Springer Tracts in Mechanical Engineering

Rosanna Fornasiero · Tullio A. M. Tolio
Editors

The Future of Manufacturing: The Italian Roadmap

fabbrica intelligente

OPEN ACCESS

Springer

Springer Tracts in Mechanical Engineering

Springer Tracts in Mechanical Engineering (STME) publishes the latest developments in Mechanical Engineering - quickly, informally and with high quality. The intent is to cover all the main branches of mechanical engineering, both theoretical and applied, including:

- Engineering Design
- Machinery and Machine Elements
- Mechanical Structures and Stress Analysis
- Automotive Engineering
- Engine Technology
- Aerospace Technology and Astronautics
- Nanotechnology and Microengineering
- Control, Robotics, Mechatronics
- MEMS
- Theoretical and Applied Mechanics
- Dynamical Systems, Control
- Fluids Mechanics
- Engineering Thermodynamics, Heat and Mass Transfer
- Manufacturing
- Precision Engineering, Instrumentation, Measurement
- Materials Engineering
- Tribology and Surface Technology

Within the scope of the series are monographs, professional books or graduate textbooks, edited volumes as well as outstanding PhD theses and books purposely devoted to support education in mechanical engineering at graduate and post-graduate levels.

Indexed by SCOPUS, zbMATH, SCImago.

Please check our Lecture Notes in Mechanical Engineering at https://link.springer.com/bookseries/11236 if you are interested in conference proceedings.

To submit a proposal or for further inquiries, please contact the Springer Editor **in your region**:

Ms. Ella Zhang (China)
Email: ella.zhang@springernature.com
Priya Vyas (India)
Email: priya.vyas@springer.com
Dr. Leontina Di Cecco (All other countries)
Email: leontina.dicecco@springer.com

All books published in the series are submitted for consideration in Web of Science.

Rosanna Fornasiero · Tullio A. M. Tolio
Editors

The Future of Manufacturing: The Italian Roadmap

Springer

Editors
Rosanna Fornasiero
CNR-National Council of Reseach
Padua, Italy

Tullio A. M. Tolio
Department of Mechanical Engineering
Politecnico di Milano
Milan, Italy

ISSN 2195-9862 ISSN 2195-9870 (electronic)
Springer Tracts in Mechanical Engineering
ISBN 978-3-031-60559-8 ISBN 978-3-031-60560-4 (eBook)
https://doi.org/10.1007/978-3-031-60560-4

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

Paper in this product is recyclable.

Foreword

Manufacturing is the mainstay of many modern economies, capable of generating social, economic and environmental benefits, as well as helping overcome the great challenges of our times. The last two years have been particularly challenging for economies the world over, and Italy—with its wealth of flexible businesses, a diversified industrial culture and the ability to swiftly reconvert its processes—has managed to respond to the market-induced criticalities.

With its "Manufacturing a Resilient Country" document, the Cluster has already offered a proposal to face situations like the pandemic crisis, pointing out the need for Italy—as a country working together in a networked system—to adopt strategies that can leverage that solid industrial system to strengthen and develop processes, sectors and applications by creating collaborative ecosystems that pool regional specialization area excellences capable of working in national and international supply chains.

This roadmap is the result of intense work put in over two years, which has seen companies, universities, research bodies and associations come together to build a systemic vision for the themes of research and technological innovation with a medium- to long-term outlook. The aim of the document is to recommend paths for improving manufacturing's positioning in the international arena, facing challenges head-on and opening up new strategic opportunities to strengthen Italy's specific industrial leadership across the globe. The roadmap follows seamlessly from Horizon Europe's European research policies, developed in line with these policies and with what has been defined in the regional Smart Specialization strategies.

It is based on a collaborative approach whereby top-down analysis of the global development trends and scenarios generating the challenges for manufacturing are integrated with a bottom-up approach that engages the Cluster's members in bringing forward their research needs for the coming years.

The roadmap is structured along seven strategic action lines for which specific priorities for research and innovation have been identified, designed to seize and develop the opportunities offered by emerging and potential enabling technologies (which have also been identified with the aid of Pathfinders) in relation to the challenges companies are fielding from the market (which have also been identified with the aid of Lighthouse plants).

This work was started under the previous presidency of the Cluster, Luca Manuelli, and has been completed under my mandate and represents a coherent and harmonized vision of the Cluster of Intelligent Factories over the years.

In presenting this document, first of all I would like to thank my closest collaborators of the previous and current management boards for their valuable support on the strategic development of this roadmap: the president of the cluster, Gianluigi Viscardi, Tullio A. M. Tolio, Antonio Braia, Ivan Boesso, Leda Bologni, Paolo Calefati, Mauro Castello, Paolo Dondo, Sauro Longhi, Alberto Longobardi, Luca Manuelli, Alessandro Marini, Maria Rosa Raimondo, Mario Ricco, Daniela Sani, Giuseppe Saragò, Marco Taisch, Flavio Tonelli, Lorenzo Molinari Tosatti, Daniela Vinci and Andrea Volpi.

A particular thanks to the previous and current members of the Scientific Board of the Cluster that gave the scientific direction to the development of the roadmap. Tullio A. M. Tolio (President), Paolo Calefati, Sauro Longhi, Alberto Longobardi, Marco Taisch, Flavio Tonelli and Gianluigi Viscardi.

This work would not have been possible without the continuous and strong commitment of the roadmap editors, Tullio A. M. Tolio and Rosanna Fornasiero, who coordinated the work of all the cluster groups, assured the consistency of the whole document and supported the definition of the coherent and complete vision of the content generated along the process of roadmap development.

My thanks go to Cluster Manager Paolo Vercesi who organized the work around the creation of the roadmap, organizing webinars, managing surveys and supporting actively discussions and various technical meetings.

This roadmap is the result of a collaborative approach involving all the members of the Cluster of Intelligent Factories who have provided their competence, ideas and vision on the future of Italian manufacturing through an interactive process. Companies, Universities, Research Bodies and Associations have lent their expertise in various capacities, called on by the Cluster to take an active part in this process.

In particular, I would like to thank the following groups that have dedicated continuous effort in the development of the roadmap.

The Roadmapping group of the Cluster: Rosanna Fornasiero (Coordinator), Marcello Colledani, Guido Colombo, Melissa Demartini, Paolo Dondo, Luca Giorleo, Cristian Secchi, Flavio Tonelli and Marcello Urgo.

The members of the Steering Committees of the technical and scientific group (GTTS) and their delegates:

- Accurso Damiano
- Auricchio Ferdinando
- Baglietto Marco
- Barberio Grazia
- Beghi Alessandro
- Biele Enrico

- Benatti Paolo
- Biglia Mauro
- Bonaiti Giacomo
- Bortoluzzi Davide
- Bosi Gildo
- Calefati Paolo
- Callegati Enrico
- Campatelli Gianni
- Caramella Nicola
- Cardinali Fabio
- Catalano Antonio
- Ciarapica Filippo Emanuele
- Chiabert Paolo
- Colledani Marcello
- Colombo Guido
- Cotti Piccinelli Renato
- Crippa Marino
- Demartini Melissa
- Dondo Paolo
- D'Orazio Tiziana
- Fornasiero Rosanna
- Galassi Carmen
- Ghignone Antonello
- Gilioli Edmondo
- Giorleo Luca
- Giuliani Fabio
- Golinelli Fabio
- Lacobucci Donato
- Macchi Marco
- Melchiorri Claudio
- Messina Angelo
- Monti Marina
- Munaro Roberto
- Parrini Mauro
- Pellicciari Marcello
- Peruzzini Margherita
- Petrali Pierluigi
- Picone Nicoletta
- Pontrandolfo Pierpaolo
- Previdi Fabio
- Previtali Barbara
- Rampa Vittorio
- Salmoiraghi Sandro
- Salvio Marcello
- Scandelli Nadia

- Scippa Antonio
- Secchi Cristian
- Semeraro Luigi
- Sortino Marco
- Susto Gianantonio
- Tomesani Luca
- Trotta Gianluca
- Urgo Marcello
- Virgilito Giuseppe
- Viscardi Mauro
- Viscardi Michele
- Vistoli Maria Cristina
- Zanichelli Francesco
- Ziprani Francesco
- Zuffada Roberto

The representatives of the Lighthouse plants:

- Fabio Golinelli—ABB
- Luca Manuelli—Ansaldo
- Fulvio Rinaldi—Hitachi
- Paolo Galli—HSD
- Maurizio Zanforlin—Ori Martin
- Enrico Malfa—Tenova
- Giuseppe Saragò—Wastila

The representatives of the Pathfinder companies:

- Michele Dalmazzoni—Cisco
- Fabio Bonanni and Andrea Muggetti—Deloitte
- Stefano Venchi—Ernst andYoung
- Andrea Pagliari—SAP
- Franco Megali—Siemens

The representatives of the organizations indicated by Regional Councils:

- Alessandro Marini—AFIL for Lombardy Regional Council
- Leda Bologni, Daniela Sani—AR.TER for Emilia-Romagna Regional Council
- Antonio Braia—Cluster Lucano Automotive for Basilicata Regional Council
- Mauro Castello—Cluster Marche Manufacturing for the Marches Regional Council
- Saverio Maisto—COMET for Friuli-Venezia Giulia Regional Council
- Silvio Atonioni—HIT for Trento Autonomous Provincial Council
- Mario Ricco—MEDISDIH for Apulia Regional Council
- Paolo Dondo—MESAP for Piedmont Regional Council
- Flavio Tonelli—SIIT for Liguria Regional Council
- Elisabetta Boncio—Sviluppumbria for Umbria Regional Council
- Ivan Boesso—VenetoInnovazione for Veneto Regional Council

This work would not have been possible without the economic support of the following organizations:

- Autodesk
- Cefriel S.C.R.L.
- Comet S.C.R.L.
- Cosberg Spa
- Dassault Systems Italia Srl
- Efeso Consulting Srl
- Enel Spa
- Feralpi Siderurgica Spa
- Fondazione Bruno Kessler
- Itelyum Regeneration Srl
- Masmec Spa
- Menarmi Manufacturing Logistics and Services Srl
- Nokia Solutions and Networks Italia
- Nuova Icom Srl
- Oracle Italia Srl
- Sacmi Coop. Meccanici Imola
- Smart Track Srl
- Siemens
- Unioncamere
- Università Politecnica delle Marche
- Università degli Studi Guglielmo Marconi
- Wärtsilä Italia Spa

I think this roadmap is an essential tool for supporting members in determining their paths going forward and, at the same time, to inspire specific policies and actions for research and innovation as well as internationalization at the various stakeholder levels, including at a government level. It can be used to bring institutions—above all, Ministries in particular MUR, MIMIT, MAECI, MASE and MLPS—into the discussion, representing the visions brought into focus by the members of the Italian Cluster of Intelligent Factories. At the European level, it is a qualified point of view for possible interactions with the Manufuture platform, existing partnerships like Made in Europe, Clean Steel and Processes4Planet, the Chips Joint Undertaking and the new partnerships in the area of advanced materials, the KIC Manufacturing and all the other initiatives related to manufacturing. Lastly, this document can further be used for actions to support cross-fertilization between national and regional policies and to support bilateral discussions with other countries.

Bergamo, Italy

Gianluigi Viscardi
President of the Cluster of Intelligent Factories

Preface

Manufacturing is the mainstay of many modern economies, capable of generating social, economic and environmental benefits, as well as helping overcome the great challenges of our times. From a broader point of view, the availability of advanced expertise, industrial culture, image, brands and reputation, availability of resources for innovation and research, and the right conditions to attract talent are all elements that can seal a country's success.

Over the last three years, it has become even more apparent that—based on the characteristics and availability of resources (such as skills, manufacturing plants and raw materials)—each country needs to develop a strategy to ensure a strong industrial sector, focusing on processes, sectors and applications that embody the uniqueness of the region's characteristics, with a view to achieving excellence in strategic areas of specialization.

Italy, more than most, has a unique heritage in terms of tradition, culture, skills, image, design and technologies, which represent the optimal environment for a manufacturing sector that produces high-added-value products and services exported worldwide.

The only conceivable engine for driving continuous evolution in a country is a research and innovation plan accompanied by a training plan designed to refocus the set of skills within the national industrial fabric in line with European policy objectives. A multi-year research plan must leverage the qualities of Italy's available production resources and must be aligned with research challenges and international trends in the manufacturing field.

The pandemic has put all companies and economies through the wringer, and no analysis of historical data is complete without also looking at current economic data, which nonetheless makes coming up with any forecast for the future much more difficult and calls for great caution in a context that is still very much evolving and marked by a great deal of uncertainty.

On the one hand, it is necessary to avoid the risk of being influenced by the latest trends that the shifting current scenario can easily overturn; on the other, it is necessary to define pathways that take into account challenges and the opportunities they bring for an overhaul of Italian manufacturing.

The Cluster's strategy is based on the fact that the development and application of scientific research outcomes is recognized as one of the most effective levers for improving competitiveness and creating products and processes that are more efficient and sustainable and, more generally speaking, better able to meet people's needs.

In addition, this has a considerable impact on society as it can help improve the quality of life of its citizens and the competitiveness of the system as a whole, tackling social challenges, such as sustainability, product customization and development of human resources.

A process of this kind is complex and involves various components and different roles, taking into consideration different points of view, interests and needs. Over the last 15 years, models capable of supporting an innovation process of this kind have been discussed at length and analysed at a scientific, industrial and political level with the goal of finding more effective ones. Today, one of the most widely adopted models of innovation is the so-called triple helix model.

According to this model, the growth of a country, capable of considering the needs and characteristics of the society and industrial system, can be achieved through proactive collaboration between research, business and government. On one side, the objective of the research activities is the development of innovation that can be applied to different contexts. On the other side, it is the task of businesses to ensure they are profitable, competitive and offer value for money.

Institutions must provide a regulatory framework supporting effective collaboration, assisting them during the initial phase from research to innovation through to actual industrialization, as they often prove unfeasible where they rely on market forces alone. Moreover, a virtuous system should be based on social and economic improvement, which researchers and companies should factor into the technological development models, possibly also backed by government bodies.

In this context, there is no denying the paramount importance of the Cluster's role: it becomes a facilitator of research and innovation networking processes, acting as a soft-governance body to bring together the needs of all these actors through processes designed to help define appropriate policies to support and stimulate research and innovation, and their implementation, with the aid of strategic documents such as the roadmap.

Therefore, with its ultimate goal of defining the new roadmap for research and innovation for the Italian manufacturing industry, this book groups the work of more than 200 people involved with different sessions of brainstorming, focus groups, expert elicitation and content analysis.

The first chapter "Defining a Collaborative Framework for Roadmapping Activities" proposes a collaborative framework and methodology that can be used for supporting roadmapping activities involving large groups of actors representing different interests.

The second chapter "Analysis of the Italian Manufacturing Sector" proposes an insight into the context of the Italian manufacturing sector, comparing it with other countries in Europe and across the globe, also offering a focused look at the sector's response to the pandemic crisis, and with a focus on the machine tools sector and on system competitiveness.

This is followed by the chapter "The Role of Industrial Policies: A Comparative Analysis" with the analysis of the reference documents that are orienting industrial policy at the European, national and regional levels to study how these decisional levels can interact in terms of content and synergies of objectives.

The following chapter ("Building Scenarios for the Future of Manufacturing"), referring to a number of important environmental, social and technological trends, offers a number of reference scenarios that are emerging for having a significant impact on the manufacturing sector in terms of changes in production models along the time horizon from short to long term and that can be used to identify the strategic lines.

Chapters "Strategic Action Line LI1: Personalised Production"–"Strategic Action Line LI7: Digital Platforms, Modelling, AI, Cybersecurity" expand on the content in terms of strategic action lines each covering a specific macro-area and identification of related research and innovation priorities.

Padua, Italy Rosanna Fornasiero
Milan, Italy Tullio A. M. Tolio

Contents

Strategic Action Line LI3: Factories for Humans

Paolo Dondo, Michele Viscardi, Mauro Viscardi, Fabrizio Cardinali, Paolo Chiabert, Tiziana D'Orazio, Claudio Melchiorri, Marcello Pellicciari, Margherita Peruzzini, and Nadia Scandelli

Abstract The objective of this chapter is to describe the strategic action line related to the factories for humans (LI3). In particular, this chapter proposes research and innovation priorities aimed at designing and developing new solutions to enhance the role of human resources and their skills, and contribute to their satisfaction and wellbeing; research and experimentation of new technologies for reducing physical exertion, cooperation with advanced support systems, with collaborative robots and with AI-powered technologies; mapping of knowledge generated on the job, especially implicit knowledge, in a way that is compatible with privacy requirements, introducing advantages both on the human wellbeing front—whether the individuals are users, operators or managers—and in terms of business strategies and procedures. In this regard, innovative factories will need to be increasingly inclusive, strongly geared towards the engagement and participation of individuals (users, operators and managers). These models must take a human-centric approach to look into/

P. Dondo (✉)
MESAP, Torino, Italy
e-mail: p.dondo@advsor.mesap.it

M. Viscardi · M. Viscardi
COSBERG, Bergamo, Italy

F. Cardinali
MYWAI Srl, Sestri Levante, Italy

P. Chiabert
Politecnico Di Torino, Torino, Italy

T. D'Orazio
CNR-STIIMA, Milan, Italy

C. Melchiorri
Università Di Bologna, Bologna, Italy

M. Pellicciari · M. Peruzzini
Università Di Modena E Reggio Emilia, Modena, Italy

N. Scandelli
Cefriel, Milan, Italy

R. Fornasiero and T. A. M. Tolio (eds.), *The Future of Manufacturing: The Italian Roadmap*, Springer Tracts in Mechanical Engineering,
https://doi.org/10.1007/978-3-031-60560-4_7

investigate new technologies and all the dimensions through which the new factory is defined.

Keywords Workers · Human–machine interaction · Skills and competences · Training · Safety and ergonomics

1 Introduction

In the coming years, exponential growth in connected IoT devices is expected. It will include consumer, industrial and healthcare applications, with a market forecast of between $4 and $11 trillion by 2025, around 1600 billion in Industrial IoT (*Source* McKinsey). Machines will be increasingly pervasive, intelligent, connected, and equipped with forms of distributed intelligence that will interface with users.

Ongoing technological changes call for the definition of socially sustainable digital innovation pathways make technology work at the service of humans (workers, citizens, students, or else) and for the development of a human-centred society. According to a 2018 study by the McKinsey Global Institute, in urban contexts, digitization has contributed to raising various quality-of-life indicators from 10 to 30%, in areas ranging from transport and healthcare to the reduction of the pollution generated by manufacturing.

In particular, according to a recent Microsoft/IDC study, about 85% of jobs are expected to undergo a transformation in the next 3 years, 33% of workers will have to engage in re-skilling, 26% will take on new roles, 27% of works will be outsourced or automated.[1] Skills will undergo essential changes accordingly. A ranking of the skills necessary to use artificial intelligence shows that technical, cognitive, process and social skills will need improvement. New future professions include, among others, data scientists, data engineers, data analysts and the like.[2]

The new document of the European Commission on Industry 5.0 focuses on the crucial role of people, in industrial contexts, on data, information and knowledge management. Industry 5.0 presents a business model based on cooperation between machines and humans, which implies rethinking and innovating models and tools for managing information, as the current ones are often inadequate to deal with the complexity of present socio-technological environments. Particularly so in fact, as the evolution of information technology has made new developments possible.

In the new scenarios, the debate on the role of people in factories is spurred by a wealth of new ideas. This makes it increasingly urgent to study new models that can enable people to improve their work and have a leading role in the evolution of production processes and in the introduction of systems for the exploitation

[1] Microsoft (2018). Brave New World - How AI Will Impact Work and Jobs. Retrieved from https://news.microsoft.com/en-hk/2018/05/02/brave-new-world-how-ai-will-impact-work-and-jobs/

[2] Deloitte (2018). Global Human Capital Trends. Retrieved from: https://www2.deloitte.com/us/en/insights/focus/human-capital-trends/2018.html.

of artificial intelligence. All these studies have to consider the diversities of the workers' cognitive and physical skills. Artificial intelligence and future technologies will increase the workers' skills and knowledge, providing physical help in dealing with the heaviest and riskiest jobs and decision-making support.

However, knowledge generated during the job (particularly tacit knowledge) must be mapped before it can be re-used in the company in a way that meets the privacy requirements of the factory and the individuals. All this requires an intensive effort from both a technological and an organizational point of view.

The continuous introduction of new technologies and management practices calls for new skills and knowledge that should be developed through training for people wishing to enter the job market and through continuous education programs for those already in employment.

This action line aims to design and develop new solutions to enhance individuals and their skills, thus contributing to their satisfaction and well-being. Innovative factories should be increasingly inclusive and firmly focused on the involvement and participation of people (users, operators, managers). These models should be human-centric. Humans run and control technologies and, in general, all the dimensions through which the new factory is defined.

The most relevant challenges certainly include the creation of safe and comfortable workplaces capable of generating positive emotions in the people involved in the production, and workstations that reduce the workers' physical and cognitive effort and help them move on to activities with greater value added. In the new factories, the design of spaces, workstations, new facilities architectures, and new models for the safe interaction between humans and machines will become central aspects. Particular attention will be paid to improving human interaction with an environment populated by various technologies/systems such as robots, machinery, interfaces, and automation systems.

The study and experimentation of new technologies for reducing physical effort can be sparked by exploiting the potential of wearable devices and exoskeletons. The cognitive effort could be eased by intelligible and straightforward information, profiled according to the worker's needs.

Similarly, the role of workers is shifting from traditional repetitive to higher-level tasks thanks to the cooperation with advanced support systems, collaborative robots, and AI-based technologies. On the one hand, the objective will be to provide all the material and cognitive support tools that can improve workers' skills and knowledge and, on the other, generate new training procedures and tools to help workers be up-to-date and keep step with the changes in manufacturing processes.

Finally, the knowledge generated on the job, particularly tacit knowledge, will be mapped and reused within the company to be compatible with individual privacy. This will bring benefits both in terms of the well-being of people, whether users, operator or managers, and in terms of company policies and procedures.

Expected impact: increasing workplace safety and well-being; reducing psycho-physical stress; increasing qualification opportunities and promoting the personal enhancement of workers, preserving them from exclusion and downgrading; improving the transparency of the algorithms that regulate the operation of digital

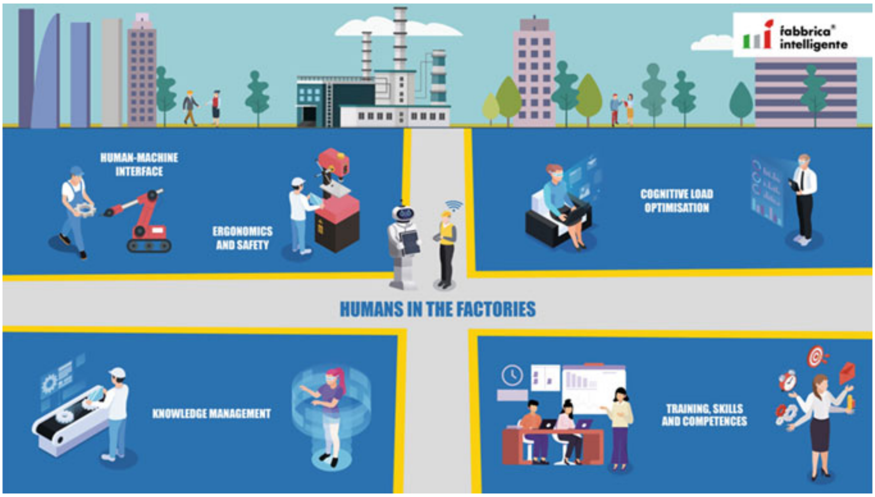

Fig. 1 Strategic Action Line 3—Factories for humans

platforms; improving the capacity of companies and workers to exploit the advantages of the data economy to ensure, in compliance with ethical-legal limitations and individual freedom, the achievement of collective goals in terms of the workers' health and well-being in the factory.

The research and innovation priorities of the strategic action line on Factories for humans are (Fig. 1):

- PRI3.1—New Technologies, Methods and Tools to optimize the work environment, human–machine interactions and cognitive load
- PRI3.2—New Technologies and Methods for the management of Knowledge, Information, Privacy and the Company's Human Capital
- PRI3.3—New Technologies and Methods for the training and certification of the skills and professionalism of persons and of the human capital in the Life Long Learning (LLL) era

2 PRI3.1 New Technologies, Methods and Tools for Optimizing the Work Environment, Human–machine Interactions and Cognitive Load

People play a central role in designing intelligent factories and, above all, in generating their flexibility and "resilience". Factories can thus adapt to new and not entirely predictable contexts and reconfigure promptly and efficient according to new work patterns and production models.

This research and innovation priority proposes to design new technologies and methods for managing human resources as a critical element in the new concept of "resilient factory". In particular, this priority proposes objectives connected with ergonomics, human–machine interaction, and the person's cognitive load, promoting new ways of working and communicating (remote work, collaboration with automation systems, and management of production re-purposing).

The proposal is to develop methods, models, and systems to support operators in their work, increase their physical and cognitive abilities, improve work quality and productivity, and reduce margins of error while ensuring the workers' general well-being. As a result, safety and well-being in the workplace will be increased by acting on numerous factors: an adequate redesign of the type and sequence of activities during work shifts, better organization of the premises, information display mode optimized according to needs and activities, natural and intuitive interactions between humans and machines). This will reduce psycho-physical stress, mental and psychological fatigue, anxiety, and overload.

One of the fundamental themes for the future will be to guarantee a continuous and rapid evolution of production systems to seize new opportunities and to face ongoing changes. Humans are at the centre of a constant redevelopment that requires analytical skills, goal identification, and creation of solutions and planning of pathways to achieve the desired results. This shift has to take place at all levels, from the local improvement of individual workstations, geared to increase efficiency and respond to new needs in terms of products and materials, seizing new opportunities in terms of tools, sensors and plants, to factory networks, supply chains and interaction with the markets. To be effective, this change must be pervasive and see the joint effort of all the people who take part in this evolution at different levels. The ability to manage this evolution, rather than the optimization of individual situations, will in all likelihood be the real competitive lever in a rapidly and radically changing context such as the current one. Humans are the critical resource, as they can use their intelligence and dedication to ensure high performance and competitiveness for their company. In this perspective, it is important to underline that people must be put in a position of dominating changes. The rapid and continuous evolution of technological products and production systems should parallel the ongoing and targeted development of the knowledge and skills of the people who cooperate to manage change at different levels.

In particular, the goals of this research and innovation priority concern:

- **New materials and tools for workstation ergonomics and safety:** development of active and passive PPE (Personal Protective Equipment) including materials that absorb high levels of thermal and mechanical energy, safety devices, wearable sensors, smart work clothes, workers' supports for repetitive tasks, intelligent exoskeletons for workers' safety, digitization of workers and work environment so that the worker's operations can be designed in a human-centred perspective and complex tasks can become more accessible.
- **New technologies for customization of work environments:** development of intelligent solutions designed to adapt workstations to the specific physical and

cognitive skills of individual workers, considering their role, duties, abilities and needs; developments of intelligent solutions designed to recognize operators and to reconfigure the working environment based on working conditions.

- **Methods and technologies for the management of the human–machine interaction: development of** natural and intuitive interaction models, new human–machine interaction paradigms, new methods and tools for the analysis of workplace interactions, new human–robot cooperation and collaboration models, natural communication languages, natural and transparent intelligent adaptive interfaces, including environmental, wearable and multi-modal types (immersive interfaces with Virtual and Augmented Reality, Brain Computer Interfaces, etc.).
- **Methodologies and technologies for optimizing the cognitive load**: development of work environment design models and advanced interfaces capable of supporting control activities and decision-making; structured approaches for the measurement of mental stress in the industrial environment, intelligent systems (based on Deep Learning, Digital Twin, Artificial Intelligence, GANs networks, etc.) to help optimizing mental load, avoiding both overload and underload.
- **Tools to bolster adaptation to continuous changes in production**: development of intelligent systems that can predict the operator's actions and provide online support on Virtual and Augmented Reality (operations to be carried out, procedures, activity tracking, etc.), Virtual Training systems and immersive, augmented or mixed Virtual Reality tools, that can help to improve staff safety by providing remote training on how to deal with risky situations.

Interaction with Other Action Lines

This research and innovation priority is transversal and will have strong interaction with action lines LI5 and LI6.

- Human–machine collaboration and integration in innovative manufacturing (LI5) will increase human capabilities rather than replace them, allowing humans to focus on higher value-added, creative and socially relevant activities.
- Human–machine interaction will be studied in close connection with Strategic action line LI6. The aim will be to provide guidelines for designing collaborative human–robot systems within evolutionary and resilient manufacturing systems geared to enhance people's work and gain by the workers' experience.

Time Horizon

Short-Term Goals (2–3 years):

- Materials and tools to improve workplace ergonomics and safety,
- Models for the management of the human–machine interaction geared to enhance the work of people in factories,
- Models for designing working environments and advanced interfaces that can provide support for control and decision-making,
- Digital models of workers to be deployed in planning their operations and designing the means to facilitate complex tasks.

Medium-Term Goals (4–6 years):

- Technologies for the customization of work environments,
- Intelligent solutions capable of adapting machines to operators, detecting the presence of DPIs and checking in real time that the correct procedures are being carried out,
- Technologies for the management of the human–machine interaction,
- Technologies for the optimization of cognitive load

Long-term goals (7–10 years):

- Tools to bolster the adaptation to continuous changes in production processes (intelligent systems capable of predicting the operator's actions and offering online support, and advanced Virtual Training systems to train operators to deal with changes)

3 PRI3.2 New Approaches to the Management of Corporate Knowledge, Privacy and Human Capital

Knowledge, creativity and the human capability to cope with unforeseen events play a fundamental role in generating innovation and managing production. Competitiveness involves acquiring awareness of these aspects and enhancing the human component and its ongoing development. As machines become increasingly intelligent and connected (Smart Machines), new business models will lead the way from a product economy to a product-service economy (Servitization) also in manufacturing. Prognostics and remote configuration of the new "connected products" will be the basis for this change. Knowledge is increasingly important and remotely available thanks to new digital tools.

Furthermore, emerging production models provide for the pervasive introduction of AI-based tools, which involves the creation of knowledge management and decision-making support tools, as well as smart machines that work together with humans. In this scenario, it is necessary to keep the focus on the central role and skills of people means promoting the trustworthiness and explainability of AI methodologies, with a view to ensuring that AI-based systems comply with the ethical principles of respect for people, prevention of damage, fairness and explicability.

The research and innovation priority must therefore address the following objectives:

- **Methods for managing information, privacy of people and factories:** Define rules and methodologies to collect, manage, harmonize and share information related to workers and factories. They should ensure an appropriate acquisition and use of data with a particular focus on sensitive data Privacy and Security. This area includes: CyberSecurity (i.e. IT equipment safety and security), anonymization of data both at data generation and data processing level, certification of data from its generation all along the management and analysis process chains. The issue of the workers' self-sovereignty with regard to their digital identities (Self Sovreign Identity) is also very important.

- **Technologies and methodologies for the management of corporate knowledge:** It is necessary to develop new tools for the collection, integration and harmonization of knowledge generated by people and databases, with a view to ensuring that such knowledge can be reused and optimized. In particular, data should be made accessible, available and easily integrated through new methods in support of data analysis and event prediction. Specific consideration should also be given to systems for the management of information useful in carrying out the manufacturing and decision-making processes assigned to the workers. Structured and shared knowledge will help workers be more productive, sharing experiences that will help them find easier, quicker and cheaper solutions to problems, contributing to their personal development and training in the specific field. In particular, this goal requires actions to be deployed along three lines:
- **Knowledge capture:** Defining "Human Computation" methodologies and technologies to transform tacit into explicit knowledge by actively involving people in processing information, putting users back at the centre of the process (human-in-the-loop), to collect, improve and preserve the quality and reliability of knowledge. This will make it possible to create and enhance a company's living asset capable of generating systems that can be used by workers for their self-improvement, favouring a natural transition from a behavioural to a cognitivist perspective on skills. Knowledge capture systems will also make it possible to valorise intangible assets through appropriate measurement systems, also for valorising them in financial statement.
- **Knowledge Analysis & management:** Developing a new generation of methodologies and application tools capable of combining the analysis of captured and structured knowledge with the management of information, whether from human sources or machine interfaces. The aim is to support operations and decision-making processes, by defining conceptual reference models, sharing and managing assets according to FAIR (Findable, Accessible, Interoperable, Reusable) principles. Throughout this process, it is essential that formalized knowledge is communicated in understandable formats to the operators so that new knowledge can constantly be built on existing one and the operator can maintain control of this evolving situation.
- **Knowledge transfer and sharing:** Once become a corporate asset, knowledge can be shared, exploited and preserved within the company. Thus it is necessary to develop systems for sharing information and data among people and manufacturing units within the factory with the aim to create value for the workers, for instance through re-skilling and coaching sessions conducted by experienced people for recruitment of new resources and field support. There is a need for Human–Machine Knowledge Transfer mechanisms (Artificial Neural Networks, ANNs) and collaborative robots (Cobots) that operate taking into account human behaviour, using artificial intelligences based on Explainable & Trustworthy AI. As a result, ANNs and cobots will be assigned to small value added activities, and to facilitate workers in their daily actions and support them in their decisions, by

providing them with the necessary decision-making elements. It is expected that in these systems, the "human factor" will be at the centre of the decision-making process.

- **Systems for the management of Knowledge IP:** it is essential to define methods, infrastructures, guidelines and application tools to ensure that the ownership of knowledge is available and valued, as both a corporate and a personal asset, in a perspective of trust and enhancement of the ideas of those who generated them and of those who provided the tools to generate them.

Interaction with Other Strategic Action Lines

- Data protection and workers' privacy issues need to be addressed in close relation with the actions carried out in Strategic action line LI7 regarding cyber-security.
- With reference to LI6, digitization/digital twin issues will be useful in defining the tools for sharing and managing knowledge within the digital factory.

Time Horizon

Short-term goals (2–3 years):

- **Knowledge**: the digitization of the working experience of operators (mapping skills and digitizing them to create value for the company) is a key issue and will lead to the creation of a shared re-skilling knowledge base for the rapid recruitment of new resources. To date, these issues are regarded by companies as interesting and certain initiatives are underway, but no structured solutions are as yet available. For this reason, the goals in this area are defined in the short term of 2 to 3 years, to start raising awareness and promote the creation of solutions to channel these needs. More complex solutions, for instance based on Explainable and Trustworthy AI, should be set in motion promptly to avoid losing ground to competition from other markets. However, their full integration will only be achieved through medium-long term actions (1–5 years)
- **Information & Privacy**: data privacy, security and Self Sovreign Identity are certainly extremely engaging issues for both companies and workers, and should be addressed in the short term.

Medium-term goals (4–6 years):

- **Advanced Interactions:** The definition and development of IoT, AR and smart wearable technologies, for monitoring and supporting workers, can be addressed through actions in the short-medium term.

Long-Term Goals (7–10 years):

- **Advanced Interactions:** Natural multi-modal interfaces, capable of allowing intelligent and self-adaptive interaction with the industrial environment and robots, and convergence of AI, CBI and Exoskeleton systems should instead be addressed in the medium-long term, given the complexity of the context.

4 PRI3.3 New Technologies and Methods to train and certify the skills and competence of individuals and of a company's human capital in the era of Life Long Learning (LLL)

The constant introduction of new technologies and new management practices in companies is creating a lack of coordination between demand for new professional profiles, the qualification of operators active on the labour market. In Italy, the difference between supply and demand amounts to more than 150,000 jobs available within companies that are not matched on the labour market (2019 data).

In addition, the knowledge acquired by the current workforce during their educational career becomes obsolete quickly and continuous training is required to generate added value for the company. Accordingly, there is a demand for new skills and knowledge in the offer of training programs for people entering the job market, and of updating programs for those already in employment.

From a company's point of view, it becomes essential to map the workforce's competence and skills to understand proactively the impact of a new technology, the timeframe to its full exploitation as added value and the most effective training methods.

From an individual's point of view, the need is for virtual and tangible tools and environments to be constantly available, to ensure a continuous education and the certification of the skills and knowledge acquired, in a Life Long Learning (LLL) perspective. New teaching frames must be used to increase the power of attraction of the manufacturing world and the efficacy of training.

New tools should be developed also to provide user support functions, to manage knowledge and training for classes of both younger and more experienced users, to develop/improve high-profile skills in manufacturing.

Finally, it is essential to develop tools to assess the work carried out and test the skills and abilities acquired, so that the new strategies and technologies introduced can be properly validated from a corporate point of view, the effects of the training received can be assessed, and objective tools can be provided for the certification of the skills and abilities acquired on the job.

The research and innovation priority must therefore address the following objectives:

1. **New methods and tools for active training**: the availability of new hardware devices such as smartphones, tablets, smart glasses, combined with the prompt availability of protocols with enormous bitrates (5G) and the use of software such as social media and APPs pave the way to the interaction with digital twins of machinery, lines and production environments. The focus is on strengthening MOOCs (Massive Open Online Courses) and experiential tools such as Mixed, Augmented and Virtual Reality, alongside innovative methodologies and new educational models such as "serious games", to further enable training both in presence and at a distance.

2. **Physical environments for the education and training:** Development of "protected" physical environments where people can be educated and trained on new technologies, and pilot and demo work environments (Teaching & Learning Factories) which can also be used remotely. An environment of this type should facilitate training in value-added manufacturing, providing workers with interdisciplinary skills, preparing them to integrate new technologies and empowering them with the capability of combining knowledge. The goal is to design and plan "hands on" training courses, in which workers can directly experience technologies. This will guarantee an immediate return from the prompt redeployment of such technologies in the factories.
3. **Methods and tools for assessing the acquired skills and abilities:** Development of automatic systems for the assessment of the operative skills achieved and required for the performance of the various tasks assigned. Methods and tools to track the impact of education and training in terms of improving and increasing the efficiency of production systems.
4. **Methods and tools for planning staff development paths:** development of systems that make it possible to plan an evolution of products, processes and manufacturing systems in parallel with the development and acquisition of skills by the staff. This opens the way to the adoption of planning models that focus on improving knowledge and skills through exchanges between operators with different experiences. Such models need to hold into account the knowledge's evolution timing and connect it to the systems' evolution timing.

Interaction with Other Strategic Action Lines

- With reference to LI6, digitization/digital twin's issues will be useful in defining tools for sharing and managing knowledge within the digital factory.

Time Horizon

Short-term goal (2–3 years):

- New serious-game methods and tools for active training
- Physical environments for the education and training of people
- Methods and tools for planning staff growth paths

Medium-term goal (4–6 years):

- New methods and tools for active training based on virtual reality and multisensory approaches
- Methods and tools for assessing the skills and abilities acquired

References

BCG. (2015). Man and machine in industry 4.0: How will technology transform the industrial workforce through 2025?

Digitising Manufacturing in the G20—Initiatives, Best Practice and Policy Approaches, March 2017, conference report available at: http://www.kmu-digital.eu/de/publikationen/tags/produktion/233-digitising-manufacturing-in-the-g20-initiatives-best-practice-and-policy-approaches/file.

EIT—Manufacturing—Teaching & Learning Factories—https://eitmanufacturing.eu/pillar/education/

ETHICS GUIDELINES FOR TRUSTWORTHY AI", HIGH-LEVEL EXPERT GROUP ON ARTIFICIAL INTELLIGENCE SET UP BY THE EUROPEAN COMMISSION

EU Project—FIT4FoF—New skills for the Factory of the Future—https://www.fit4fof.eu/about/objectives-and-benefits

European Commission. (2021). Industry 5.0: Towards a sustainable, human-centric and resilient European industry).

Human-centered factories from theory to industrial practice. Lessons learned and recommendations. Publisher: uman Centred Factories (ACE), 2019. White paper.

Humans Wanted: Robots Need You, 2019 Skills Revolution, ManpowerGroup, report available at: https://www.manpowergroup.com/workforce-insights/world-of-work/skills-revolution-series.

ICT e lavoro: nuove prospettive di analisi per la salute e la sicurezza sul lavoro, INAIL report, 2016, available at: https://www.inail.it/cs/internet/comunicazione/pubblicazioni/catalogo-generale/pubbl-ict-e-lavoro-nuove-prospettive-di-analisi.html.

Manufuture—STRATEGIC RESEARCH AND INNOVATION AGENDA 2030.

Safer and Healthier Work for All—Modernisation of the EU Occupational Safety and Health Legislation and Policy, European Commission, January 2017, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2017%3A12%3AFIN.

World Manufacturing Forum https://www.worldmanufacturingforum.org/report-2019.