors will be analyzed in order to develop a comparative analysis between sectors.

CRediT authorship contribution statement

Fabio De Felice: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Francesco Longo:** Conceptualization, Data curation, Methodology, Writing - original draft, Writing review & editing. **Antonio Padovano:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Domenico Falcone:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Ilaria Baffo:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Appendix A. Context analysis (mapping)

Check list: Building behaviors to get results to manage ageing workforce

Instructions:

Qrcode

Please use the Likert scale assigns a score from 1 to 7. It is an increasing scale of values (1 indicates low capacity - 7 indicates maximum capacity)

For days of absence at work consider (% performance at work)

- Max. 9 days = 70% performance
- 10 - 24 days = 60% performance
- 25 - 99 days = 50% performance

Worker (name& surname)		**Age**	
Gender	**M**	**W**	**Prefer not to say**
Education			
Department of work / job			
Type of work	**Cognitive work**	**Manual work**	**Cognitive and Manual Work**
	□	□	□

Main Current diseases and llness			
	Rather often	**Sometimes**	**Rather seldom**
Do you manifest musculoskeletal disorders?			
Do you manifest diseases of the cardiovascular system?			
Do you manifest diseases of the respiratory system?			
Do you manifest stress, depression, anxiety?			
% performance at work	**Max. 9 days**	**10 - 24 days**	**25 - 99 days**
Days of absence at work: During the last 12 months how many whole days have you been off work because of illness	□	□	□

Code	**Questionnaire**	**Likert Scale**							**Score**
		1	**2**	**3**	**4**	**5**	**6**	**7**	
Q#1	What score would you give to your current work capacity?								
Q#2	How do you rate your current work capacity in relation to the manual demands of your job?								
Q#3	How do you rate your current work capacity in relation to the cognitive demands of your job?								
Q#4	Are you able to do your job without getting sick?								
Q#5	Do you believe, according to your present state of health, that you will be able to do your current job two years from now?								
Q#6	Considering the last three months: Have you been able to enjoy your regular daily activities?								
Q#7	Considering the last three months: Have you felt yourself to be full of hope about the future?								
Q#8	Considering the last twelve months: Have you felt yourself to be full of hope about the future?								
Q#9	Have you been able to carry out your usual daily activities with satisfaction in recent times?								
Q#10	Considering your current health condition, will you be able to do your current job in the next two years?								

Which of the following technologies do you consider most useful for your work? *(it is possible to give more answers)*		
□ **IoT**	□ **Robot**	□ **Simultion/digital twin**
□ **AR/VR**	□ **Additive Manufacturing**	

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