OPERATOR 4.0: A HUMAN PERSPECTIVE OF INDUSTRY 4.0

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Abstract

Operators play a vital role in any manufacturing setting. They are an essential part of the workforce behind all manufactured goods in the market today. Recent technological advancements in such revolutionized industry, i.e., Fourth Industrial Revolution (Industry 4.0), have brought much attention to the interaction and application between tools and operators. For example, exploring the nine technological pillars, such as Augmented Reality, Virtual Reality, Collaborative Robots, Cyber Physical Systems, etc., has been investigated widely in different use case scenarios. Never before has there been more attention to the influence of technology over industrial and manufacturing exercise and implementation. However, the current view of Industry 4.0, its scope and application, are young and heavily prevalent from a technical and technological perspective. This one-sided perspective respectively impacts the views on the workforce and the operator in Industry 4.0 environments. There is an acute need to balance such a technology-driven focus of the industry with a better level of human inclusiveness and considerations, especially at the workforce and operator scale.

In this context, a novel approach that represents two redefined and updated concepts of the human perspective for Industry 4.0 is proposed. First, Human Capital 4.0 integrates future-proof attributes that will support the workforce at its best in the advents of Industry 4.0. Second, the new view of Operator 4.0 is an assembly of factors found throughout the research to provide a perspective that best advocates a human-centered approach for Industry 4.0. This research aims to facilitate theoretical methodology that provides principled explanations and practical models for human-based and worker-centric inclusion into Industry 4.0.

A systematic development method for the new version of Operator 4.0 is presented based on different workforce implications, i.e. role interactions, capabilities, and skill cooperation. These aspects were explored and analyzed with a straightforward human approach, i.e. a worker-centric perspective. Therefore, the updated version of the operator highlights the job implications to the manufacturing worker due to recent technological implementations. Moreover, the proposed overview of Operator 4.0 is complemented by three important attributes found necessary for human capital in advents of Industry 4.0, such as wellbeing, holistic competence, and holistic preparation. The representation for wellbeing is elaborated to seek equilibrium between existing challenges in the industry and the needed resources of the workforce. The model for holistic competence is developed to support and enhance human capital not only at the technical side but, more essentially, at the human side. The model for holistic preparation is designed to embrace a human-centered approach and a holistic competence for workforce development. A method of application was derived from this model to tackle some of the contemporary challenges affecting the workforce. For example, such models and method developed in this study could be utilized by personnel of human resource department, as the end-user, when training and upskilling their colleagues in a company. This company should consider the key competences and attributes presented in this research work as part of their core strategy for labor culture and human capital development. As per future work, this thesis lays down the ground for two things primarily. First, the research, coherence, and merged of these new or updated concepts (Human Capital 4.0 and Operator 4.0) to the idea of Industry 5.0 that recently emerged in Europe. Second, a step-by-step manual of implementation of these presented frameworks to the different management levels of a company. .

Part of the research work in this thesis has been reported in one journal paper and presented at three international conferences.

Keywords: Human Capital 4.0, Operator 4.0, Industry 4.0, Workforce, Competence, Preparation, Human-centred, Holistic approach

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Nomenclature

AI	Artificial Intelligence
AM	Additive Manufacturing
AR	Augmented Reality
CIM	Computer Integrated Manufacturing
CoBots	Collaborative Robots
CPAS	Cyber Physical Assembly Systems
CPMT	Cyber-Physical Machine Tool
CPPS	Cyber Physical Production Systems
CPS	Cyber-Physical Systems
CSR	Corporate Social Responsibility
DT	Digital Twin
EMAM	Electric Mobility Architecture Model
EQ/EI	Emotional Quotient / Emotional Intelligence
ERP	Enterprise Resource Planning
ESN	Enterprise Social Network
FQ	Financial Quotient/Intelligence

HBAM	Home and Building Architecture Model
HC 4.0	Human Capital 4.0
HC	Human Capital
H-CPPS	Human Cyber-Physical Production Systems
HCPS	Human Cyber-physical Systems
HitL	Human-in-the-Loop
HMI 4.0	Human Machine Interface 4.0
HMI	Human Machine Interface
HPS	Human-Physical Systems
HR 4.0	Human Resources 4.0
ICT	Information Communication Technologies
IEC	International Electro-technical Commission
IIC	Industrial Internet Consortium
IIoT	Industrial Internet of Things
IoP	Internet of People
IoTSP	Internet of Things Service and People
IQ	Intelligent Quotient / Cognitive Intelligence
IT	Information Technology
MABA-MABA	Men Are Better At – Machines Are Better At
MES	Manufacturing Execution System
MINT	Mathematics, IT, Natural Sciences, and Technology

NIST	National Institute of Standards and Technology
OECD	Organization for Economic Co-operation and Development
RAMI 4.0	Reference Architecture Model for Industry 4.0
ROI	Return on Investment
SCIAM	Smart City Infrastructure Architecture Model
SDG	Sustainable Development Goals
SGAM	Smart Grid Architecture Model
SHRC	Symbiotic Human-Robot Collaboration
SMEs	Small and Medium Enterprises
SQ	Spiritual Quotient/Intelligence
STEM	Science, Technology, Engineering, and Mathematics
TFP	Total Factor Productivity
TOGAF	The Open Group Architecture Framework
UN	United Nations
VR	Virtual Reality
VUCA	Volatility, Uncertainty, Complexity, Ambiguity
WBAN	Wireless Body Area Networks
WEF	World Economic Forum

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Research Outputs

Journal Publication

- **Flores, E.**, Xu, X., & Lu, Y. (2020). Human Capital 4.0: a workforce competence typology for Industry 4.0. *Journal of Manufacturing Technology Management.* Doi: 10.1108/JMTM-08-2019-0309.

Conference Publications

- **Flores, E.**, Xu X. (2018). Operator 4.0: The human factor in the new era of manufacturing. *Proceedings of International Conference on Computers and Industrial Engineering, CIE, 2018-December*, Vol.2018-December.
- **Flores, E.**, Xu, X., & Lu, Y. (2020). Human Cyber-Physical Systems: A skill-based correlation between humans and machines. In *2020 IEEE 16th International Conference on Automation Science and Engineering (CASE)* (pp. 1313-1318). IEEE.
- **Flores, E.**, Xu, X., & Lu, Y. (2020). A Reference Human-centric Architecture Model: a skill-based approach for education of future workforce. *Procedia Manufacturing*, *48*, 1094-1101.

Conference posters

- **Flores, E.**, Xu, X. (2019). Operator 4.0*: A human perspective for Industry 4.0. Manufacturing & Design 2019 (MAD2019), Auckland, NZ*

- ***Flores, E.**, Xu, X., & Lu, Y. (2020). Human Capital 4.0: competences and skills for disruptive challenges. Manufacturing, Design & Entrepreneurship 2020 (MADE2020), Auckland, NZ.*

Chapter 1

Introduction

From its conception in 2011 to this date, Industry 4.0 has expanded its popularity and reach by becoming a pervading topic in industry and academia alike. This term has gained further attention, especially in the last five years or so, due to the substantial spread of digital technologies, i.e. artificial intelligence (AI), digital twin (DT), block-chain, Human Cyber-physical Systems (HCPS), but also due to the recent event of the pandemic, Covid-19.

In this sense, the fourth Industrial Revolution - Industry 4.0 - has been a significant focus of concern and research. This term can be found in topics regarding businesses, manufacturing operations, digital technologies, supply chain management, education, and the workforce. In the latter, the labor force, this research is focused.

Owing to the unique pace at which advancement in technology has influenced the current industrial revolution, there is an urgent need to study and address the implications for humans, i.e. operators, general employees, entrepreneurs, or even employers. It is safe to state that whatever was required in the previous Industrial Revolutions would be insufficient for what is necessary for vision to today's Industry 4.0 concept.

In order to address part of the human-side need, a concept has been brought to light recently, 'Operator 4.0'. However, such effort needs thoughtful improvement and consideration of a wide range of aspects if the aim is to support the human perspective of Industry 4.0. This research is systematically designed to address and elaborate on such a quest.

1.1 Research Background

This section introduces and explains the background information of this research. The evolutionary history of the Industrial Revolutions is presented as well as the evolution of the pioneering Operator 4.0 concept.

1.1.1 Fourth Industrial Revolution

From its beginnings 300 years ago, the manufacturing industry has been a critical player in disruptive changes in society. Today, this industry alone is one of the most important financial activities in most countries (14-17% of the GDP) [1]. In this respect, many governments have expressed their interest in supporting a technological evolution and application in their own countries and their global alliances.

The English term Industry 4.0 was first pinned in Germany with the name 'Industrie 4.0' in 2011[2]. Later in 2013, the Industrie 4.0 Working Group released the 'High-Tech strategy for 2020' document and plan. They developed a scheme of recommendations to initiate the Industry 4.0 concept in its manufacturing network in Germany [3]. It was not long after other initiatives from different parts of the world also issued their own strategies and plans, i.e. the UK, France, Japan, South Korea, and Sweden [4]. Hereafter, the race for the new Industrial Revolution had begun.

It is important to remember the overall transition of the previous Industrial Revolutions. In the middle of the 18th century, Great Britain led the first industrial revolution with the invention of the steam engine. In the second half of the 19th century in the US, electricity and the mass production line enabled the second industrial revolution. In the last years of the 20th century, the third industrial revolution occurred due to the invention of microchips and computers, with no particular pioneer [5].

Figure 1.1 represents the main characteristics of each industrial revolution. The steam power machine and the mechanical production ignited Industry 1.0. The demand from the market was simple as the production volume was not a major issue back then.

Industry 2.0 began on the use of electrical energy, and therefore it gave place to the production in flow-line, which was electronically controlled. The market was stable because there was no demand for variety, but mainly for volume. Information Technology (IT) in the form of microchips and computers facilitated Industry 3.0, allowing the arrangement of production in cells. The market was volatile because the production had to deal with the variability of volume and product [6]. Lastly, Industry 4.0 has emerged from the combination of many technologies, namely Internet of Things (IoT), Cloud Computing, Big Data, AI, Additive Manufacturing (AM), Cyber-physical Systems (CPS), Virtual Reality (VR), and Augmented Reality (AR). This new concept has provided the means to control remotely different types of production systems. The market is considered smart as it allows for the customer's participation to customize the production order.

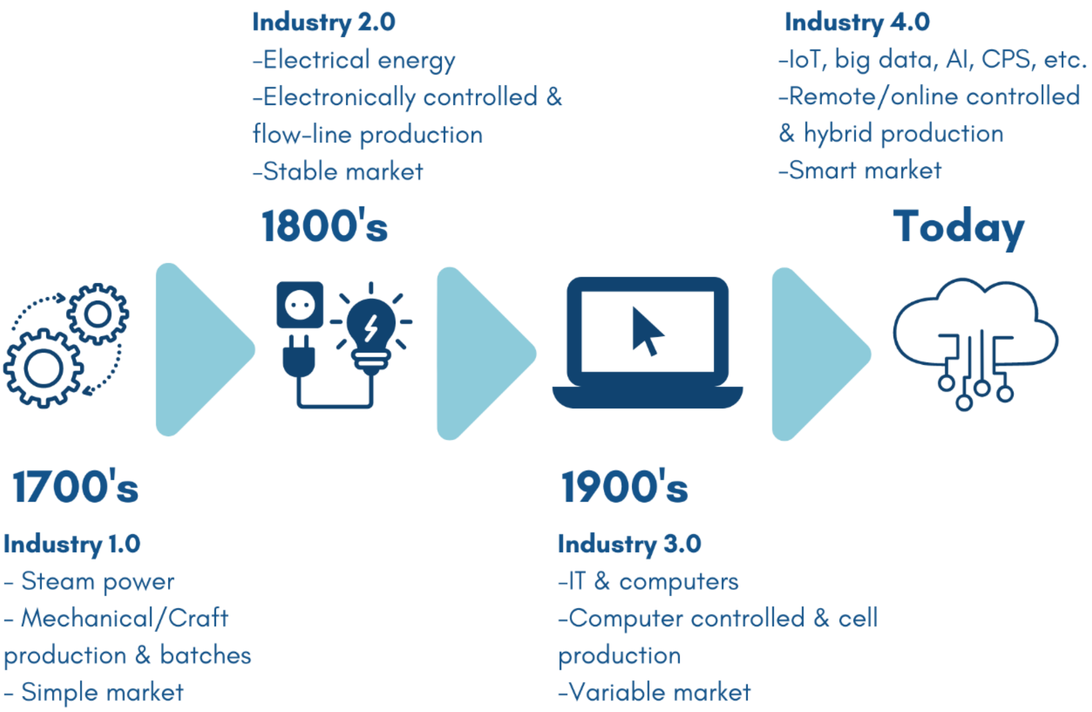


Figure 1.1 Transition of the Four Industrial Revolutions

Regardless of the advanced technologies, Industry 4.0 faces some manufacturing challenges today. The first challenge is customization, which requires producing the same product but with individual specifications. The second is the challenge of shorter ready-to-market delivery channels and the means for production and communication in those channels. The shorter life cycle of products and their reusable cycle for sustainability production means is another challenge. Lastly, the challenge of fierce competition at a global level [7]. In general, these challenges will require the systems to become fast in real-time, agile, and reconfigurable to cope with the quick-changing pace from the customer demand [8].

In brief, there are four highlighting promises from Industry 4.0 to the future companies and businesses to explore:

- There will be interrelated dynamic processes. This means flexible, quick-respondent, and last-minute changes or dynamics will be possible in the whole cycle, end-to-end, of the supply chain. Manufacturing factories and business operations are to be interlinked within the same supply network of a particular product or asset.

- There will be a productivity and efficiency boost. Assets and goods that sometimes are seen as raw resources (i.e. gas, water, electricity) will be employed, distributed, or monitored in a more efficient and productive manner. This should also support the targets of an environmental-friendly production system [9].

- There will be room for better competitiveness. Production processes will be able to make products of even one-batch size and still be accountable for profits. This will be true not only for the end-Tier1 company but for the whole supply network of such products [10]. Both customer and business partners are to be satisfied with better costs and quality.

- There will be accountability on and for the human side of the industry. Recognition has been given to keeping the quality of life for people. It is expected to find a balance between a personal and professional life due to the technologies and flexible systems involved. Moreover, there is the allusive idea of fostering late retirement, or maybe none, by increasing the professional and productive life of employees to support employment at old ages.

Out of the four key points above, it is in the latest point that this research finds its interest, i.e. a human perspective for Industry 4.0. The following section brings the introduction to the workforce and Operator 4.0.

1.1.2 Human workforce and Operator 4.0

As a brief reminder, the vision of the manufacturing industry back in the 1980s was very different from that in Industry 4.0 today. Back then, the Computer Integrated Manufacturing (CIM) perspective tried to completely eliminate the presence of human intervention by using computers and fully automated systems. Nevertheless, this view failed due to complexity and lack of flexibility in the systems, which were amended by including humans and their inherent qualities, i.e. flexibility and responsiveness [11].

Today, the vision of Industry 4.0 acknowledges humans in the loop as a backbone. Furthermore, it is required to seek social sustainability in the workplace by considering inclusiveness, health, satisfaction, safety, motivation, and continuous workforce learning [12]. In addition, the work in this new age is predicted to become increasingly mental and less physical. This will allow people to find employment regardless of their age, and it will push people to increase other human skills, such as creativity, flexibility, and intelligence. However, such changes would also bring some challenges, sometimes considered negative implications, i.e. emotional stress or psychological disruptions, due to the persisting flexibility and responsiveness demanded from the new productive systems [9].

Overall, the operators involved in Industry 4.0 face four main challenges [13]:

1. The coping with the complexity of the productive system, which will require process and data understanding of digital high-flexible production processes.
2. The alienated interaction with intelligent assistance systems that will be embedded in digital productive processes.
3. The capacity acquisition of becoming future-proof, in a way to predict and quickly learn which new interdisciplinary competences will be required to adapt.
4. The tune and balance between personal and professional life to reassure the work-life impact.

Operator 4.0 is a concept created in an effort to address some of the previous challenges. It has been proposed as the new generation of operators that will be smart and will use technologies to help them enhance their cognitive and physical capabilities to perform autonomous work [12]. Similar to the Industrial Revolutions' transition, the operator's evolution has been pointed out accordingly. Figure 2 shows that Operator 1.0, who emerged in Industry 1.0, initiated with manual skills, using manually operated tools, and performed dextrous work. Similarly, from Industry 2.0, the Operator 2.0 developed electrical skills and used tools electronically operated, performing assisted work by machines (i.e. Numeric Control machines). The Operator 3.0 in Industry 3.0 acquired IT skills to work cooperatively with computer-operated tools and machines (i.e. robots). In addition to the IT skills involved in the previous operator, the recent Operator 4.0 is also characterized by the management of cognitive and physical skills that are enhanced by means of technologies (i.e. AR, VR, AI, etc.).

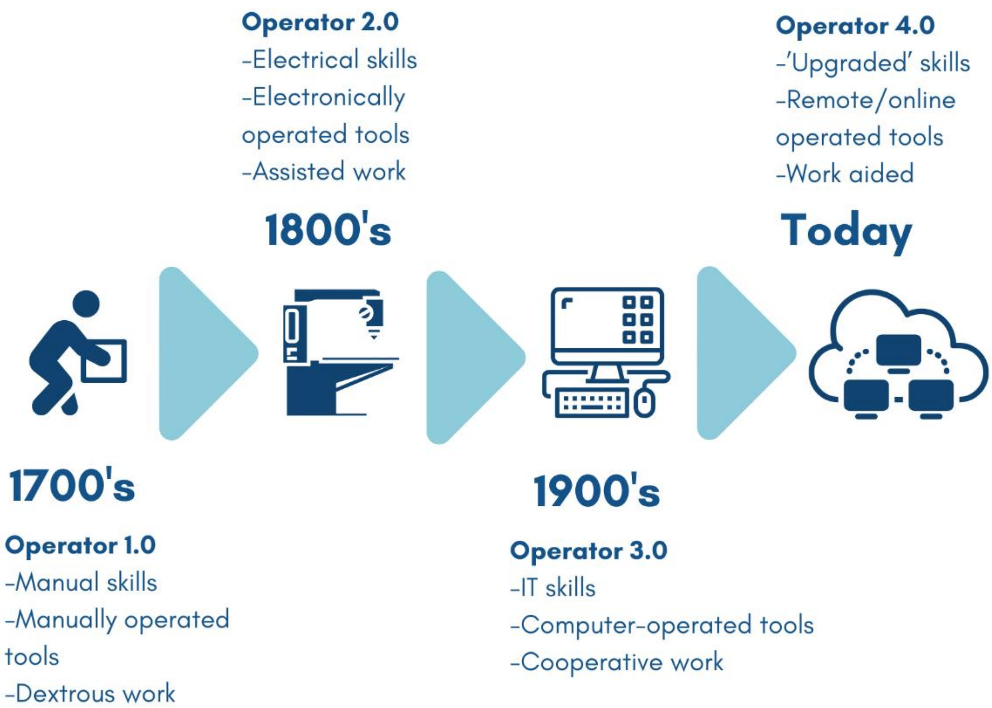


Figure 1.2 Evolution of the operator generations

The original author of Operator 4.0 has extended his effort on the topic by proposing a typology comprising the new operator on the rise. According to some technological characteristics, the Operator 4.0 idea has been classified into eight different types.

There is the super-strong operator wearing exoskeletons, the augmented operator using augmented reality, the virtual operator supported by virtual reality, the healthy operator attaching wearable trackers, the smarter operator using AI, the collaborative operator working with CoBots (collaborative robots), the social operator participating in social networks, and the analytical operator working with big data analytics [14].

The concept of the mentioned typology is mainly defined by the technology involved with the user. However, the type and level of competence or training suggested for operators to possess and display is still unclear.

1.1.3 Workforce skill issues

As with all that is new, the advent of Industry 4.0 has brought two opposite perceptions regarding a skilled debate, the upskilling and deskilling of human labor. On the one hand, it is thought that degradation and elimination of skills will happen due to automated technologies taking over the worker's activities [15]. This view triggers fear that such technologies will pull out the person from the command in production systems. On the other hand, there is another view about upgrading the operator via technological systems, making the persons more skillful and independent by demanding more of them due to higher complexity in production systems [16].

As the new change into Industry 4.0 is already unfolding, it would be better to look at the bright side and focus on the needs for this respect. That is why a diverse collection of skills has been expressed as preferred for the future. For instance, higher-order thinking and decision-making abilities are considered required skills the employees will need to improve and display because job activities are becoming less routine and require continuous knowledge [13]. Moreover, problem-solving and decision-making skills are thought to support benefits sought by Industry 4.0, such as productivity, efficiency, and cost reductions [17]. In addition, consideration of emerging competences is on the rise, i.e. creativity, social intelligence, IoT knowledge, or CPS configuration, which are considered 21st-century competences [18].

A key competence that is mentioned in the literature is those called 'digital skills.' Digital and automated processes will become predominant in modern manufacturing plants, making the new jobs highly demanding for these skills [5]. The Internet networks make a prevailing digital world, connecting things easier, influencing how humans interact, consume, and work. Therefore, it is perceived that digital skills will now be part of the standard in educational literacy [19]. However, as these skills have been explored recently, there is still discussion about the specifics of these skills.

Unfortunately, current news report that employers and governments complain and recognize that there is an emergency for employees' preparation to meet the required professional curriculum in the advents of Industry 4.0 since current employee's competences are not satisfactory. On this note, some government agencies and private companies have worked to find out skill gaps in different zones.

For instance, in the UK, companies have identified that new applicants lack technical skills and face problems with written and oral communication, literacy, numeracy, and problem-solving abilities [20]. Moreover, while searching and applying for new job opportunities, the tendency of missing skills has been found more persistent among younger applicants (i.e. graduate students) than in senior applicants [21]. Similarly, in other places, such as Europe and the US, the forecasting for future shortages of skills has been studied, and in China, this topic has been ranked high as one of the top concerns to be addressed soon [22]. Meanwhile, Europe has reported that 44% of its population does not have an acceptable level of digital skills [23]. This creates a problem in the near future because almost 1.5 million professionals with IT and KET skills (Key Enabling Technologies) will be needed by 2025 [24].

Overall, the skill demand over the skill offer seems to be insufficient. The literature around this topic constantly keeps blaming the educational sector for not being able to prepare students and the workforce properly. From the social side, family parents have also expressed that schools and universities are vital actors in instructing and developing future skills [25]. Therefore, preparation means and teaching methods may be seen as another aspect that will be disruptive by this new age of Industry 4.0. All of these skill issues open space for research on new paradigms and models on how to develop and enhance workforce skills and competences more complete and robustly.

1.2 Identifying the Challenges

The technological advancements in Industry 4.0 represent an opportunity to improve both job and human conditions. Yet, it is highly relevant to focus on and (re)search for critical areas to achieve such improvements. In this sense, this search can impose a challenge since the topic on the human side of Industry 4.0 is very recent in the field.

Industry 4.0 is bringing an urgent need to develop and adopt new approaches for addressing most of the changes imposed to the human side of the industry, i.e. the workforce. Today, there is a tendency to move industrial processes from mass production to individual production. Everything is becoming interconnected and flexible, looking for higher levels of productivity and service satisfaction. As a result, this would mean that manufacturing and production systems must evolve. However, individuals working with such new environments need to develop and be upgraded if the goals of Industry 4.0 are to be met to the highest extend. Moreover, the importance of accountability and wellbeing development on the human side is paramount in the Industry 4.0 vision. Nevertheless, the search and understanding for achieving such development and characteristics are still vague and in their infancy. Therefore, **the first challenge is identifying and allocating a concept that facilitates the embrace of the human perspective for Industry 4.0.** Such a concept needs to include new perspectives regarding the elaboration and inclusion of human wellbeing, competence, and development sought and expected in the Fourth Industrial Revolution.

Most literature and case studies present a quest to find a perfect symbiosis between the two agents, machines and men. Nevertheless, the focus of those studies is mainly on machine and automation enhancement rather than on human competence. Moreover, from the evidence in the research background, one can infer that there is a lack of knowledge about the wholesome of human capabilities required for Industry 4.0 successful implementations. Consequently, it is with no surprise that the workforce has been found to be behind what is needed for the industry today. Furthermore, there is still no consensus on which abilities and competences people need to be instructed. For instance, there is no clear idea of the differences between some skills, i.e. IT skills and digital skills, which can cause confusion at the practical level. Therefore, **the second challenge is developing a skill framework that will support the**

adaptability of the future workforce into the Industry 4.0 conception. Such framework should provide a reasonable, specific, yet holistic, and easy-to-understand model for the needed competence in Industry 4.0.

For this case, the third challenge will require the second challenge to be completed. As the competences and skills changes for existing and future workers, it is essential to look at ways of supporting such new preparation and development. Moreover, if the new competence is to be holistic, the approach and method to aid such competence should facilitate a similar holistic perspective. Therefore, **the third challenge is to propose a model that enables the visualization and designation of a holistic competence while supporting the Industry 4.0 workforce preparation on such competence.** Such a model should look for integrating key human factors to be considered a worker-centric approach.

The pioneering idea of Operator 4.0 has gained substantial attention since the beginning of its conception. The concept intended to redirect the attention to the workforce element in factories, namely the operator. However, this effort has been proposed based only on technicalities and technological aspects, leaving aside men-like attributes, i.e. skills, job interactions. Consequently, this has led to a heavy focus on applications dependent on sheer technological development but more minor on operator development. Therefore, **a fourth challenge is to redefine and expand the conception of the workforce, particularly that of Operator 4.0, to provide a more inclusive human element to Industry 4.0.** Such a redefined concept for the operator should balance the heavy technological emphasis given by the initial term with a more comprehensive human perspective expected for Industry 4.0. Nevertheless, since the operator forms part of a larger group, such as the manufacturing workforce, the new update of Operator 4.0 needs to account for this in its conception. For example, since human-machine interactions will become more common due to new technology applications, it is necessary to identify changes that come to the scope of the manufacturing workforce, i.e. job structures, H-M collaboration. These types of aspects need to be reflected in the Operator 4.0 view. Therefore, **a fifth challenge is identifying and explaining implications that influence the manufacturing workforce due to the evolution of humans with technology.** Such analysis should facilitate understanding of critical changes for the factory in terms of the workforce, for instance, appreciation for main differences or similarities between humans and machines. Keeping a worker-centric perspective should bring the results of the analysis into the new Operator 4.0 conception.

1.3 Objectives and Scope

The overall objective of this research is to apply an interdisciplinary methodology and approach to support the adaptation and symbiosis between the human aspect of the industry, the workforce of the future, and the disruptive technological changes in the advent of Industry 4.0. Moreover, the distinctive objective of this study is the redefinition of the conception for Operator 4.0 from a more human-centric and thorough-researched approach. This will be based on engineering, industrial, and social concepts, along with their synergy for interaction within the areas of study. As a result, innovative and value-added theories and methodologies should be presented to the field of knowledge for Industry 4.0 and the workforce.

In the previous section, five significant challenges have been identified. To address those challenges, the main objectives of this research work are proposed as follows:

Provide a systematic concept for the human perspective in Industry 4.0. The new concept should aim at supporting and empowering the human element who are to work in the new paradigm of Industry 4.0. In addition, this proposal should be structured in a simple and effective form that promotes understanding, reasons, and benefits. Elements of this concept are expected to be identified.

Devise a systematic typology of competence for the workforce in Industry 4.0. A set of specific and interdisciplinary skills and competences should be identified as the key supporter for the workforce to embrace Industry 4.0 challenges better. The creation of this typology requires expanding and covering specific areas that are technical and fundamental for individuals to thrive in this new age of disruptive changes. Therefore, the new typology should cover the most needed skills according to current technological and social urgent topics, forming a holistic skill set.

Develop a model and method to support the workforce preparation of the new proposed competence. The development of the model should embrace and facilitate a holistic human-centered perspective for the allocation of the competences found for Industry 4.0. In addition, the model should allow for an approach that enables a simple, understandable method of use to aid in the workforce preparation in today's idea of Industry 4.0 needs.

Identify key implications of the manufacturing workforce due to technological and Industry 4.0 implementations. The analysis and presentation of these implications should consider a human-centric/worker-centric perspective on changes influencing the manufacturing work. Therefore, this type of analysis should consider covering essential aspects such as job structures, interactions, or responsibilities, along with some capabilities in collaboration with machinery in manufacturing, i.e. CPS.

Develop an updated and expanded vision for Operator 4.0. The new refinement of this term should include the results from the above objectives. Consequently, the new proposed Operator 4.0 should be based on the research results provided by the previous points to support the consistency of the human-centric focus for Industry 4.0. Moreover, it should allow a more thorough picture of the operator's considerations than the technical-based original concept. This new development needs to be bold and optimistic due to this industrial era's disruptive social and technological challenges.

Developing each of the objectives mentioned above requires a wide range of interdisciplinary knowledge, profound analyses, and systematic study work. Furthermore, most of the necessary work to achieve the goals needs comprehensive and deep literature review comprehension. As a result, the opportunity for case studies was limited. It was recognized that the empirical implementation of this study work was not feasible given the time limits of this Ph.D. research. However, the systematic development of this research goes thoroughly into the theories and topics regarded as substantial in the academic and scientific field while keeping an existing and practical industrial and social context.

1.4 Thesis Synopsis

This section describes the research work conducted to achieve the objectives prescribed. The thesis is structured into nine chapters. A brief synopsis of the remainder of the thesis is provided.

Chapter 2 provides a critical and exhaustive literature review of the state-of-the-art research related to Industry 4.0 and the workforce, concerning topics relevant to both in this new age. Current technological developments and tendencies are exposed. Research work related to competences is analyzed. Contemporary challenges faced by the workforce are identified, and Operator 4.0 is further explored. Limitations of current work are discussed. Research gaps are identified, and motivations for this research are explained.

Chapter 3 introduces the methodology of this research. The explanation for deductive and inductive processes is given, followed by the approach taken in this work. The definition for the systematic search and review is provided, along with a diagram of the research approach for this study. The research questions are elaborated and posed, with a clear, complete diagram of their structure.

Chapter 4 addresses research question number one. More specifically, it introduces and elaborates on the new human capital terminology. The transition from the old to the new is explained considering Industry 4.0 goals. The introduction of wellbeing into the new concept is graphically structured to represent the benefits.

Chapter 5 addresses research question number two, as it presents and works on the competence and skill set for the future workforce. The principles and reasons behind the proposed typology of skills are provided. The systematic structure of the model is explained.

Chapter 6 addresses research question number three since it introduces and elaborates on a novel model for human capital preparation of the future workforce. The proposal for a human-centric architecture model is presented using an Industry 4.0 existing model as a base. A method for applying the proposed model is described as well as its benefits.

Chapter 7 addresses research question number four. More specifically, it presents the cooperative evolution implications on the manufacturing workforce due to technological advancements and Industry 4.0 development. For instance, a new smart working interaction structure is justified, and further analysis for human-machine capabilities is presented.

Chapter 8 addresses research question number five since it introduces and elaborates on the new updated concept for Operator 4.0. The highlights and main limitations of the pioneering concept are discussed. The future work interactions for the operator are described. The professional skills of the operator are systematically explained. The updated definition of the operator is given.

Chapter 9 closes the thesis. The significant achievements and contributions of this research are concluded. Improvement opportunities and limitations of current work are discussed. An outlook of future research directions is provided.

Chapter 2

Literature Review

This chapter provides a review of state-of-the-art research studies and the resources required to develop the stated objectives. First, a current view on Industry 4.0 and its technological trends is mentioned. This covers the technologies considered essential and the changes and characteristics for future smart factories in Industry 4.0. Second, a review of the workforce in the face of Industry 4.0 is presented. This covers major aspects of the workforce, such as the idea of human capital, the competences and skills, existing challenges, and the emerging development and preparation. In addition, it also explores the Operator 4.0 view to gain an existing perspective for this concept of the worker. Lastly, the research gaps are pointed out, along with the motivations for this research.

2.1 The Industry 4.0 Paradigm and its Technological Advancements

Today, the booming of the Internet and the digital world brings up the possibility for a new age of world engagement, i.e. social, environmental, and professional. Moreover, after the pandemic of Covid-19, it could be safe to assume that such types of engagements have been innocently and promptly tested. All of these factors happening at the same time can be an excellent reason to bring significance for the study of the Industry 4.0 paradigm.

The initial visionaries of the Fourth Industrial Revolution have described and mentioned many of the new changes in the trends to come, but with specific emphasis on the working space and scope. This next section examines the idea of Industry 4.0 in relation to the working environment and its reach.

2.1.1 Industry 4.0 Overview

Although the idea of Industry 4.0 was conceived in 2011, it was until 2013 that a visionary German proposal was made about what it could mean to become part of a smart interconnected world. The report explains the main characteristics that the concept of Industry 4.0 envisions, i.e. smart factories, smart products, product personalization, novel business opportunities, new social-technical interactions, new social infrastructures, and paradigm shifts in human-technology and human-environment interactions [3]. Therefore, this may be the first Industrial Revolution that was foreseen before it has happened.

The umbrella idea of Industry 4.0 comprehends a whole network of reconfigurable, dynamic, interconnected, self-organized, collaborative, and personalized manufacturing and business interactions [26], [27]. On top of that, the new paradigm also pushes technology in three main approaches. One, through an increase of mechanization and automation, creating automated solutions for executing versatile operations. Two, through increased digitalization and networking, supporting the control and analysis of productive processes and data. Three, through miniaturization of components and equipment, enabling new fields of application in logistics and production [28]. Moreover, this broad scope of functionalities and approaches could set Industry 4.0 as a provider for sustainable answers. A recent study on sustainability creation has found that Industry 4.0 qualifies as a valuable and feasible practice that holds the potentials to meet expectations in three ways of sustainability: social, environmental, and economic [29].

The idea behind Industry 4.0 has been a key intention around the globe. Similar to Germany, other leading countries have issued their initiative for the outbreak of the digital era. China has announced “Made in China 2025” as a strategic plan for reforming the current Chinese manufacturing approach from men-intensive labor to knowledge-based production and manufacturing [30]. The European Union released an ambitious strategy called “Factories of the Future.” The plan is under the EU Research and

Innovation program Horizon 2020 to support European companies to adapt global cutting-edge tendencies and competitiveness by developing key technologies across different sectors [31], [32]. Lastly, the American institute Industrial Internet Consortium (IIC) proposed the term "Industrial Internet of Things" (IIoT). This concept covers the connection of intelligent machines, advanced data analytics, and the workforce, using different technologies and focusing on manufacturing enterprises and sectors like energy, agriculture, and health [33].

Nevertheless, such new industrial concepts also come with some challenges to face before their full implementation. At the technical level, implementation of modern IT infrastructure, data security, and lack of standardized protocols are among the top challenges [34]. At the company level, organizational transformation, financial resources and investment, qualification of workforce, and cooperation through value chains are perceived as the main concerns [29]. Many of such challenges are the leading causes to attract the attention of scholars and industrial stakeholders to research further and create new frameworks to generate a solution to those concerns.

2.1.2 Industry 4.0 Technologies

The Fourth Industrial Revolution is different from previous predecessors mainly due to the technologies developed and utilized recently. However, still today, the application of such technologies tends to be in isolation, localized, with a specific and limited scope or reach. A primary goal of the aforementioned global initiatives is the development and implementation of technologies that enhance the reach, flexibility, connectivity, and intelligence of existing manufacturing systems. Nine types of technology, also known as the nine pillars, have been emphasized to underpin Industry 4.0. These leading technologies are robots, simulation or virtual reality, the internet of things, cybersecurity, the cloud, additive manufacturing, augmented reality, big data analytics, and cyber-physical systems [27].

- ***Robots.***

The use of robots may be perceived already as a standard in most manufacturing industries at this stage of technical advancements. Nevertheless, Industry 4.0 goes beyond having an assembly line full of robots working in a programmable manner. In the new age, it is expected that robots will be capable of reprogramming themselves according to the specific needs of the manufactured product. This level of flexibility and autonomy will also be integrated with close cooperation among the robot, the product, and the human. The new term Symbiotic Human-Robot Collaboration (SHRC) raises the opportunity to work fenceless, allowing the collaboration of the machine precision and the human flexibility [35], delivering a system that enables communication and operability in the system for a harmonious work environment.

- ***Simulation/Virtual Reality (VR).***

Simulation is a comprehensive utilized tool that allows the modeling of 3D products, representation of materials, and analysis of processes. In addition to that, this technology has been foreseen to support decision-making, logistics, and management control by simulating the whole value supply chain in real-time. A well-known version of the simulation is called virtual reality. The first theoretical idea of VR came by the end of the 1960s [36]. A VR system is a 3D-environment creation that dips the user into a human-to-computer platform employing software, hardware, and peripheral devices [37]. This type of virtual simulation opens opportunities for further job applications such as virtual tours of restricted spaces or skill training for employees.

- ***Internet of Things (IoT).***

The IoT term was originated by Kevin Ashton in 1999 [38]. The Internet plays an essential role in the whole concept of Industry 4.0. When the Internet is applied to objects, these objects are seamlessly interconnected and become members of the business process [39]. Existing items have been embedded with network connectivity that enables the communication between users of the product and servers of the network. However, the application of IoT stretches further than mere mobile phones with connectivity. It is meant that the Internet would become the bloodstream of communication throughout the manufacturing company and ultimately throughout the value supply chain. Furthermore, the term "Internet of Things, Services and People" (IoTSP) is a new concept to emphasize the importance between people, services, and the Internet of Things within the environment of smart factories. The three elements are to be connected to achieve ultimate results: optimization, productivity, flexibility, and cost reduction [40].

- ***Cybersecurity.***

Sensitive information and know-how have always been the concern of companies because this type of information can dictate the current and future state of the market. Throughout the years, companies, and even governments, have been exposed to cyber-attacks and threats from sources out of their systems. As Industry 4.0 visions extensive connectivity and management of information across different numbers of organizations, it will require a complex and robust system to protect the companies within the network of the value supply chain and limit the access among the companies within such network. In other words, there will be a need to allow just enough information access between companies without breaching each other cyber-security.

- ***The Cloud.***

The whole concept of cloud manufacturing relies on having an integrated system to provide on-demand manufacturing resources and manufacturing services, both physical and digital [41]. Nowadays, thousands of services can be delivered via the cloud. Nevertheless, most of those services offer a very limited or isolated service, such as cloud computing or cloud manufacturing services. Industry 4.0 seeks to capitalize on the cloud as an extended gate for sharing information across boundaries. In this sense, it opens opportunities for flexibility, real-time data, and responsiveness of more complex network systems.

- ***Additive Manufacturing (AM).***

This technology is also known as 3D printing. Manufacturing firms tend to use this layer-by-layer technique primarily for individual components and rapid prototyping. AM holds the basic capabilities sought by Industry 4.0. First, flexibility to work with different manufacturing systems. Second, programmability, as AM is easy to run and operate. Third, variability to work with other techniques and different materials. Fourth and last, the precision to support individualization and repeatability. In addition, additive manufacturing is considered a friendly production technology for the environment as minimum waste is generated, it requires fewer resources, and logistics or transportation could be eliminated by decentralization [42].

- ***Augmented Reality (AR).***

This technology has been developed and used in the manufacturing industry very recently, and its application still holds a vast potential for future implementations [43]. AR, different from VR, brings 3D animations to a natural environment where the user can physically interact with the animation in real-time. Industry 4.0 pretends to utilize this technology to support workers in their daily tasks by providing the most effective means of communication between the system and the operator. Some essential AR advantages that can be briefly mentioned are the attention shift acceleration, the eye and head movement reduction, and the spatial cognition supporting the user [44], [45].

- ***Big Data Analytics.***

As the collection of data increases in companies, the storage and the analysis for such an amount of information can pose some challenges and difficulties. Industry 4.0 will need to rely on systems capable of handling a considerable amount of data. The data would need to be collected throughout the process of the value supply chain, while at the same time, information would require to go under analysis. Predictive analytics, together with VR, may be the answer to support real-time interactions among data and models that have not been achieved yet [46]. Therefore, to support such demanding application for data management, the system would have to be assessed for the 7V's of big data: volume, value, variety, veracity, velocity, volatility, and validity [47].

- ***Cyber-Physical Systems (CPS).***

In 2006, the term cyber-physical system was coined in the US [48]. Mechatronics came from an electrical and mechanical background, whereas CPS has come from electrical and computer engineering backgrounds [35]. CPS comprises physical and software elements, such as machines, robots, and simulations, which are communicated through a structured network, resulting in complex distributed systems. CPS are systems that connect the virtual and the real world as they are interconnected via digital networks, depending on embedded sensors and actuators that at the same time allow data exchange with the opportunity of local and global services. Interestingly, Industry 4.0 has been seen as a unique form of CPS. It is characterized by decentralized intelligence, high versatility, and flexibility, which uses IoT to customize production systems [49].

CPS platforms are being used as the controlling brain in manufacturing processes because they control and monitor the physical elements through computational and digital application integration [50]. These platforms are thought to be critical enablers while implementing a horizontal and vertical integration across the value supply chain in Industry 4.0. They should ensure the proper functionality between the physical and the virtual world. However, the flexibility of CPS systems is at risk of performing poorly if it does not integrate the flexibility and qualities of humans through people integration in the whole system [51].

Some specific human activities in the manufacturing environment are decision-making, supervision, and knowledge sourcing. It is considered that for a total potential display of CPS production systems, the human presence in the system is required [51]. Human-in-the-loop (HitL) is a type of human integration in CPS systems, granting humans some control in the loop, applying activities such as supervision, adjustment of parameters, direct commanding, and reporting. There can be two types of human participation in CPS, either people inside the loop for a more active role (shared control) or people outside the loop for a more passive human role (fully automated) [35]. An example of the former system can be the automatic gearbox system of a car because it allows a shared control with the user on operating the vehicle. The stability system of a car is an example of the latter system as it is independent of user control.

New diverse CPS terms alluding to distinct characteristics have been emerging. For example, a Cyber-Physical Machine Tool (CPMT) is proposed as a CPS application that integrates tooling, processing, networking, and embedded computing to monitor and control the machining process [52]. Cyber-Physical Production Systems (CPPS) are systems with collaborative and autonomous components that are connected at different levels of the production and logistic process [53]. Cyber-Physical Assembly Systems (CPAS) is a useful concept to cope with the challenge of volatile and individualized customer demands and the diversity of workforce skills.

Moreover, CPS has also been referred to as open socio-technical systems because of their cross-linking between the virtual, physical, and social environment using smart information and communication technologies (ICT) [54]. The recent term Human Cyber-Physical Systems (HCPS) has been proposed because the system embraces three important scenarios, the cyber world (i.e. software and internet), the physical world (i.e. workstations and equipment), and the human world (i.e. communication and services) [55]. The evolution from the past, present, and future of intelligent HCPS has been explained. It is expected that future systems will strengthen the industry and human society by arriving at an "age of intelligence" [56]. Another new term is Human Cyber-Physical Production Systems (H-CPPS), where the system is supposed to enhance the abilities of the working operator through the platform of the physical and cyber world, supporting the interaction among machines and humans [14].

Although the implementation of these types of systems wants to increase, there are still some challenges that need to be addressed for their better deployment. These challenges are not just technical aspects, i.e. interoperability, complex management, and security, but also human factors, i.e. work organization, life-long learning, and education.

- ***Human Cyber-Physical Systems (HCPS).***

The topic of CPS has increased in popularity in many fields, especially in manufacturing. From 2010 to 2015, nearly 2000 publications were founded on this technology with applications in manufacturing [57]. Therefore, it is not surprising that recent views perceive CPS as a pivotal base for Industry 4.0 and the smart companies of the future [58].

CPS has become a mainstream of research alone. Plenty of study and work has been done to understand the concept and application of this technology. In general, the CPS's main functions can be listed in six. Data collection and data interpretation is the first function. Real-time data acquisition is the second function. The third function is the capability for analytics. The next function is services, processes, and network configuration. The fifth capability is the inclusion of large-scale systems. Lastly, cooperative learning constitutes the sixth function for CPS [52], [59], [60].

Furthermore, a popular cited publication has presented the leading architecture of CPS into five levels [61]. The base level is called the connection level due to the sensed and acquired data information gathered from the components involved in the system. The following up level is the conversion level, where the information received is processed and translated into the system's status by the power of computing algorithms. This level may bring self-awareness to the system due to the estimation and prognostication possible from the gathered data. The cyber level is the third level, where the information of a system is compacted as an asset, and then such asset is compared against other assets from a cluster of systems. Historical data is used to perform such comparisons from both the individual system and the group of systems. The next level, known as the cognition level, processes the data obtained and presented from the previous level to seek confirmation or support for the decision-making step. Lastly, at the configuration level, the system performs and acts according to the input or feedback introduced from the previous level. The command or instruction obtained from cyberspace retrofits the physical space to carry out adaptable, self-configurable action. Figure 2.1 overviews the description given of the five-level architecture, where each level can be summarized in two main processes.

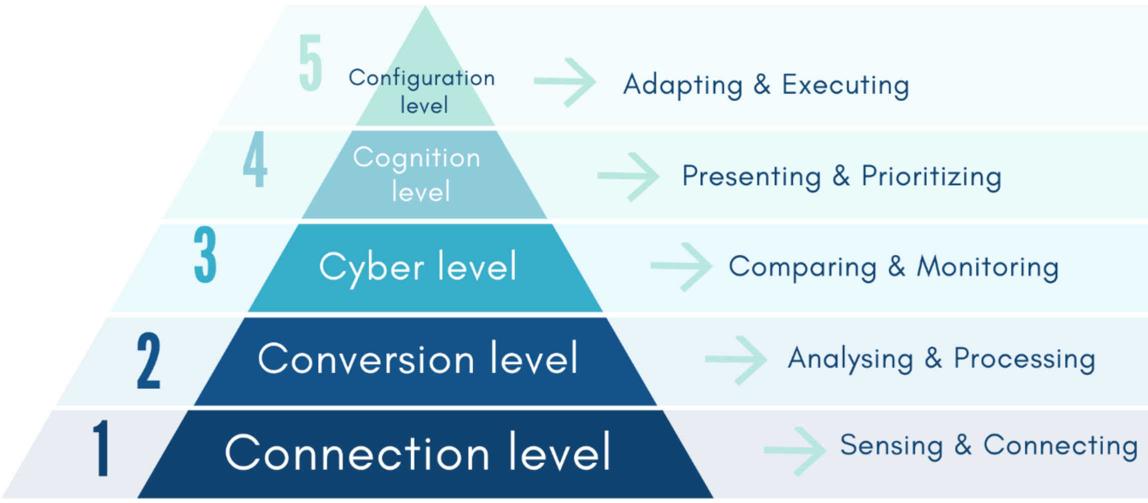


Figure 2.1 Five-level architecture of CPS, adapted from [61]

The interaction between the physical and cyberspace has been in existence for some decades now. Nevertheless, the interaction between the physical and the human space has been there much before. The cyber o digital space came to the integration of the human-physical interactions, creating the idea of HCPS. The development of this triple integration has been elaborated in three phases, according to Zhou et al. [56]. The first phase took place with the traditional human-physical systems (HPS). In this type of system, the operations were performed totally manually, where sensing, analysis, decision-making, and control of information relied solely on human responsibility. Therefore, there were particular human-related limitations in this phase, i.e. efficiency, quality, and performance. In the second phase, HCPS emerged, where the cyber o digital integration was introduced. At this stage, the same operations, i.e. sensing, analyzing, decision-making, and operation control, turned over the digital agent. Thus, the process stability's quality, efficiency, and performance were significantly enhanced. At the latest phase, also known as the 'new generation' of HCPS, expectations are that technologies such as AI, machine, and deep learning, will become vital elements in supporting the system. For example, while working with humans, the system will generate experience and learn analytical thinking from people. As the HCPS improves its capacity to generate knowledge, humans working with it will be allowed to engage in other aspects of the work more creatively.

The idea of the new generation of HCPS has ignited studies to achieve such a level of intelligence and integration. A study on cloning human behavior has pointed out two examples of this [62]. One is the creation of a platform as a prototype to use physiological signals, semiautonomous robotics, intent-inference algorithms, and wireless body area networks (WBAN) to support and augment human physical activity. Another is Pi-Mind, a patented technology that intends to clone human decisions by implementing AI and human modeling to aid Industry 4.0 environments in decision-making rationality.

However, regardless of the level of intelligence obtained in HCPS, the multitasking flexibility in the human side makes people the most independent and flexible element in the system. In general, six unique human characteristics can be identified in HCPS: problem-solving, production supervision, controlling at higher-ranked scenarios, responsibility at a larger-operating area, and implementation of technological and organizational methods [63].

As a general view, the composition of HCPS is formed of four main components [64]. The first is the controlled entity or object, such as a robot, a car, a production process, etc. The second is the person or user operating the system, for example, the driver in a car or the manufacturing operator in the production process. The third is the autonomous controller, also known as the agent that takes on fully automated decisions or actions in the system. The last one is the advisory or supervisory system, which facilitates the mediation of decisions and actions between the autonomous controller and the user to direct the system accordingly.

The following two figures will help visualize both the components and the interactions mentioned between the elements of HCPS. Figure 2.2 presents the components and connections in the system. In this, the person communicates with the digital space to interact with the physical space. At the same time, the physical space feeds back cyberspace to communicate or retrofit the user. The back and forth of communication and interactions carry on until the specific process is achieved. Figure 2.3 emphasizes the relation and communication between the three different spaces. The human sphere carries on activities such as monitoring, analyzing, and decision-making, based on knowledge and experience, which then is fed into cyberspace. Cyberspace gathers the data, analyses, and processes the information, generating a type of knowledge and prediction. Then it feeds back the system into both the human and the physical spaces. The physical sphere has only the functionality to receive the information and execute the action, providing to the human or cyberspace accordingly.

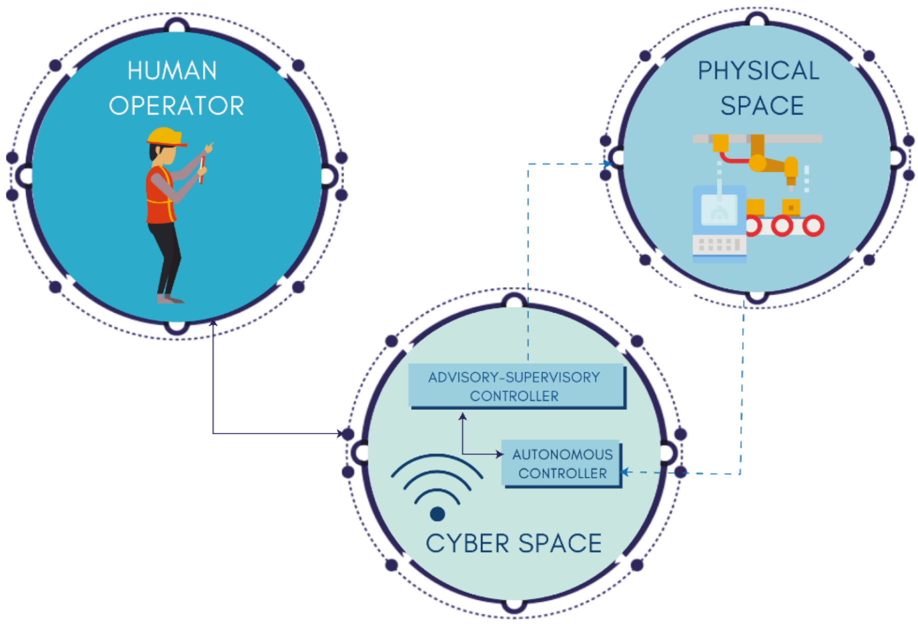


Figure 2.2 HCPS general composition, adapted from [64]

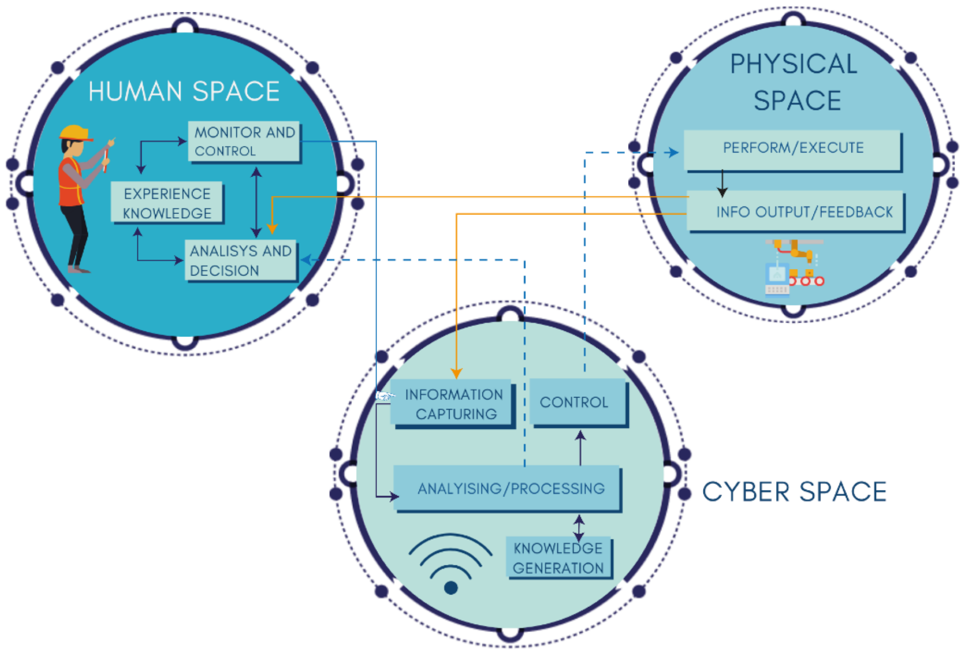


Figure 2.3 HCPS general communication, adapted from [64]

2.1.3 Smart Factories, Smart Products, Smart Customers

The vision of Industry 4.0 and its technologies bring the idea of smart factories to the picture of future manufacturing. A smart factory has been defined as "an intelligent production system which utilizes the integration of manufacturing services, integrating communication process, computing process, and control process to meet the industrial demands" [65]. That means that they depend on the integration and digitalization of many different structures in the factory environment, i.e. sensors, machines, robots, conveyor belts, etc. [66].

Just as factories start being integrated at different levels in structure to help them become smart, the products are also being designed to become smart products. Some of the ideas and functionalities behind smart products are their capability of becoming self-aware of their lifecycle. In other words, they should monitor their own status from production to usage with the end customer [3]. The smart product should store data in and about itself across the value supply chain displaying a high level of autonomy according to its environment. The information gathered could be used for different stages down the line, i.e. production, reconfiguration, maintenance, repositioning, or even disposal [67].

In addition, customers are also becoming part of the smart loop surrounding Industry 4.0 scenarios. Customers, being the end reason for any company and business, will have the opportunity for further participation in creating their own products or services [10]. For example, now customers will have input in producing their goods, being able to personalize and make changes in their products [68]. Smart products and participative customers will be able to engage together to further provide feedback to companies about features on products and the service, usage, and composition. Moreover, today's empirical research shows that customers are interested in starting to engage with their companies more than being passive consumers [69]. For instance, people want ways of communication, the opportunity of co-creation, and value sharing with companies to embrace corporate social responsibility (CSR) practices. Such practices are essential from the customer point of view to generate connection, commitment, and trust with the companies [70].

In the attempt to incorporate such a big mission of interconnection and interoperability between factories, products, and customers, the idea of Industry 4.0 introduces the aspects of two types of connection, vertical integration, and horizontal integration. The former refers to integrating activities and structure within companies or factories, i.e. department relationships, organizational structures, technical equipment. The latter refers to the integration of external structures and activities of companies, i.e. customer networks, supplier networks, market development [71]. The end-to-end embedded structure and connection in such a huge joint between the vertical and horizontal integration will have a primary goal to add value across all the product life cycle stages [72].

2.1.3.1 Smart Factory Structures in Industry 4.0

Plenty of research work is done to study the transformation from the past conception of the industry to the new Industrial Revolution. In this sense, attention to the well-known pyramid structure of production systems has been allocated to visualize operational and managerial levels for any given company [73]. The pyramid structure illustrates the most common hierarchy-based architecture in the industry.

Nevertheless, the new view of Industry 4.0 requires transforming and reshaping the pyramid structure to a decentralized, flexible, and self-organized interaction between all different levels of the factory [8]. This new form of organization for the companies can also be known as 'organic organization' design due to its adaptive, loose, free-flowing, and unique characteristics [74]. This new structure comprehends the closest conception of Industry 4.0, and the desirable scope so far.

Figure 2.4 illustrates the standard pyramid structure and the transformation from a traditional factory structure into the emerging Industry 4.0 factory structure:

- The pyramid (a) to the left is the typical representation of operations at companies. They usually are represented in five layers from bottom to top: the finished product level, the machine-device level, the process control level, the manufacturing execution system (MES), and the enterprise resource planning (ERP) [73].

- The pyramid (b) to the right exhibits examples of different components that can be found at each level. For instance, the product in the market at the bottom level can be represented by a wide variety of consumables, which are out of the production company. On the above level at the shop floor, it can be found equipment such as PLC's, machines, robots, etc. The following level may include workspaces that can support the supervisory control of production processes, i.e. workstations, laboratories. Production-aiding facilities such as planning or warehousing departments may be involved at the MES layer. Lastly, management offices and human resources departments can be incorporated at the ERP top level.

- The image (c) in the middle resembles the expected Industry 4.0 emerging structure. Here, the idea of a centralized and hierarchy-based architecture, communication, and interaction in the company is replaced with an interconnected and decentralized network. In this type of web structure, components at each one of the different levels can cooperate and interact with one another indistinctively. Moreover, as it was mentioned before, products at the hands of customers will also have the capability to be integrated into this type of structure, which further supports the conception of smart products [75]. In overall, this new arrangement enables the flexibility in systems and machines, the distribution of functions throughout the network, the interaction across all hierarchy levels, connection and communication among all participants, and the inclusion of a (smart) product in the network. This future like scenario will be possible due to four main pillars in the system, such as decentralization, vertical integration, connectivity and mobility, and cloud computing and advanced analytics [75].

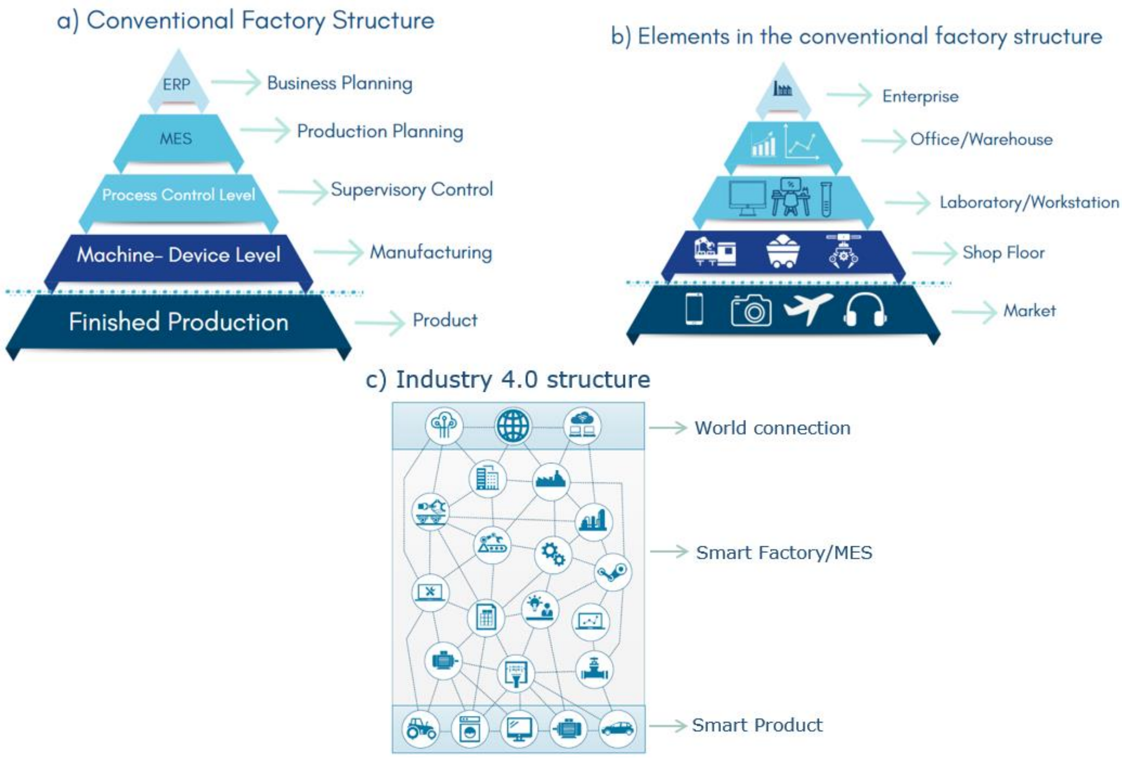


Figure 2.4 The transition from traditional factory architectures to the new Industry 4.0 structure

All in all, the previous figure pictures that the products being made, the equipment producing parts, and the operators working at the shop floor level, all along with the engineering department and the service department in a company, will be vertically integrated. In other words, vertical integration is the virtual interconnection among all those participants and elements in the production and service processes in a manufacturing plant.

Once the previous integration took place at the manufacturing plant level, horizontal integration can start among all the companies in a manufacturing supply chain network. This gives rise to the complete virtually interconnected value supply chain. At this stage, a virtual world has been created, where virtual twins of the physical elements in the value network can co-exist to allow integration.

2.2 The Workforce in the Fourth Industrial Revolution

Although Industry 4.0 is on its way to facilitating and improving the industrial economy, there are still many questions and gaps to work on to make sure that the human aspect is actually benefited. Such disruption of technological advancement could hinder or enhance people's life, i.e. workers or community, depending on the direction taken and guided by the stakeholders, i.e. the government, academia.

Unlike previous industrial revolutions, Industry 4.0 offers both employers and employees an opportunity to find a tune alignment between work life and personal life. Industrial and community leaders acknowledge the importance of aiming for human wellbeing among the different job and social interactions, i.e. the workplace. This section reviews the recent literature on future work, human capital, and Operator 4.0.

2.2.1 Foreseen Work in Industry 4.0

With the arrival of Industry 4.0, there has been an interesting debate about the future of work and jobs, polarizing pros and cons on each side. Regardless of a more predominant uplifting perspective about the autonomy and flexibility of Industry 4.0 technological systems, there are encountered points to this. For instance, some researchers believe that both low-skilled jobs, such as repetitive and manual work, and high-skilled jobs, such as engineering and management, will become obsolete [76]. Moreover, there is a concern about technology at workplaces affecting the levels of complacency, workload, and situational awareness of workers [77]. In other words, the attention allocated to the job and the perceived satisfaction could be hindered by an excessive, or lack, of involvement in job responsibilities.

Nevertheless, the mainstream of work that supports and acknowledges the inclusion of automation and technologies is optimistic since they still keep the empowerment of the human in the loop. It has been recognized that human supervision, namely information gathering, analysis of information, decision-making, and execution, in any manufacturing system can hardly be replaced effectively by machines [78]. Furthermore, the proposal of keeping the human operator as a maker, and not only as a standby or monitoring operator, has been defended if the goal of the process is efficiency, quality, and safety [79]. Such a proposal seeks the total commitment of the workers along with their abilities, willingness, and imagination by keeping them in the phases of creating and making products by valuing their creativity and decisions. Moreover, for any revolutionary paradigm shift, there is a need to consider human aspects and factors because people are the leading component for such new changes [80].

In general, Industry 4.0 looks more favorable for the future of work, which is opening new ways for changes at the structural levels of companies, human roles, and job activities. For instance, there will be an attempt to customize products and services [81], while the company's structure will need to reconfigure on-demand production systems [81]. In addition, the same company will need to adopt manufacturing systems that display flexibility and adaptability, with an integration of communication between producers and customers [82]. Furthermore, the whole communication structure of companies will change. The Internet of Things will empower smart factories [83]. Therefore, this would create an opportunity to make the Internet of People (IoP) by pervasive computing connection among users of the system [84]. In this sense, the inclusion of the customer in the information exchange within the manufacturing process becomes part of the new structural system [85]. All these recent changes and adaptations will force shifts onto the interactions in the workplace.

However, Industry 4.0 will also disrupt job activities in companies considering that employees will become highly strategic, creative, and coordinated. A literature review on this possible disruption has summarised five key points [86]. First, the operational level worker will mainly find support from CPS. Second, processes such as planning and decision-making will become highly decentralized. Third, a new norm for cross-functional interactions and perspectives will occur, along with an ongoing integration process. Fourth, the management and integration of functions such as quality and maintenance will increase complexity and agility as they become automated. Fifth, there will be an increase in importance and flexibility towards integrating partner networks and the balance of working life.

Following the disruption of activities, another research has classified a four-based perspective on the new possibilities emerging activities, such as technical, methodological, social, and personal perspectives [87]. The technical view of activities covers main digital activities, i.e. growing digitalization use, higher complexity integration of systems, and daily servers' utilization. The methodological perspective comprises activities such as continuous sourcing of information, service orientation, customer relationship, examination of large databases, and higher process responsibility. The social view mentions virtual communication, expertise and knowledge exchange, globalized networking, and the adoption of more responsibilities as hierarchies flatten. Lastly, from a personal perspective, the activities cover digital security, work-task allocation independent of the time and space, constant participation with innovation and sustainable initiatives, and continuous change and challenges at work.

2.2.2 Human Capital and Workforce Competences

There is a tendency to call it 'asset' to anything that supports the generation of value into the company, i.e. buildings, equipment, technology, etc. However, the most important and valuable asset a company or business can have should be appreciated as people. Often referred to as Human Capital (HC), this terminology comprises the value of skills, talents, education, and expertise found in the workforce [88]. The stock of such attributes (skills, education, expertise) helps infer productivity in a company.

Out of the attributes above of human capital, significant attention has been paid to the topic of skills or competences, which is sought particularly by organizations and governments. This attention and research into the skills of the workforce may be well justified due to the relation between the upskilling of people and the growth, productivity, and employability rate in a country [22]. The definition of competence covers the mixture of knowledge, abilities, experience, and skills of individuals required to perform job roles and life activities [89].

Recent research has been done to compile a list of different competences that employers seem to look for in employees. For instance, a poll experiment with experts in production management and human resources of 103 companies found an increasing need for the skill of 'openness to change' [89]. In addition, the same study reports a rise in the market for interdisciplinary knowledge, teaching abilities, personal responsibility, and learning abilities. Another study tried to visualize the future workforce competences by developing a model based on analyzing current challenges such as economic, social, technical, environmental, and political [87]. This study also carried out a comparative analysis with other references to support the deduction of the competences proposed in the model. Lastly, meta-analysis research of over 2700 samples found the 14 most wanted skills by different corporations located at different geographies around the world [90].

However, such efforts represent a very holistic approach and viewpoint of the proposed models and categories, lacking further information on how the categories in such models would impact the employees in an Industry 4.0 context. Furthermore, in those studies, the types of skills are broad or generalized, making it difficult to separate other emerging competences also considered necessary. For instance, those studies miss the integration of emotional intelligence and digital skills. These two types of skills influence the performance of employees in the work environment [91], [92]. Missing the inclusion of essential attributes and more profound knowledge into the classification of skills could resolve a difficulty for the training and assessment of workers.

2.2.2.1 Traditional Competences and Skills

Competence is a combination of attributes or skills that a person displays throughout a lifetime around different engagements, i.e. jobs. The most common discussed competences in the labor environment can be presented into five groups: hard, soft, cognitive, emotional, and digital skills.

Hard skills, also known as technical skills [93], are those skills and know-how needed to perform a job, trade, or craft, that require special training and dexterity [94]. Technical or hard skills are special knowledge for specific job occupations, and they are said to have boomed during the production line of Henry Ford [95]. These skills are regularly trained within the work companies because they require a unique and restricted environment. They are commonly seen as hands-on work skills, i.e. working with equipment or hardware. However, they are not limited to this. For instance, working with data, software, abstract knowledge, or methodical techniques can also be considered hard skills, as long as they fit the skill needed for the specific occupation or job role. Nevertheless, today, having only this set of hard skills is not enough for professional success [96].

The origin of studies on soft skills started in the middle of the 19th century, and they are connected to personality types or traits [97]. Social traits or non-cognitive skills are other names for this kind of general competence [95]. Soft skills constitute those essential traits that a person displays as social graces in particular environments [98], and they allow individuals to maintain and manage interactions with others [96]. There is considerable value in this kind of competence as it mainly relies on the self-monitoring performance of a person [94] and their ability to become more prompted to continuous learning, adaptation, and interdisciplinary learning [99]. For instance, teamwork skill, which fits in this category, is highly appreciated and requested by businesses that deal with R&D, high customization, rapid changes, supplier-customer relationships [100]. Nevertheless, it has been noticed that both employees and new job applicants in the industry show a lack of this type of soft competence [101].

Cognitive skills, also known as the popular term of Intelligent Quotient (IQ) [102], are those abilities that facilitate learning. IQ aids in the performance, dexterity, and mastery of topics and activities by enhancing the ability to learn [103]. Between the ’80s and ’90s, numerous studies have looked into this competence and concluded that IQ influences the performance of jobs, training sessions, and other general aspects of life [104]. This skill has also shown estimations where people or countries ranked with higher IQ may achieve better financial growth, as there seems to be a connection between the level of cognitive skills and economic growth [105], [106]. Moreover, consideration of IQ attributes during the development of new technologies and applications is believed to lead to better task accomplishment for the workers [107].

Emotional Intelligence (EI), or also called Emotional Quotient (EQ), is understood as the ability to perceive, understand, and regulate emotions in the person, to then lead towards thinking and actions [108]. The study of this skill began in 1990 and is known for being the driving or self-state motivation that leads behaviour [109]. EQ supports complex-control activities since it influences the sensations of satisfaction, commitment, motivation, stress, performance, and quality decision-making of employees [91]. Furthermore, the higher the level of emotional intelligence, the better the chances of success in personal or professional commitments because handling challenges, frustration, and stress becomes an improved ability [110].

Digital skills are those abilities that support and enable people to manipulate digital hardware, i.e. computers, devices, systems, and search, process, and apply software or digital content in such hardware [111]. In the middle of the '90s these skills started growing in popularity [112]. An interesting aspect of this kind of competence is that they also include the action of other types of skills, such as cognitive, technical, and social competences [92]. Three different life contexts are supported by these digital skills, namely the personal, the social, and the professional. The personal context is considered the basic level, the social context is the intermediate level, and the professional context is the advanced level [21]. To support the understanding and applicability of these skills, a framework has been created, where there are five main competent areas and two dimensions to develop digital skills [23].

Table 2.1 gives the basic view of the framework DigComp2.0 to represent the applicability of digital skills in five main areas with different bullet points to consider in each area [23].

Table 2.1 DigComp2.0 framework for five areas of digital skills

Dimension 1	Dimension 2
1. Information and Data literacy	1.Browsing, searching and filtering data
	2. Evaluating data, info and digital content
	3. Managing data, info and digital content
2. Communication and Collaboration	1. Interacting, Sharing and Collaborating through digital technologies
	2. Engaging in citizenship through digital technologies
	3. Netiquette
	4. Managing digital identity
3. Digital content creation	1. Developing digital content
	2. Integrating and re-elaborating digital content
	3. Copyright and licenses
	4. Programming
4. Safety and Security	1. Protecting devices
	2. Protecting personal data and privacy
	3. Protecting health and well-being
	4. Protecting the environment
5. Problem solving	1. Solving technical problems
	2. Identifying needs and technological responses
	3. Creatively using digital technologies
	4. Identifying digital competence gaps

2.2.2.2 Emerging Competences and Skills

The following two competences are more recent in the literature of manufacturing and industry; therefore, their studies and implications are less commonly discussed up to now than the five competences described above. However, in today's disruptive world conditions, spiritual and financial intelligence can significantly support employees' and corporations' performance and wellbeing.

Spiritual Intelligence, or spiritual quotient (SQ), is the third 'Q' that has come up by the end of the 20th century. This skill is understood as the intelligence that helps to address the high-level problems of meaning, value(s), and purpose [113]. Unlike IQ and EQ, SQ allows humans to ask fundamental questions, which provides them with the creativity and understanding to discern or change situations. In this sense, SQ is the intelligence needed at the foundation level to operate and function IQ and EQ effectively [114]. Moreover, high spiritual intelligence has been recognized among leaders motivated by service and purpose, leading by example of development, inspiration, and mentorship [115]. In addition, recent empirical studies have highlighted the importance of this skill at working and enhancing employees' outputs. For instance, the individual spiritual intelligence of workers can positively influence their resilience, awareness, and engagement with their organization [116], [117]. Multiple regression analyses have also shown that SQ in workers plays a key role in employees' behavior, commitment, and motivation towards their work because it facilitates workers to adopt organizational citizenship in alignment with their own purpose and values [118]. When spiritual intelligence is boosted among employees in the forms of creativity, innovation, and commitment simultaneously, this creates a positive impact at the organizational level. Data has shown that SQ is positively related to an organization's profitable and financial performance [119].

The concept of financial capability was promoted in 2007 as the need for individuals to develop financial skills, knowledge, and experience to handle economic policies, instruments, and services to become better financial citizens [120]. This capability is also known as Financial Intelligence or Financial Quotient (FQ). Financial intelligence is not meant only for specific roles or careers. Instead, it is for leaders, managers, employees, and ultimately any person who needs a financial perspective of a given situation to work and manage more effectively [121]. In this sense, FQ can be integrated into two main parts, personal finance, and business finance. Both parts have to deal with financial ideas such as present and future expenses, present and future income, cash-flow, taxes, insurance, and economic development [122]. However, this competence not only covers the study of financial knowledge and skills that a person may have, but it also investigates the financial attitude or outlook toward money. For instance, it has been noted that emotions or beliefs around money can positively or negatively affect FQ [123], [124]. Moreover, it has been statistically identified that emotional intelligence and financial intelligence together can significantly affect both the business performance of SMEs [125] and the economic behavior among students [124]. In addition, spiritual and financial intelligence can also play a significant correlation on the personal financial management of students [126]. In other words, it can be summarized that the FQ of a person is related and influenced by his financial literacy in addition to his SQ and EQ.

2.2.3 Contemporary Challenges Impacting the Workforce

Industry 4.0 should not be seen only as a technological promise but also as a human opportunity for solutions in many industrial and global aspects, i.e. the workforce care and inclusion. Industry 4.0 offers opportunities to disrupt the way of working and employment. However, for it to happen, it is essential to consider the most relevant issues affecting the employability of the workforce to this moment. This section briefly discusses four main challenges in terms of employment concerns.

2.2.3.1 Skill Gap

At the same time as the introduction of the new Industrial Revolution has taken place in different countries, similarly in such countries have been studies to investigate and highlight a skill gap in the offer and demand of workers and students in the industry.

For instance, in recent years, the UK government found that the percentage of hard-to-fill jobs had increased from 16 to 22 percent due to a skill shortage in general with emphasis on technical and digital skills [127]. Similarly, in the European Union, 37-43 percent of the labor force population was reported to have poor digital skills, which hindered their participation in both the economy and society [23], [128]. Moreover, a New Zealand leading organization has found that 71 percent out of 206 businesses in the country were concerned about a skill shortage already happening in their industry sector [129]. Furthermore, in the US, attention has been given to the lack of skills perceived by the industry, especially the soft and interpersonal skills, for both employees and students alike [94], [101]. On top of that, a European survey study found that there is work to be done in universities due to a lack of awareness and knowledge among young university students regarding Industry 4.0 or smart factory topics [19].

The skill gap is a topic that has gained even more focus with the advent of Industry 4.0, which will promote the need for further work on the subject. Moreover, since the job profiles will evolve in demand to Industry 4.0, it is still unclear how skill gaps and new types of skills will continue for some time [130].

2.2.3.2 Aging Population

Similar to the skill gap topic, different countries worldwide are concerned about their population growing older. This issue seems to primarily affect the workplace and the workforce as no new employee generation would be taking over the positions from those employee generations seeking retirement.

For instance, in the Asia-Pacific region, it is expected in the medium-term a sluggish productivity caused by a growing-old population, which may result in a lower income per capita [131]. In Asia, the speed of aging compared to the United States and Europe is remarkable, especially in old Asian countries. Moreover, New Zealand findings suggest that the island is among the top rate OECD (Organization for Economic Co-operation and Development) countries with employees over 55. It is expected to rise in the coming years [132]. The same study also suggested the need to focus on the job design to support the future training and conditions of the 'mature-age' worker. Furthermore, in Europe, they have referred to a new phenomenon named "workforce aging", which expresses the tendency over the next few decades of experiencing an increasing share of workers over the age of 55 [133]. Italy, Greece, Ireland, Spain, and Portugal are among the main workforce aging countries expected to drag European productivity growth.

In general, the consensus result from aging-population studies indicates that this challenge threatens the labor productivity of single companies and the growth of the total factor productivity (TFP) of a country.

2.2.3.3 Compromised Wellbeing

As mentioned in the first chapter, the recognition for the wellbeing of people (i.e. workers, society) has also been included in the reach and interest of Industry 4.0 adapters [3]. In this sense, it is vital to have an overview of ways the existing physical and mental wellbeing of individuals is compromised.

It is expected that by 2050 there will be an increase of 21% of people aged 60. Nevertheless, living longer does not necessarily mean living better [134]. Unfortunately, mid-age people struggle with chronic conditions such as diabetes, cancer, respiratory disease, dementia, among others. Furthermore, chronic diseases, mental stress, and poor physical ability have been found to be factors associated with premature cessation from the working life of individuals [135]. Moreover, due to the perceived threat to social wellbeing, tackling challenges such as loneliness, anxiety, mental stress, and suicide rates are among the top priorities around different countries.

For instance, New Zealand set mental health and improved social wellbeing among the top budget priorities in 2019 [136]. In addition, as of 2019, compared to the previous ten years, New Zealand has suffered an increase of 29 percent in suicide numbers, making this issue one of the 'biggest long-term challenges' in the country [137]. On a similar note, Australia is struggling with the growth of loneliness. The Australian Psychological Society is trying to address loneliness and wellbeing issues in the country [138]. The study showed that younger adults tend to feel more anxiety and loneliness than Australians over 65 years, but one-quarter of adults generally feel lonely. Another report on loneliness has found that in the US, 47 percent of Americans, including teenagers and old adults, suffer from a feeling of isolation and disconnection [139]. This issue is slightly reaching the classification of 'epidemic' because it is a social problem that is increasing, affecting health across different nationalities. The modern world's mental distress and isolation have caused that the UK named her first Official Minister on Loneliness [140]. This new appointment attempts to create a strategy for supporting the 9 million people (14 percent) of the British population that have been found with a feel of loneliness distress.

In everyone one of such cases, it is well acknowledged the need to improve and resolve old and new ongoing health and wellbeing factors, not only for the economic burden that such problems bring to the country but also for the potential of social instability in the near future.

2.2.3.4 Volatility, Uncertainty, Complexity, and Ambiguity (VUCA)

Volatility, uncertainty, complexity, and ambiguity are becoming more noticeable and commonplace in today's economic and enterprise environment. Therefore, this integrated type of challenge influences human capital interactions that are important to consider.

The complexity of tools, machines, and operational systems has increased substantially every new industrial revolution [28]. More than ever before, today's companies and their workforce are facing an increasing VUCA-type of the world, which is not only a risker environment but also a more difficult one to succeed in. VUCA conditions in existing disruptive changes and challenges require entrepreneurial leadership to design and frame new organizational capabilities, promoting innovative business models [141]. Moreover, companies in service-based economies that face and undergo such disruptive changes and transformations will need a Human Resource reshaping at the strategical and organizational level, including internal and external layers [142]. This will impact all types of businesses, including the manufacturing industry, which is incredibly encouraging the Industry 4.0 revolution. For instance, it has been found that small and medium manufacturing enterprises (SME's) tend to find themselves with struggles managing complex computer-based solutions, or achieving autonomous processes, or synchronizing production flows in real-time [143]. This new kind of challenging situation also raises difficulties for capital investment, not only at the machinery and engineering level but also at the operational skilled workforce level.

Industry 4.0 may be an opportunity to tackle and minimize VUCA conditions. However, it is required to reengineer both the business model and the workforce structure of companies to achieve specific features, such as interoperability, decentralization, virtualization, service orientation, and real-time capability [144].

2.2.4. Emerging Preparation in Scopes of Industry 4.0

Human development is fundamental for the development of society, and preparation and education are considered one of the major driving forces for economic growth in a country [22]. Amid the new Industrial Revolution, the required type of education for Industry 4.0 will disrupt and bring challenges to the conventional system to develop and prepare students or employees for it.

For instance, a new term called Education 4.0 has appeared to highlight how education has evolved from the early to the traditional to the following type of education [24]. This concept explains that the revolution in human development and education will require a blend of face-to-technology interaction with AI technologies to achieve flexible and personalized learning. In other words, with Education 4.0, people will require advanced digital technologies for learning and be aided in understanding. Moreover, research has been prototyped to implement Education 4.0 approaches to teach Industry 4.0 principles in a so-called teaching factory [145]. This work emphasizes the need and development of emerging engineering skills, such as intelligence, teaching aptitude, creativity, and social interaction. These skills are considered a requirement for future engineers working in technology-driven environments, such as learning factories or Industry 4.0 companies.

However, the current idea of Education 4.0 only offers guidance on leading a future of teaching and training in terms of tools (i.e. technologies). This is still leaving the challenge of identifying the appropriate content to be taught, which will meet the needs in the market. As evidence has pointed out, the existing offer of the labor force, i.e. employees or students, does not meet the criteria needed on the skills to take on the job field [21]–[24], [130].

In the overall market, there is a demand that has not been met successfully for competences, such as soft (i.e. flexibility, decision-making, cooperation), technical (i.e. production understanding,), digital (i.e. digital literacy), and cognitive (i.e. problem-solving, analytical thinking) [90]. Furthermore, the need for delivering emotional intelligence skills in engineering education has been acknowledged as relevant for professional engineers [146]. In addition, it has been outlined that most teachers in the educational system are not yet well-positioned and prepared in the instruction and teaching of the up-to-date industrial competences and needs [147]. This poses a more significant challenge at the academic in two ways. One, the graduates are missing the required competences to embrace the new industry. Two, the academic staff does not understand the industry's needs and the knowledge needed to teach.

2.2.4.1 Workforce Preparation and Development for Industry 4.0

To tackle some of the skill gap issues, different countries have tried to adopt new approaches with their workforce development programs and education. For instance, countries in Europe have been attempting recent actions:

- A collaboration between Turkish and German universities has elaborated a teaching framework with three main aspects: (1) a curriculum highly focused on ICT and computing subjects, (2) the usage of technological equipment at a visual production laboratory, (3) an Industry 4.0 student club for research projects and conference organization [148].

- Education in Germany has emphasized the attention to those subjects they consider key for the invention of novel future technological developments, such as Mathematics, IT, Natural Sciences, and Technology (MINT) [149]. An example of this effort is the Excellent Teaching and Learning in Engineering Science (ELLI) project. This is a collaborative work between three German universities to develop a network of virtual laboratories to increase the dynamics among innovative education and Industry 4.0 technologies [150].

- In Ireland, the attention is focused at postgraduate and master levels, aiming for interdisciplinary skills and collaborations, working closely with local industries and their real needs. This program requires technological-driven topics presented in a laboratory with the physical and digital twins of manufacturing cells to practice theoretical and empirical research [151].

- Sweden also focuses on postgraduate levels of preparation, such as research, innovation development, and Ph.D. education. They have made Producktion

2030, a program that aims to develop six manufacturing areas: sustainable environment, flexible production, virtual production, humans in production systems, product & production-based services, and production development [152].

Similarly, in the US, there is an increasing focus mainly on developing STEM subjects (Science, Technology, Engineering, and Mathematics), technological literacy, and manufacturing topics. For instance:

- High-school teachers have become participants of an educational program to be trained and upskilled in manufacturing education. The program has been created to start introducing production and manufacturing design subjects to high school curriculums [153].

- Another project was developed to teach novel additive manufacturing prototyping to undergraduate students while at the same time using gamified prototyping to teach high school students. The idea is to create AM parts from the advanced lessons the undergrads learned and pass on those formed parts to high school students for their basic knowledge about advanced manufacturing concepts [154].

- A new approach seeks to implement the topic of the digital twin and its integration in the curriculum for the next generation of engineers in Industry 4.0. This is proposed under a framework to develop innovative digital manufacturing using a model-based system to drive product development while integrating high-level modeling according to the requirements of the product [155].

Lastly, but similarly, a major leading country in Asia, Japan, explores new avenues of preparation and education. A recent program in a Japanese technical college has incorporated a new social perspective into the curricula to ignite a creative and practical engineering experience involving problems between an engineering field and a social need [156]. One of the most valuable results from this program was the personal experience reported by the student participants, which was of personal motivation, excitement, and enjoyment from participating in the solution of a real problem.

Overall, in terms of human development and education, most institutions, programs, or projects are commonly focused on MINT, ICT, and STEM subjects and technical skills. Furthermore, as noticed in a study, most undergraduate engineering programs have a considerable number of domain subjects, i.e. engineering sciences, product process development, materials composition, etc. However, they leave less room for other topics and skills equally crucial for future manufacturing, i.e. innovation and entrepreneurship [157].

2.2.5 The Operator 4.0 Overview

The operator is the ordinary person working in the factory next to production processes and performing different work activities, such as assemblies, inspections, and material handling. Today, Operator 4.0 is understood as “a smart, skilled operator who performs not only cooperative work with robots but also aided work by machines as and if needed by means of human cyber-physical systems, advanced human-machine interaction technologies, and adaptive automation towards achieving human-automation symbiosis work systems” [12]. Such an idea of the concept emphasizes technical solid and technological aspects of working under conditions of smart factories and Industry 4.0.

In addition, Operator 4.0 has been classified into eight different types of workers, depending on the kind of technologies attached [14]:

- Operator + exoskeleton = super-strength operator. The physical interaction and combination of these two elements would allow the improvement of physical ergonomics by supporting manual operations that represent a risk due to the limited strength of the worker.

- Operator + augmented reality = augmented operator. AR helps as a means to support the cognitive perspective of the person, i.e. memory or attention. Human-machine interfaces using AR can bring digital information to the physical world to support the operator.

- Operator + virtual reality = virtual operator. VR technology can further aid the operator in enhancing technical and cognitive abilities in terms of simulation and virtual spaces for workforce training.

- Operator + wearable trackers = healthy operator. Smart trackers' physical interaction and connection would allow the generation of workforce analytics while monitoring and keeping track of health-related metrics, i.e. stress.

- Operator + intelligent personal assistant/AI = smart operator. AI personal assistants offer many benefits to human-device interactions, which facilitate planning, logistics, mobility, or scheduling. This allows the efficiency of performance from workers in contact with such systems.

- Operator + collaborative robots = collaborative operator. Operators and collaborative robots (CoBots) can work hand in hand without much restriction as conventional models of robots. This new type of cooperation aims for a more intuitive, ergonomic, and safe work environment.

- Operator + social networks = social operator. Social networking may be a way to improve communication and connection within the company's employees. This can create better means of knowledge sharing and accessing collective knowledge. At the same time, this opens opportunities for cooperation between machines and operators.

- Operator + big data analytics = analytical operator. Implementing big data analysis can support the worker to clearly collect, organize, visualize and improve performances, forecasting, and key indicators at the shopfloor or company level.

In the attempt to study and apply some of the different types of Operator 4.0, efforts have been made to showcase such concepts. For instance, a research group demonstrated four case studies on this topic [158]. The first case is an application named Legacy of screens, an HMI application to improve operators' reaction time. The second case is a solution to provide cognitive healthcare to operators using the cloud HMI system, which includes the smart, the healthy, and the social operator typology. The third case is a solution for maintenance and prediction, helping operators know about production interventions, where the smart and the analytical type of operator were included in this application. The fourth case is a machine-to-people interaction based on the operator position to aid workers and supervisors in the production system, which included the typology ideas for the smart and the augmented operator. Similarly, another elaborated work has been done to provide an overall framework of human-system interactions on the idea of Operator 4.0. The framework uses a complex integration of VR, AR, biosensors, eye-tracking, motion capture, and survey application to monitor and analyze the operator's physiological parameters, visual interactions, and physical movement [159].

In general, a good amount of IoT-based architectures and infrastructures efforts have been presented and surveyed to find the applicability and benefits of Operator 4.0-enabling integrations [160]. It would be safe to state that the present idea of Operator 4.0 relies on a structural framework of feedback technologies that support the monitoring and analysis of data from the user and which is trying to support his integration into a system. In other words, the works around the new operator are mainly focused on technological possibilities, without consideration of other factors, i.e. organizational, processual, and psychosocial environments that exist in human systems [161]. Moreover, a recent study points out that the concept of Operator 4.0 is still unclear and needs to keep evolving, for a human-centered design should also embed human values, which are not existing in the approach of the so-called new operator [162].

2.3 Research Gaps and Motivations

This segment summarizes the literature review and identifies the research gaps. In addition, it presents the motivations for conducting this research.

The Fourth Industrial Revolution is providing an opportunity for massive technical changes and applications aided from the nine technological pillars, such as Robots, IoT, VR, CPS, AM, AR, the Cloud, and Big Data. The scope of this disruptive paradigm is expected to enhance the industry by employing interconnected, dynamic, reconfigurable, and collaborative manufacturing and businesses. Moreover, with the vision of intelligent factories and smart products, the rigid pyramid structures from earlier industrial revolutions are transforming. Such new features and changes have opened the opportunity for new loose web-like designs at different technical levels of businesses. However, while the potential benefits of the technical side of Industry 4.0 draw more attention ever, the human side on it is neglected. No clear studies emphasize the human aspects, attributes, or capability that will be required to counterbalance the demanding technicality of Industry 4.0. For example, it is still vague how Industry 4.0 will influence the workforce perspective, structure, and dynamics inside and outside corporations. Furthermore, there is a lack of studies trying to compensate for the holistic paradigm of Industry 4.0, but in the human-sided perspective. For instance, state-of-the-art research has thoroughly found that the driving focus on Industry 4.0 is technology, while the human factor is highly neglected [161]. Therefore, the human side of Industry 4.0 requires study efforts.

The work prescribed under an Industry 4.0 set will revolutionize the type of jobs. There is a common consensus that many jobs will disappear due to highly advanced technologies and that many new forms of employment will appear. As new positions emerge, the requirements on the human capital arise to cope with new and disruptive changes. For instance, there is a need for the workforce to become collaborative, interdisciplinary, flexible, self-driven, and achieve an upgraded version on different types of competences. Yet, it is still unclear how to achieve such an upgraded version of the workforce by the conventional approaches to competence development. Moreover, the inclusion of new competences for the workforce strongly emphasizes popular ones, such as digital or soft skills. In contrast, emerging ones such as EQ, SQ, or FQ have not been considered. A significant reason for this omission is that efforts on this topic typically present a very broad and generalized approach, which misses relevant analyses, such as competence implications on employees or the adaptation of emerging skills. Such mismatch of the proper skills and an inadequate upskilling development are top factors for high rates of today's unemployment [163]. Therefore, research on a suitable framework of competences and skills for the future of work and industry is required.

In addition to the Industry 4.0 challenges, contemporary challenges are impacting the workforce. Many countries, and most of the job market in general, encounter an aging population, deal with unprepared employees, face an increasing compromised health, and cope with continuous VUCA situations. These factors affect the industry, but in consequence from the affected workforce. In other words, all the mentioned factors affect the human side, which at the same time affects the job place. Unfortunately, these factors have not been considered in research approaches when preparing and upskilling the workforce. Moreover, the workforce's emerging efforts on preparation and education are falling short of tackling this kind of issue. For example, while some programs and efforts are being made to improve the agenda of competence, most of these efforts are predominant on a technical-driven subject or a domain-based perspective. Such types of approaches are traditional or single-sided, which fail to provide and prepare the workforce in today's market. Furthermore, this missing part can be clearly aligned with what has been reported repeatedly throughout the literature, that conventional schooling is not delivering well-prepared prospects of employees [21]–[24], [130]. Therefore, this leaves a need and provides room for a novel alternative that can be both a human-centric perspective and a multi-sided (holistic) approach to aid in the workforce preparation while coping with the mentioned challenges.

Operator 4.0 has been defined as the intelligent and skilled operator who cooperates with machinery and robots, performing work aided by technology. The typology of Operator 4.0 depends on different technologies. For instance, the virtual and the augmented operators employ virtual and augmented reality systems, whereas big data analytics and artificial intelligence form up the analytical and competent operators. Many cases have been prototyped to study the different breeds between the technological pillars of Industry 4.0 and the human user. However, the existing definition of Operator 4.0 misses further details about the operator and its relation as a workforce member in a factory. The original view solely stresses 'aiding technologies' for the operator to be able to work, which can denote a technological dependency. In addition, this view focuses on technical cooperation with tools, robots, or HCPS, but it leaves out the human or workforce cooperation into consideration, i.e. colleague interactions. Despite the considerable attention to this concept and its collaboration with CPS interactions, it has been noted that the mainstream approach on this topic area is technology-driven [162]. Therefore, the whole view on Operator 4.0 needs further study to not only include the technical part but, more importantly, the human part of the workforce. Furthermore, since the operator is part of the manufacturing workforce, analysis on how Operator 4.0 might be influenced by the changes in the manufacturing workforce due to technology advancement also requires attention.

Consequently, based on the research gaps, a number of motivations for conducting this research can be outlined:

1) The current view on Industry 4.0 needs to be supported to counterbalance the permeated technical and technological focus it has acquired today. Such techno-driven view should not go alone in direction, as it will also impact society, particularly the workforce. Therefore, this research will provide the human side perspective of Industry 4.0 that needs to be explored and defended in parallel.

2) The topic of skills and competences is relevant to the success of an Industry 4.0 environment. Therefore, this research will work on identifying the proper competence with a well-identified set of competences needs dedication to be studied. Moreover, the study of a systematic typology of competences for the workforce under the Industry 4.0 vision should facilitate understanding of the most needed skills according to this new industrial age.

3) The challenges faced by the workforce, whether Industry 4.0 challenges or contemporary challenges, need to be mitigated by workforce preparation and development. However, today's human capital preparation cannot only focus on technology-driven subjects or domain-based approaches. Instead, such essential preparation and development also require the consideration of

existing human labor needs. Therefore, this research will facilitate the proposal of an alternative approach that should be studied and developed to support the workforce upskilling from a human-centered and holistic approach as the key characteristic.

4) The workers in a factory play a vital role, regardless of automation. Although the concept of Operator 4.0 remembered and uplifted this vital role in the advent of Industry 4.0, it primarily took on technological tools, devices, and applications for its conception. Therefore, this research will elaborate on the study and elaboration of a holistic, more complete human view of the operator begs attention. Moreover, such expanded analysis should include the perspective of other human working factors that can influence manufacturing and impact the workforce, such as interactions, capabilities, or H-M cooperation.

Chapter 3

Methodology

This chapter introduces the methodology of this study. It explains the approach and steps taken into consideration for the development of the research. Then, it describes the research questions to be answered.

3.1 Research Design

Scientific and academic research can be derived from both deductive and inductive processes. The deductive process implies a top-down hypothetic-driven approach, whereas the inductive process comprises a bottom-up data-driven approach [164]. The former relies on having a theory, formulating a hypothesis, testing the hypothesis, and presenting the conclusion/results of the study. The latter depends on observing a phenomenon, identifying patterns, developing hypotheses or questions, and creating new theories.

While both processes are well established in providing research outputs, it is vital to apply them accordingly to the characteristics and needs of a particular case. For instance, deductive approaches are usually more rigid confirmatory hypothesis-testing research. On the other hand, inductive approaches are naturally more flexible exploratory problem-focused research [165]. Therefore, according to the character and needs for this particular research topic, we opted to implement an inductive process. See Figure 3.1 for a representation of the inductive approach.

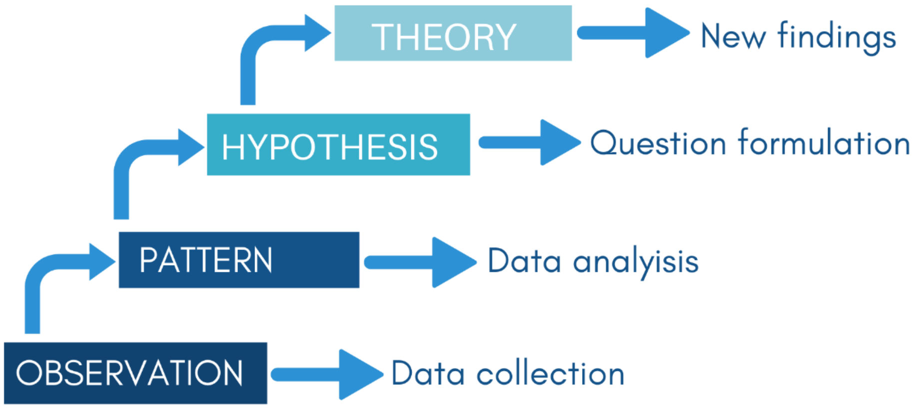


Figure 3.1 The inductive research methodology (bottom to top approach), adapted from [166]

Today, there are only ten years since the word 'Industrie 4.0' came to the picture for the first time (2011), and five years later, after that, for the word of Operator 4.0. The topics around Industry 4.0 and Operator 4.0 are essentially in their infancy, especially those subjects around the aspects and affairs of human involvement in the advanced technological age. This opens doors for inductive research in the area, especially since inductive approaches are suitable for revising theory and building new knowledge or discovery [167]. In this sense, the completeness throughout this study comprised the observation and research of existing data while identifying patterns and needs. Moreover, advantages of using this methodology approach have been used in different case studies. For example, a case study specifically did an engineering analysis to study the gathered raw data from users and programmers to draw brief summaries of the data, to develop theories based on data, and to make clear links between the objectives and the results sought in the research [168]. Similarly, those advantages will be looked for in this research work.

The selected method for the research collection and pattern identification is described as 'systematic search and review'. The systematic search and review is a method that combines the strengths of a comprehensive search process with a critical review, aiming for an exhaustive and comprehensive search that can include multiple study types rather than a single type [169]. This review method is suitable for addressing broad questions and producing evidence synthesis, thus providing more comprehensive or complete pictures of a research topic than systematic limited reviews. In this sense, the characteristics of this method align with the inductive approach and the goal of this research, which is the progress for the field on human aspects in Industry 4.0.

Figure 3.2 synthesizes the research design throughout this study. For simplicity, three phases have been illustrated. The first phase covers the information in chapters one and two, which is the collection of data as well as the study and analysis of such data, to identify then the gaps within the existing knowledge. The second phase elaborates the research questions expressed in this chapter. The third phase includes the rest of the chapters, where the proposed questions are addressed to search and elaborate their answers. Both the inductive approach and the systematic search and review are present in the methodology development of the study.

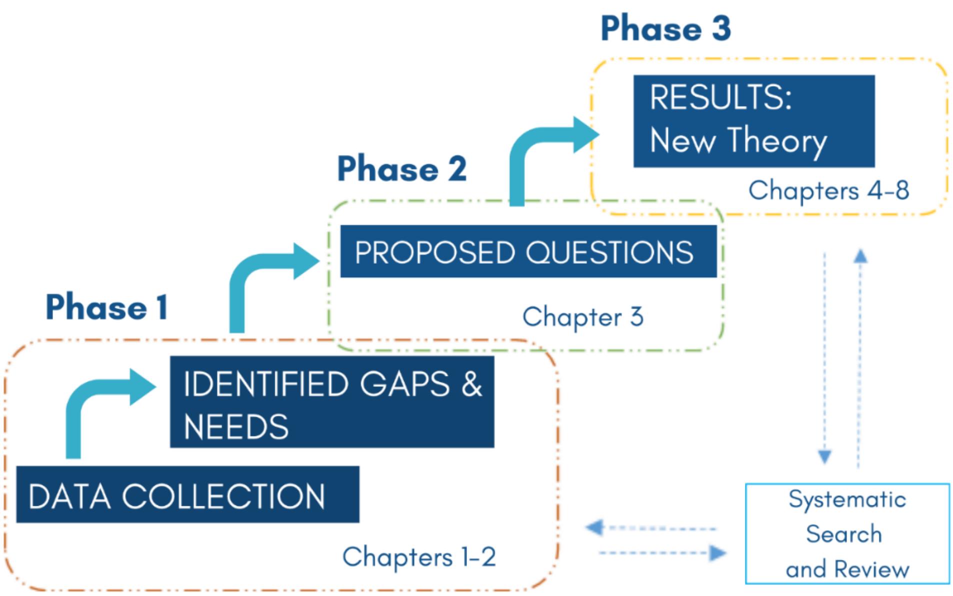


Figure 3.2 Research design of this study

3.2 Research Questions

The research questions are formulated from the research gaps and needs identified in the previous chapter. Moreover, these questions have been proposed to follow the inductive approach principle, which is placing and moving from the particulars to the general [165]. As a result, four primary research questions have been pondered to be answered. However, due to the needs for the last question, this has been split into versions (a) and (b) for a better final answer. Therefore, this research resulted in four particular questions to answer one general question. In other words, the topics into RQ.1, RQ.2, RQ.3, and RQ.4A will help build on the subject into RQ.4B. Figure 3.3 shows this connection among the research questions.

Figure 3.3 Rationale behind the research questions

3.2.1 Research Question Number One

As identified in the literature review, Industry 4.0 is permeating the academic and industrial practice. It is a new phenomenon that brings up a technical and technological characteristic to an expanded field of applications, i.e. businesses, manufacturing, and community. Nevertheless, being this a recent topic, the primary focus has been on the technology-driven side of it. This has created a misbalance on the human side, which needs attention and development that can counterbalance the solid technical focus.

Therefore, the first research question requires an effort to acknowledge and support the human aspect in the workplace. However, this new effort clearly needs to present a shift from the past to present perspectives that can better suit the changes and challenges brought by the Industry 4.0 ambition. To this end, the proposed research question to answer is:

1. ***What is the term to best represent an inclusive set of future-proofing attributes for the workforce in advents of Industry 4.0? and what can be the distinctions from a previous perspective?***

3.2.2 Research Question Number Two

As efforts on Industry 4.0 proceed to the different fields of implementation, it is highly relevant to aid and provide support to workers by enhancing their craft and skills accordingly. Some partial work has been done to support the topic around the skills of the future. However, most of the findings on this area tend to be too wide or generalized in perspective, lacking further analysis on how such proposals may impact the labor force in the Industry 4.0 context. Moreover, the vast majority of such efforts mainly cover a technical side of the skills, i.e. robotics, programming. This misses further emphasis on those skills and traits that are not technical but still important, i.e. self-awareness, value-oriented.

Therefore, the second research question requires an effort to identify a set of skills for the future of work, beyond the technical part, but the human side as well. In addition, it should offer an effort to the classification and explanation of such skills in an Industry 4.0 context. To this end, the proposed research question to answer is:

2. ***What are the competences and skills required for the new paradigm of Industry 4.0, not only from the technical side but, more importantly, from the human side? and how can they be best identified comprehensively in a human-centric way?***

3.2.3 Research Question Number Three

Industry 4.0 has brought the need for upskilling with traditional and emerging skills, while individuals, i.e. workers, students, must be prepared and updated accordingly. That is why models on workforce preparation and development for facilitating abilities are significant to this end. Ideally, today's workforce preparation models would need to support the holistic competence and scope that is required in Industry 4.0 ambitions. However, based on the recent efforts found on this topic, the vast majority of those approaches on workforce preparation are taking a conservative and traditional practice, i.e. job-based, rather than a disruptive approach, i.e. challenge-based. Therefore, their applied methods still maintain a strong focus on single-sided perspectives, i.e. technology-centric, subject-based, with less of a multi-sided view, i.e. human-centric, problem-based. In short, such approaches miss to provide and promote the preparation of a holistic competence and skills, which are required for Industry 4.0.

Therefore, the third research question requires the effort to develop a model that can aid in preparing the human capital with a human-centric perspective to facilitate a multi-sided view. Moreover, the model should encourage the inclusion of a complete competence for Industry 4.0, as well as promote a method of use on a challenge-based approach. To this end, the proposed research question to answer is:

3. ***What is the human-centered model that can best support the allocation of a holistic competence for human capital preparation and development? and what contextual method can be developed from such a model with a challenge-based perspective?***

3.2.4 Research Questions Number Four

The existing work on Operator 4.0 is a considerable effort on supporting the inclusion of the human aspect into Industry 4.0. It brings the awareness of roles performed by humans in the factories, such as operators. This concept emphasized that working roles need research of considerations when implementing new technologies at work. However, the current understanding of Operator 4.0 relies strongly just on technological implications and applications, which misses further study into considerations such as human attributes, competences, or interactions. Moreover, it leaves out the silent but relevant comparison between 'operator capabilities' versus 'machine capabilities' and the design of future operational structures.

Therefore, the fourth research question requires an effort to enhance the current concept of Operator 4.0. However, to achieve this sensibly and thoroughly, two investigative steps need to occur. The first is to identify and denote key implications happening at the manufacturing workforce viewpoint due to the technological and Industry 4.0 influence. This should show how the manufacturing workforce is or will be impacted by Industry 4.0 influence. The second step is to consider and implement results from the previous researched questions into the newly updated notion of Operator 4.0. This should secure a clear human perspective and the competence and considerations that will enhance the Operator 4.0 scope. To this end, this challenging task is proposed to be split into two questions:

> ***4A. Bearing in mind the latest technological implementations in manufacturing, and keeping a worker-centric perspective, what are the key implications that can contribute to the understanding of the existing workforce?***
>
> ***4B. Considering the factors found until now, what is the updated version of Operator 4.0 that best advocates for a human perspective of Industry 4.0? and what are the distinctions for such an updated version?***

3.3 Embodiment of the Research

Figure 3.4 summarizes the structure of the research study by topics in general. Each research question provides an answer to the issues to be addressed, respectively. Therefore, they all are interconnected to some extent, to continue building up until the last question. In the end, the content and the main points of the proposed questions will help elaborate on the primary goal of this research, urging for the human perspective of Industry 4.0 and seeing the Operator 4.0 conception in that inclusion.

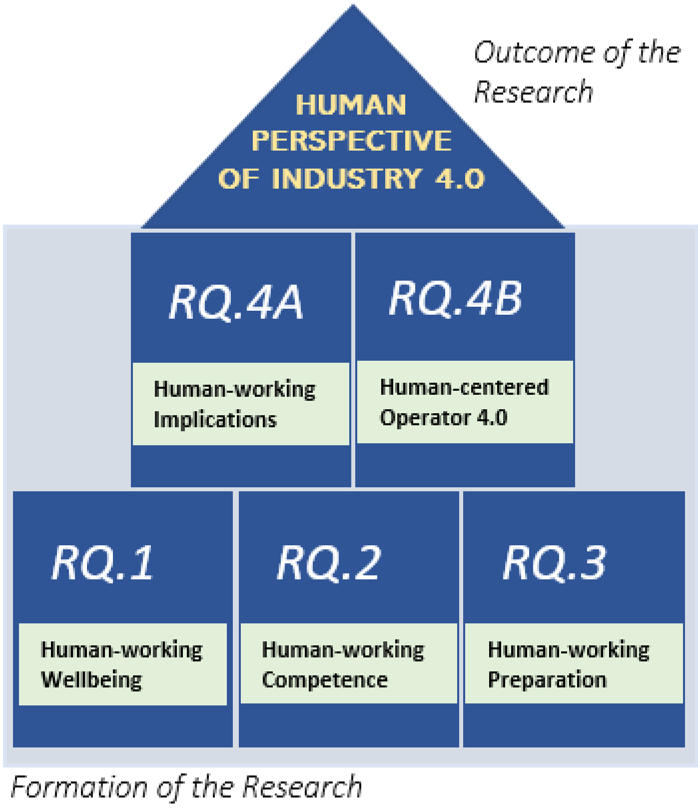


Figure 3.4 Structure of the study by research question and key topic

Chapter 4

Human Capital 4.0: A Future-proofing Set of Attributes for Industry 4.0 Workforce

This chapter presents the development of the new term Human Capital 4.0. The proposed term arises from the need for a human-sided perspective of Industry 4.0 that can support the labor force in existing times of disruptive change, i.e. technological advancement. This chapter contributes towards answering research question number one: “What is the term to best represent an inclusive set of future-proofing attributes for the workforce in advents of Industry 4.0? and what can be the distinctions from a previous perspective?”

4.1 Introduction

The Industry 4.0 view promises a brighter future in many subjects, i.e. manufacturing, logistics, businesses, the environment, and society. This new technological revolution opens the path for closer and dynamic interactions regardless of physical locations, allowing companies and individuals to engage in day-to-day activities, i.e. jobs, services, and professions. Therefore, to a considerable extent, human activities will be empowered by this age's state-of-the-art technologies and applications.

However, Industry 4.0 cannot, and should not, be driven by pure technology advancement and focus. Human-based efforts must come into perspective for the basis and creation of the Fourth Industrial Revolution. Otherwise, there could be a risk of forgetting the primary purpose of technology for serving people, and not the other way around, people serving technology.

As expanded in Chapters 1 and 2, Industry 4.0 comes from the succession of three previous industrial changes, i.e. the steam-pumped work, the electric-aided work, and the computational-supported work. Those previous job disruptors occurred at different stages of history, where such changes impacted the type of work at the time. In other words, each one of them changed the way the world operated at the time. Similarly, today's new job disruptor, Industry 4.0, will influence jobs and labor activities. Nevertheless, the big difference between this and the past job disruptors is that Industry 4.0 is happening just now, which allows visioning, planning, and executing according to the best interest of stakeholders, i.e. employees and employers. This means that there is an opportunity for inputs from academia, the industry, the government, and society to steer the direction of Industry 4.0 implementations to become human-centric and benefit people.

From an academic and engineering perspective, we want to enhance the human outlook for Industry 4.0. Therefore, it is crucial to start from heeding and looking into a basic concept with variables or elements that can integrate the current understanding of human labor, Human Capital.

4.2 From Human Capital to Human Capital 4.0

The definition of Human Capital (HC) is considered as the acquisition and investment in talents or skills that people develop during education and training to add to their productivity, fortune, and contribution to society [170], [171]. The current view on HC is solely referred to the competences in people that support a form of labor, income, or service. However, while such skills are essential for generating personal economic growth by performing a job, the standard view of HC is missing the current needs of the workforce for Industry 4.0, i.e. wellbeing, adaptability, among others. As found out in the literature, the demands and expectations for employment have increased, which causes a similar effect on the expectations for the labor force. This, in turn, requires an adjustment and enhancement towards the very concepts or paradigms that can influence the worker.

In Figure 4.1 is possible to visualize the more square or traditional version of HC in comparison to the proposed circular or holistic version for the new concept. It displays the main differences between the existing and the proposed vision for human capital in Industry 4.0.

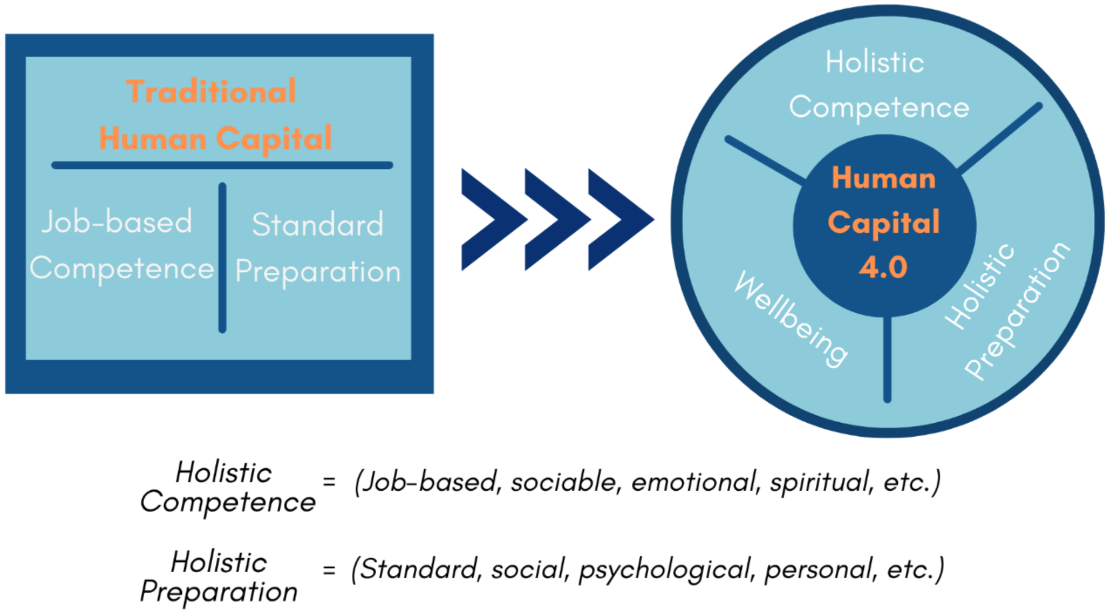


Figure 4.1 Transition from traditional HC to the next HC 4.0

On the one hand, the ordinary understanding of human capital considers only two attributes, standard preparation, and job-based competence. This common view has already outdated elements in it, which in turn they cannot deliver for those challenges in Industry 4.0. Moreover, as it can be highlighted, such features are driven mainly by a job and a technical side in their implication, which has been repeatably pointed out as one of the main issues found in the literature.

On the other hand, the proposed version, Human Capital 4.0, not only adds a new attribute, wellbeing, but also implies a new updated approach to the other two attributes. A holistic preparation and a holistic competence are part of a much integral and wholesome context for the worker. Furthermore, there is an inherent link between competence and preparation, where the type of skills will tend to steer the kind of development required for people. For instance, the new holistic competence includes not only the job-based competence (hard skills), but also others, such as spiritual and emotional intelligence, digital, social, and even financial. All of these are detailed discussed further down in the following chapters. In this sense, the new version of HC is looking after the match between the needs of the demand and the delivery of the offer.

Since the requirements for Industry 4.0 have elevated the demand and diversity of activities for the workers, it is equally relevant to promote the standards and diversity for competence and preparation. This is the primary reason for the proposed holistic approach towards both attributes. Moreover, the potential and goals of Industry 4.0 go beyond the idea of previous standard work goals. According to the initial report on "Recommendations for implementing the strategic initiative Industry 4.0" [3], the potential and objectives of Industry 4.0 can be summarized in eight key points. Figure 4.2 summarizes the eight sought possible goals of Industry 4.0 named by the Working Group. Consequently, the labor force in this new disruptive industrial age will be required to be more diverse than previous standard approaches.

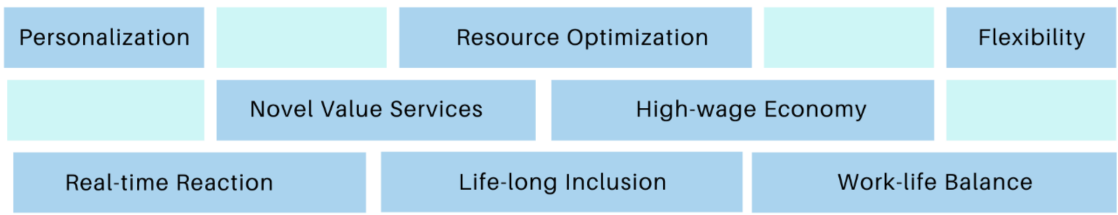


Figure 4.2 Industry 4.0 potential goals

In this sense, the proposed term Human Capital 4.0 in this research appeals to the next generation of the workforce who is provided with a future-proof set of attributes that will support them to cope with the Industry 4.0 paradigm. Moreover, it is expected that recognition and consideration of these three attributes, or elements, in Human Capital 4.0 will work out cohesively the benefits and changes sought by Industry 4.0.

Having set the reason and foundation behind Human Capital 4.0, the proposed umbrella term will expand hereafter. On the one hand, one of the critical elements, wellbeing, is explained and developed in the next section of this chapter. However, the explanation and development of the other two key elements, such as holistic competence and holistic preparation, are presented in the following chapters 5 and 6, respectively. These attributes separately confirm the answers to some of the research questions of the research.

4.3 Wellbeing into Human Capital 4.0

Industry 4.0 pioneering Working Group has acknowledged and pointed out the importance of future employees' wellbeing, not only as a means for better productivity and dynamics but also as an end for social development and thrive. Moreover, from the academic perspective, a reasonable amount of empirical work on wellbeing supports the notion that employees' good wellbeing is directly related to higher performance, productivity, and safety while keeping lower levels of errors, burnout, and absenteeism [172]–[175]. In addition, the notion of a 'sustainable workforce' has been recently proposed as an effort to promote and embed work-life balance and wellbeing practices at organizational strategies to support the long-term health of workers and society [176].

Surprisingly, the standard view of HC rarely touches or deepens into the wellbeing of workers. The information found on literature reviews about HC hardly mentions or elaborates on the health or wellbeing of employees: i.e. Human Capital and the Internationalization of SMEs [177], The Role of Human Capital in the Organization [178], Effect of Human Capital on Organizational Performance [179], Human Capital and Economic Growth [180], Human Capital Planning: Implications for Human Resource Development [181], Measures of Human Capital [182]. In general, in most of these views, the aspect of the employee's health is seen as a 'cost' or 'expenditure' to companies while leaving out the specific incorporation and relevance of the wellbeing element into the aim of the HC concept. Rather, the common view treats such an essential element as a variable that could or could not exist or be achieved, more like an optional than an obligatory element. As a result, there is a lack of further attention and consideration on this important element in the HC conception.

The proposed Human Capital 4.0 concept considers both views, the acknowledgment for wellbeing from the proponents of Industry 4.0 and academic findings, and the needs exposed from the contemporary challenges impacting the workforce, described in the literature review section. Therefore, in this new version of the concept, the idea and attention on wellbeing figures as a fixed constant into it, rather than as a rare variable.

4.3.1. Workforce Wellbeing for Industry 4.0

For this research, the definition of wellbeing has been taken from a thoroughly elaborated and highly cited work named "The challenge of defining wellbeing" [183]. In summary, wellbeing is the equilibrium between a set of resources versus a set of challenges. The resources and challenges can be on different aspects, i.e. psychological, social, physical, etc. In other words, for our case, it can be referred to as the parallel balance between the existing inputs of the person versus the current demands of the situation. Figure 4.3 helps to display such a parallel balance between the resources and challenges. A person's set point of wellbeing will be affected if an unbalanced load of resources or challenges compromises the equilibrium in the seesaw from either end.

Figure 4.3 The seesaw of wellbeing, adapted from [183]

From the illustration above it is easier to depict the idea of wellbeing from a worker's point of view. Naturally, the wellbeing of the worker is affected when the challenges of their job or condition are heavier or higher than the resources of their persona. Hence, the importance of keeping the worker's resources up to the tasks and requirements at jobs. According to the recent book titled "Wellbeing at work: how to design, implement and evaluate an effective strategy ", there are four key resources that are necessary for the employee's wellbeing, such as physiological, psychological, fiscal, and societal [184]. In short, the physiological aspect is related to the physical state of the person (i.e. ailments, injuries, etc.); the psychological part is concerned with the mental state (i.e. stress, satisfaction, etc.); the fiscal aspect is related to the financial state (i.e. financial distress or comfortable); the societal element is concerned with the social state (i.e. social acceptance, relationships).

The idea of Human Capital 4.0 foresees that the element of wellbeing will stay in as a goal and a means for Industry 4.0 worker preparedness. Using the previous illustration as a reference will facilitate the conceptualization of wellbeing in the Fourth Industrial Revolution. In this case, the potential goals of Industry 4.0 are used as the foreseen challenges to handle and the objectives to achieve by the workforce in the coming years of Industry 4.0 implementation.

Figure 4.4 illustrates the current situation about the wellbeing of workers, where Industry 4.0 demanding challenges are currently heavier. Such challenges unbalance the wellbeing of the labor force due to their limited existing resources. This misbalance between the wanted aims and the current resources tilt the ball of wellbeing in an unfavorable position for the workforce. In other words, people's wellbeing loses its set point when new disruptive changes, such as Industry 4.0, come into being.

Figure 4.4 Existing unbalanced wellbeing in advents of Industry 4.0

As seen in the illustration above, here lies in the importance of the proposed new version for HC and its different elements, especially wellbeing. The focus is to keep a human side with human care in the loop of Industry 4.0. Moreover, this attempt aims to balance the aspects of Industry 4.0 and the workforce and to support a more consistent equilibrium of wellness for employees regardless of the challenges. In other words, an extra benefit of this new concept is to foster human wellbeing as a standard, that is, as a means and as an end, in the equation of Human Capital 4.0 for both foreseeable and unforeseeable challenges. Hence, the expression for future-proofing attributes within this updated term.

To ensure suitable-positioned wellbeing is required to enhance the human resources, at least up to the viewpoint of the challenges. For instance, for Industry 4.0 aspects and challenges, the workforce needs to upskill their resources at the minimum level of such requirements. Particularly to the already identified challenges, the input from the worker will have to be improved to find equilibrium. As a result, after considering the eight Industry 4.0 challenges, there are a minimum of requirements from the labor force that we have considered and proposed for balancing wellbeing:

1. **For personalization.** People need to know about and work around data acquisition, data management, data analysis, as well as on interoperability of services and manufacturing.

2. **For resource optimization.** People need to know about and work on the trade-offs between efficiency and productivity, as they are not necessarily always correlated. For instance, efficiency results from keeping the resources working smartly, whereas productivity may step into the pitfall of working the resources a bit too hard.

3. **For flexibility.** People need to know about and work on adaptability, resilience, interdisciplinary knowledge, perspectives, and approaches.

4. **For novel value services.** People need to know about and cultivate creativity and build up personal and grouped innovation, along with customer-service focused.

5. **For high-wage economy.** People need to learn about financial literacy, entrepreneurship, business management, and legal business regulations. In addition, people need to keep themselves upskilled and updated in terms of the rules or changes on the market and the economy.

6. **For real-time reaction.** People need to know about and work around digital network connections, network interactions, and network interoperability.

7. **For life-long inclusion.** People need to learn about broadening their skills and attributes, such as inclusiveness and adaptability, while keeping themselves open and accountable for others.

8. **For work-life balance.** People need to know about and work on values, purpose, and satisfaction for both styles of life, professional and personal, to find a tune between carrying on a service for society and service for themselves.

Considering the above requirement list, it is feasible to assume that the existing labor force still has a wide gap to fill towards such wellbeing standards. Hence, the importance of the two other concept elements, holistic competence and holistic preparation. The conception of Industry 4.0 has facilitated setting such high goals for industry, while it also brought the opportunity to increase the standards of wellbeing for both society and the workforce. The human side of Industry 4.0 needs to work and be supported on enhancing the human capital resources by means of preparation and upskilling. This will help achieve a decent level of wellbeing according to the aforementioned listed points.

The aim behind Human Capital 4.0 is finding and facilitating the right balance between both extremities of the wellbeing seesaw, just as it is depicted in Figure 4.5. Moreover, since the element of wellbeing is not only an end but also works as a means, this version of human capital creates a close resemblance of a sustainable symbiotic relationship between people and industry. This type of relationship is especially beneficial for new foreseeable or unforeseeable challenges throughout the development of Industry 4.0.

Figure 4.5 Human Capital 4.0 fostering wellbeing equilibrium in Industry 4.0

Existing and future challenges have already been set for the new Industrial Revolution; consequently, the existing and future resources need to meet such challenges for achieving genuine wellbeing. Therefore, the aim of this chapter was to introduce the model of HC 4.0, which offers the overall formula and opportunity to respond to Industry 4.0 challenges. All this while achieving workforce wellbeing due to the nature of the HC4.0 approach, a problem-based solution. Moreover, owing to the character of the problem to be solved in the research question number one, the kind of approach taken by HC 4.0 requires it to be an interdisciplinary approach. In turn, the presented model offers the flexibility and interoperability needed to address the problem of wellbeing accordingly.

The following two chapters will elaborate on the content and development of the two other attributes of Human Capital 4.0, the holistic competence and the holistic preparation, respectively.

4.4 Summary

This chapter elaborated in answering research question one. The problem addressed was that although Industry 4.0 has promised human activities would be empowered by state-of-the-art technologies, the extensive practices, pursuits, and efforts behind this have a strong technological drive. This, in turn, has created a misbalance on the human side that Industry 4.0 is supposed to support. Moreover, a vast majority of the current terminologies on this industrial topic are with a technical orientation, i.e. CPPS, CPMT, HCPS, with a minimal number on industrial engineering terminologies with a human or worker perspective, i.e. Operator 4.0. Therefore, it was proposed a term with a clear human-centered approach that could become accountable for people, i.e. workers, in advents and visions of Industry 4.0. The revision of the term 'Human Capital 4.0' seeks adaptation towards the challenges and promises of the existing Industrial Revolution. Furthermore, it pointed out the three important attributes that integrate such a new term.

Human Capital to Human Capital 4.0

This first section generated the updated version of the concept of human capital. In contrast to the traditional view of human capital, a technical-based competence with a job-based preparation, the new view was set for a different approach. A holistic competence, and a holistic preparation and development, were presented as two of the vital other attributes needed for the future of the labor force. Therefore, the proposed version of Human Capital 4.0 was meant to look after the balance between the needs of the demand and the delivery of the offer.

In addition, a key third attribute was added to the formation of the new term, wellbeing. In short, wellbeing had not been considered in the scope of the traditional human capital. The intentional inclusion of this element aimed at fostering the vision of the pioneers and academia on Industry 4.0 people's wellbeing, which was discussed thoroughly in this chapter. Overall, the resulting term Human Capital 4.0 has appealed to the workforce provided with a future-proof set of attributes that will support them coping with the Industry 4.0 paradigm. The resulted term was visualized in Figure 4.1.

Wellbeing into Human Capital 4.0

It was found that the traditional concept of HC hardly mentions or elaborates on the health or wellbeing of employees. Most of those views saw the employee's health as a cost or expenditure. Therefore, the new term Human Capital 4.0 aimed to cover such fine needs by fixing an idea of wellbeing into the vision of human labor. As a result, the proposed term covered the views from both the Industry 4.0 proponents and the academic findings on the acknowledgment and need for meeting welfare among the contemporary challenges impacting the workforce.

The definition of wellbeing the equilibrium between a set of resources versus a set of challenges. These sets can be on different aspects, i.e. psychological, social, physical, etc. Therefore, a person's wellbeing set position would depend on the weight of their resources (physical, social, physiological, etc.) against the weight of their challenges (physical, social, physiological, etc.), as it was represented in Figure 4.3. For this case, it was considered that the eight identified challenges of Industry 4.0 were currently outweighing the existing employees' resources. This imbalance in weights between the two sets (challenges and resources) has made the wellbeing of employees tilt unfavorable, as was depicted in Figure 4.4.

The updated term attempts to achieve a balance between the sets of aspects for Industry 4.0 and those for the workforce. In other words, it supports a more consistent equilibrium of welfare for employees regardless of the challenges of the future. Moreover, it fosters human wellbeing as a norm (as a means and as an end) in the conception of Human Capital 4.0 for foreseeable or unforeseeable challenges, complying with a notion of future-proofing attributes within the term. To this effort, eight requirements of preparedness from the workforce have been proposed to tackle each of the Industry 4.0 challenges identified, as stated in section 4.3.1. However, after looking at the list of requirements, it was easy to perceive a wide gap to fill in from the existing workforce point of view. Therefore, such need brings fort the importance of the other two attributes within the updated term, holistic competence and holistic preparation, which are elaborated in the following chapters.

The aim behind Human Capital 4.0 is to facilitate the right balance between both the human capital resources and the Industry 4.0 challenges, to support the resemblance of what is known as a sustainable symbiotic relationship between people and industry. HC 4.0 stands as a problem-based solution in its nature and an interdisciplinary approach owing to the character of the addressed problem. In turn, it lends itself to the flexibility and interoperability needed to mitigate the workforce wellbeing concern.

Chapter 5

Holistic Competence and Skill Sets for Human Capital 4.0

This chapter elaborates on the competence for Human Capital 4.0 and the workforce in the light of Industry 4.0. It presents and covers a particular set of inclusive and comprehensive competences and skills to consider in the face of existing and future challenges. In other words, this chapter contributes to answering research question number two: "What are the competences and skills required for the new paradigm of Industry 4.0, not only from the technical side but more importantly, from the human side? And how can they be best identified comprehensively in a human-centric way?"

5.1 Introduction

The introduction of Industry 4.0 has brought disruptive thinking in terms of work and job operations. As a result, pondering and wondering about the future competences required for the workforce has become a common interest across different disciplines and organizations. Therefore, this lies in the importance of covering this aspect within the Human Capital 4.0 concept.

Although it notorious the emphasis on the topic of competences and skills in academic papers and public reports from the literature, not enough efforts have been made to embrace this topic comprehensively and inclusively for the human capital of tomorrow. For instance, three recent studies have been done on the competence requirements and skill models for the future of work [87], [89], [90]. However, they keep a simplistic view of the presented models, lacking further information on how the categories in such models affect the workforce in an Industry 4.0 context. Moreover, the approaches in those studies only mentioned generalized classifications, missing the emerging separation of necessary recognized competences nowadays, such as digital or emotional intelligence. For instance, these two competences have been proved to influence work performance [91], [185]. Thus, omitting this type of significant differentiation among workers' competence could make the singular or overall delivery and assessment of skills more difficult.

In this section, we present an attempt to fill such need by identifying and covering the workforce skills as a whole, bringing to the front a holistic yet particular set of comprehensive and inclusive competences to ponder in the vision of Industry 4.0. Moreover, the presented model of competence for HC 4.0 also aims at supporting a better interpretation and application of the needed competences by the following basic principles:

1) Dividing the competence into particular categories or types to make more accessible the classification or assessment of each competence.
2) Using industrial and social standard terms found in the literature to name and allude to the proposed typology for its easier understanding.
3) Exploring and explaining how each competence might support Industry 4.0 endeavors.
4) Explaining similarities or differences among each category, when applicable. For instance, those from technical skills to digital skills.
5) Giving a pool of examples of the most sought skills that the industry and academic literature agreed on.

5.2 Competence Typology for Human Capital 4.0

Competence is the combination of attributes, abilities, skills, knowledge, and experience necessary for performing both job roles and life itself [89]. The aggrupation of competences can be commonly classified into different groups or categories.

This research presents a typology set of seven significant competences that are found to have a substantial impact in the comings and dealings of Industry 4.0. The model comprehends the five most common categories of skills found in the regarded literature: soft, hard, cognitive, emotional, and digital, as discussed in Chapter 2. However, the proposed model also incorporates two emerging competences that are coming to the picture due to fresh disruptive challenges, i.e. Covid 19. These two competences are financial intelligence and spiritual intelligence.

Just as the conception of Industry 4.0 has gathered the utilization of the already existing enabling technologies, the following typology brings together seven vital enabling competences for Human Capital 4.0. Figure 5.1 shows the typology model covering the category cluster and the allusion to each competence.

Figure 5.1 The competence typology included for Human Capital 4.0

The proposed classification already covers and allocates a key named competence-type and two primary skills representing such designated competence and name to help quick recognition. In addition, this classification covers a pool of the 14 most wanted skills resulting from a recent meta-study analysis of future competences in Industry 4.0. Such a study included the results of 2079 enterprises surveys and 150 experts' interviews [90]. Nevertheless, additional skills have also been allocated as examples of the most wanted skills for each type of competence, avoiding repeatability. In addition, the designation complies with the basic principles already mentioned in the chapter introduction.

5.2.1 The Soft Workforce Competence: Adaptable + Social

The so-called soft skills play a key role in the future of jobs, especially those disrupted by the new shift paradigm of Industry 4.0. Mastery of these skills will allow the workforce to exhibit social responsibilities, such as quick social adaptation or cooperation, which can lead to different outcomes, i.e. successful or adverse results.

This type of ability will facilitate the adaptability, interconnectivity, and decentralization of job positions sought by Industry 4.0 in the human capital scenario. In other words, technical attributes that are looked for and applied to Industry 4.0 scenarios, such as decentralization, self-adaptability, or interconnectivity, will become achievable by employees through this type of skill. Moreover, another clear need for this competence type is the perception and value relevance that has been given to 'multicultural collaboration' dexterity for future networks of intercultural organizations [186]. For it is becoming more common that international members comprise today's companies.

The soft workforce, which can also be referred to as the adaptable social worker, alludes to the most common sought-after pool of soft skills for the future. The collection of these skills is formed by: teamwork/cooperation, willingness to learn, effective communication, intercultural awareness, negotiation, flexibility/adaptability, and veracity [19], [90], [94], [187], [188].

5.2.2 The Hard Workforce Competence: Technical + Dexterous

This type of competence will highly impact operations and jobs during Industry 4.0 since many disciplines are emerging together. Both knowledge and activities are merging into the interoperability and integration of the physical and digital world, a defining characteristic of Industry 4.0. Therefore, no surprise should arise when many of the new technical or hard skills for Industry 4.0 may seem to fall into another category at the same time, i.e. digital. However, it is important to notice the difference between these two types of classes. For instance, 'programming' can be both a hard and a digital skill simultaneously, but 'surfing the network' can be just a digital skill without necessarily being a technical skill requested for a job. It would be safe to assume that in the case of 'programming', and those similar mixed 'hard-digital' skills, will involve activities and competences that invite for the interdisciplinary approach of the physical and digital world so much required for Industry 4.0

The hard workforce, which can also be seen as the dexterous technical worker, should cope with the most discussed pool of technical skills for future jobs. The collection of these skills is covered by: industrial organization, industrial processes, understanding of standards, problem-solving techniques, designing with software, human-machine knowledge and interactions, digital network settings, digital security, and programming [19], [90], [130], [145].

5.2.3 The Cognitive Workforce Competence: Intellectual + Analytical

As the level of complexity increases in job systems and activities, similarly, the importance of IQ increases. This is an established correlation between the two [97]. In this respect, the future of jobs during Industry 4.0 will benefit from this type of competence since integrating new concepts and technologies is brewing complex interconnected networks and systems, i.e. CPS's. Moreover, human labor will have to learn how to use and interact with tools that will include new software (i.e. the cloud, coding programs, systems, platforms) and new hardware (i.e. mobile devices, machines, equipment). This will help build the digital integration into the Industry 4.0 infrastructure. Regardless of technological efforts developed to support the human adoption of new systems or technology, humans still need to keep learning and updating cognitively. Moreover, the development of cognitive skills will continue as a requirement for the workforce because these support the self-autonomy in people, which happens to be another requirement for Industry 4.0 systems and workforce.

The cognitive workforce, which can also be alluded to as the intellectual, analytical worker, must integrate a pool of the most relevant cognitive abilities for the future. Three aspects form the collection of this type of competence. Aspect 1 is verbal aptitude, including vocabulary, spelling, and reading skills. Aspect 2 is numerical aptitude, which can include mathematical and arithmetical skills. Aspect 3 is spatial aptitude, which can consist of coordination, memory, decision-making, problem-solving thinking, abstract reasoning, and analytical thinking skills [90], [189], [190].

5.2.4 The Emotional Workforce Competence: Self-aware + Empathetic

If appropriately addressed, this type of competence should provide to the new job roles a smooth transition from existing business models into new Industry 4.0 business models. EQ in future jobs may assist with possible answers to the different challenges such as stress, emotional fatigue, and even work-life balance that are part of Industry 4.0 circumstances. In addition, considering and leveraging EQ can potentially support the drive and motivation in employees to positively influence existing challenges. For instance, the concern of the demographic challenge of having an aging population in specific locations could find an answer by lifting the spirit of senior employees, persuading, and inviting them to stay for more extended periods in their career lives. Moreover, another practical application of this type of competence might be a response to tackle the workload and anxiety sensations recurrently reported from human-robot collaboration practitioners [191].

The emotional workforce, which can also be referred to as the self-aware, empathetic worker, should embody the pool of the most commented emotional intelligence skills. The summary of this collection of skills is covered in two levels. The first level is the self-awareness & self-management level, which considers the skills of emotional self-awareness, emotional self-control, self-adaptability/flexibility, achievement orientation (self-motivation), and positive outlook. The second level is the social-awareness & social-management level, which covers the skills of empathy, organizational awareness, situational awareness, influencing (i.e. teaching), and conflict management [146], [192].

5.2.5 The Digital Workforce Competence: Digital Literate + Digital Interactive

The impact of the so-called digital skills in today's jobs is absolute, especially for Industry 4.0. The elements of the digital world make the bloodstream for the whole concept of Industry 4.0 itself. Therefore, the learning and mastery of this type of competence could not be an option for the labor force, but rather it already represents an inherent set of skills that require rapid adaptation. The period for Industry 4.0 is just beginning, and it may be safe to assume that this new digital era is here to stay for good. Hence, the workforce will be compelled to adopt this competence and its different levels of depth. With no surprise, this digital competence has likely received the highest amount of attention and effort for understanding and application, as pointed out in the literature review section.

The digital workforce, which can also be seen as the digital literate interactive worker, should comply with those skills in the pool of the most wanted at a professional level. The list of digital skills that keeps being constant for organizations is integrated by: programming/coding, cybersecurity, digital networks, cloud computing, creation and management of databases, web development, and also the management of Industry 4.0 technologies (i.e. IoT, big data analytics, 3D printing, simulation, augmented and virtual reality) [90], [99], [130], [187], [193].

It is worth noting that most of these skills could also fit under the type of hard or technical skills since such skills are required to perform a job role. This is due to the same mixture of interdisciplinary skills mentioned before.

5.2.6 The Spiritual Workforce Competence: Innovative + Purposeful

Among all competences, probably this type of competence is one of the most relevant. SQ not only provides the competence for better management of the skills from EQ and IQ, but it is the competence where a boost of creativity and innovation can happen. In other words, the spiritual intelligence output can work as the answer to many of the challenges on the shoulders of the Industry 4.0 workforce.

Part of the goals of Industry 4.0 is the transition towards new innovative business models and novel means of the economy [5], which pushes people (i.e. entrepreneurs, workers) to exhibit creativity, innovation, and resourcefulness at some stage. Enhancing SQ might support stakeholders not only to spring the invention required for companies, but it may aid towards more inclusive, empathetic, purposeful leaders and organizations with global solutions. Moreover, people working under Industry 4.0 can be seen as direct or indirect part-takers to the recent UN sustainable development goals (SDG). The 17 SDGs represent international cooperation based on universal principles to promote the development of a sustainable world through inter-governmental agreements [115]. Therefore, the essence of SQ in the workforce will positively influence both leaders and workers in realizing and exercising labor collaboration in a more cohesive, ethical, meaningful, and integrative way. This, in turn, will foster benefits like long-term labor relationships as well as win-win situations for stakeholders inside and outside the business.

The spiritual workforce, which can also be perceived as the innovative purposeful worker, can stand out to integrate the most known spiritual skills and attributes. The list for these traits is: compassion/generosity, creativity/ innovation, trust/accountability, wisdom, gratitude, purpose/meaning, value-oriented, inclusiveness/integrity, leadership/mentoring, legacy/transcendence [113], [115], [118], [194], [195].

5.2.7 The Financial Workforce Competence: Financial Literate + Financial Planner

In todays' technological and economic disruptions, especially after Covid 19, the OECD (Organization for Economic Cooperation and Development) and the World Economic Forum (WEF) have recommended that financial literacy needs to be among the 21st-century skills [196]–[198]. During Industry 4.0, operations and services working under a digital economy will be further consolidated, which means that financial intelligence (FQ) as competence will become a necessary skill at the personal level and the professional one. The potential benefits from developing this competence in alignment with other competences, such as SQ or EQ, can positively impact the worker, the company, and the community.

Unfortunately, financial stress has been repeatedly reported to affect the performance of students and the productivity of workers [199]–[201]. This is due to the lack of focus and drive that comes from poor financial choices and the pressure on financial stressors, i.e. expenses and debts. Fortunately, Industry 4.0 encourages the balance and wellbeing of citizens and employees, as well as that of companies and employers. As a result, the financial balance and wellbeing of people should also be included in this scope. In fact, without considering this factor in the equation of Industry 4.0, hardly such ideal for a wellness state on the workforce, or businesses, would be possible to achieve.

Developing this competence can support employees and employers equally, particularly in acting appropriately and being prepared during crises. For instance, a review reports that after Covid 19, many countries and world banks, such as Germany, France, Italy, the UK, the Bank of England, the US Federal Reserve, and Japan injected considerable sums of money in the forms of loans and bonds to aid industries and the marker [202]. Such supporting programs and opportunities can be better seized and utilized by individuals who might have a higher level of FQ, whether they are entrepreneurs, freelancers, employees, or owners.

Moreover, owing to the impact of Covid 19, manufacturing companies have realized that they need to reorganize their workplace, which is a big part that requires entrepreneurship and preparedness from all employees [203]. This shift in upskilling and mindset to the workforce will necessarily lead to better awareness and training at the financial competence. This change will require employees to become more independent at making financial decisions, which can impact the company's economy directly or indirectly, i.e. consuming, producing, purchasing, selling, etc. Furthermore, according to experts, financial intelligence in individuals benefits the company in three main ways [121]. In one way, it allows balance throughout the organization by having every department manager working on and understanding their numbers. In a second way, it helps financial analysis among managers to provide a window into the future and make smarter, informed choices. Lastly, it drives everyone to work in alignment with strategies and goals to achieve healthy profitability and cash flow due to everyone understanding the financial side of the business.

The financial workforce, which can also be seen as the financial literate planner worker, will fit the most common financial skills pool. The primary collection of these skills is: cost evaluating for loans, financial planning, money-saving, budgeting, negotiating for return on investment (ROI), paying and working with debt, investing, identifying assets and liabilities, generating cash-flow, analyzing balance sheet vs. income statement [121], [122], [204]–[207].

5.3 The Skill Set Table for Human Capital 4.0

The following table 5.1 summarizes the major characteristics that have been considered for each competence in the typology. The first column gives the known names for each type of competence. According to the competence, the second column provides the main characteristic for the workforce designation with a human-centered identification. The third column comprises the most characteristic and sought-after skills, or traits, that fit within each kind of competence. The last two columns cover two aspects of Industry 4.0 interest. The first one is the benefit on the workforce, where the given competence and skills can enhance the development of the labor force for some of the proposed requirements mentioned about wellbeing, in section 4.3.1. The second one is the benefit of the challenges, where the given competence and skills can diminish the undesired effects on some of the identified contemporary challenges for the industry, in section 2.3.

This section shows the overview list of the competence required for supporting Human Capital 4.0 amidst Industry 4.0 development. This proposed collection of skills and attributes is considered to have the most beneficial impact for people (employees and employers) during the coming years of Industry 4.0. However, such collection of skills and attributes in column three is not fixed to a number, but rather this collection within each competence could expand according to the needs.

It is worth noticing that some of these competences and skills may seem similar or duplicated among them. However, as already mentioned, this is due to the interoperability that one competence might have with another in some cases. Therefore, rather than being contradictory to each other, some of them have become co-dependent or interoperable to others. For instance, as explained in the literature review, some activities that require skills from the IQ or EQ competence can also be influenced by the SQ competence. Similarly, some soft skills could find influenced by the interplay between spiritual, emotional, and cognitive intelligence.

Table 5.1 The holistic overview of Human Capital 4.0 competences and skills

<table>
<tr><th colspan="5">Human Capital 4.0 Competence</th></tr>
<tr><th rowspan="2">Competence</th><th rowspan="2">Workforce key characteristic</th><th rowspan="2">Main skills/attributes</th><th colspan="2">Benefits onto Industry 4.0</th></tr>
<tr><th>To the workforce</th><th>To the challenges</th></tr>
<tr><td>Soft (Social)</td><td>The soft workforce
or
The adaptable social worker</td><td>Teamwork - Cooperation
Effective Communication
Intercultural awareness
Negotiation
Adaptability - Flexibility
Willingness to learn (from others)
Veracity</td><td>Maximizes development for the requirements on:

Flexibility,
Life-long inclusion,
&
Work-life balance.</td><td>Minimizes the negative effects on:

The skill gap,
Aging population,
&
VUCA</td></tr>
<tr><td>Hard (Technical)</td><td>The hard workforce
or
The technical dexterous worker</td><td>Industrial organisation
Industrial processes
Understanding of standards
Problem-solving techniques
Designing with software
Human-machine interface knowledge
Digital network settings
Digital security
Programming</td><td>Maximizes development for the requirements on:

Personalization,
Resource optimization,
&
Real-time reaction.</td><td>Minimizes the negative effects on:

The skill gap,
&
VUCA</td></tr>
<tr><td>Cognitive or intelligence quotient (IQ)</td><td>The cognitive workforce
or
The intellectual analytical worker</td><td>Verbal aptitude:
Vocabulary, Spelling, Reading

Numercial aptitude:
Mathematics, Arithmetics

Spatial aptitude:
Coordination, Memory, Problem-solving thinking, Abstract reasoning, Analytical thinking</td><td>Maximizes development for the requirements on:

Personalization,
Resource optimization,
Real-time reaction,
Novel value services
&
Real-time reaction</td><td>Minimizes the negative effects on:

VUCA</td></tr>
<tr><td>Emotional Intelligence (EI) or emotional quotient (EQ)</td><td>The emotional workforce
or
The self-aware empathetic worker</td><td>Own awareness & management:
Emotional self-awareness and emotional self-control, Self-flexibility, Self-motivation, Positive outlook

Social awareness & management:
Empathy, Organizational awareness, Situational awareness, Influencing (i.e.teaching), Conflict management</td><td>Maximizes development for the requirements on:

Flexibility,
Real-time reaction,
Life-long inclusion
&
Work-life balance</td><td>Minimizes the negative effects on:

The skill gap,
Aging population,
Compromised wellbeing,
&
VUCA</td></tr>
<tr><td>Digital</td><td>The digital workforce
or
The digital literate interactive worker</td><td>Programming - Coding
Cybersecurity
Digital networks
Cloud computing
Database management
Web development
Management of Industry 4.0-technologies</td><td>Maximizes development for the requirements on:

Personalization,
Real-time reaction,
&
Life-long inclusion</td><td>Minimizes the negative effects on:

The skill gap,
Aging population,
&
VUCA</td></tr>
</table>

Human Capital 4.0 Competence				
Competence	**Workforce key characteristic**	**Main skills/attributes**	**Benefits onto Industry 4.0**	
			To the workforce	**To the challenges**
Spiritual Intelligence (SI) or Spiritual Quotient (SQ)	The spiritual workforce or The innovative purposeful worker	Compassion - Generosity Creativity - Innovation Trust - Accountability Wisdom Gratitude Purpose-drive - Meaning Value-oriented Inclusiveness - Integrity Leadership - Mentoring Legacy - Transcendence	Maximizes development for the requirements on: Flexibility, Novel value services, High-wage economy, Life-long inclusion & Work-life balance	Minimizes the negative effects on: The skill gap, Aging population, & Compromised wellbeing
Financial Intelligence (FI) or Financial Quotient (FQ)	The financial workforce or The financial literate planner worker	Money saving Cost evaluations for loans Financial planning Budgeting Negotiating for return on investment Investing Paying and working with debt Identifying assets and liabilities Generating cash-flow Analysing balance sheet vs Income statement	Maximizes development for the requirements on: Resource optimization, High-wage economy, & Work-life balance	Minimizes the negative effects on: The skill gap, Compromised wellbeing, & VUCA

The table of Human Capital 4.0 competences could be used as a reference by the Human Resource (HR) department in manufacturing firms and businesses seeking their way to Industry 4.0. For instance, HR could implement such found competences and skills in the table into an upskilling matrix for their workers. Such matrix would contain columns and rows including the competences, the skills/attributes, the worker's name and position, the ways of measurement and progress for the skills, along with the followed up of training for the workers. At the end, the table could be adapted into such matrix to display the needs and progress on training for such competences accordingly for each worker inside the business.

Once the holistic model for Industry 4.0 competence has been identified and explained, it is now necessary to seek a holistic model that will help deliver such skills. The next chapter addresses and elaborates on such a challenging task.

5.4 Summary

This chapter contributed to answering research question number two. The problem addressed was that despite efforts on competence or skills for the future of work, most of the cited efforts miss embracing this topic comprehensively and inclusively for the human capital of tomorrow. They tend to lack further depth and analysis in their views on how their proposed models may affect the workforce in an Industry 4.0 context or contemporary challenges. In addition, there is a need to emphasize the emerging of new skills on the horizon, i.e. spiritual intelligence, which also requires an understandable analysis in the integration of the competences. Consequently, the aim was to propose an integrated competence that could fit in the scope of Human Capital 4.0 to better upskill and support the future of labor in a more holistic yet particular and comprehensive manner.

In general, seven competences were identified and put together to form the typology. These competences were soft, hard, cognitive (IQ), emotional (EQ), digital, spiritual (SQ), and financial (FQ). Each of these competences comprised a cluster of the most common and wanted skills found in the literature from both perspectives, academics, and industrials.

The soft workforce competence. This group was considered because it will support the labor force for the adaptability, interconnectivity, and decentralization of job positions sought by Industry 4.0. Mastery of these skills will allow the workforce to exhibit the opportunity for social responsibilities, such as quick social adaptation. For instance, cooperation, willingness to learn, effective communication, intercultural awareness, negotiation, adaptability, veracity.

The hard workforce competence. This category was included since many disciplines are merging nowadays, and this integration will highly impact people during Industry 4.0. The activities and knowledge required for this new age are becoming integrated into the physical and digital world. For instance, industrial organization, industrial processes, understanding of standards, problem-solving techniques, designing with software, human-machine interactions, digital network settings, digital security, and programming.

The cognitive workforce competence. This cluster was incorporated because it is known that the need for IQ skills increases when a person needs to handle complex systems. In this respect, the workforce in Industry 4.0 will benefit from this type of competence as complexity on interconnected networks and systems, i.e. CPS, becomes more pervasive in job places. For instance, the verbal aptitude (vocabulary, spelling, and reading skills), the numerical aptitude (mathematical and arithmetical skills), and the spatial aptitude (coordination, memory, decision-making, problem-solving thinking, abstract reasoning, and analytical thinking skills).

The emotional workforce competence. This group was considered because EQ in future jobs may well assist with possible answers to the different challenges such as stress, emotional fatigue, and even work-life balance that are part of Industry 4.0 circumstances. In addition, leveraging on EQ might potentially support the drive and motivation in employees to tackle contemporary challenges, such as the concern of the demographic changes or the workload and anxiety sensations that have been recurrently reported. Some examples are emotional self-awareness, emotional self-control, self-adaptability, achievement orientation, positive outlook.

The digital workforce competence. This category was included because the elements of the digital world make the bloodstream for the whole concept of Industry 4.0, and it will be absolutely the impact of these skills for the future. Therefore, mastering this competence already represents a set of skills that require rapid adaptation. The list of the most common skills for this category is programming, cybersecurity, digital networks, cloud computing, creating and managing databases, and web development.

The spiritual workforce competence. This cluster was incorporated because part of the goals in Industry 4.0 is the transition towards new innovative business models, which also forces entrepreneurs and workers to exhibit creativity and innovation for accomplishing such goals. SQ can support people to spring the innovation required for companies and aid leaders in becoming more inclusive, compassionate, and purposeful with their objectives and solutions. Some of this cluster's most valuable skills or traits are compassion, creativity, trust, wisdom, gratitude, purpose, value-oriented, inclusiveness, leadership, and legacy.

The financial workforce competence. This last group was considered because FQ has been recognized and encouraged by the OECD and the WEF after the recent disruptive events due to Covid-19. This made financial intelligence a competence that will become a necessary skill at the personal and professional levels. The financial distress experienced by different groups of people made it necessary for this skill to be included in a wellbeing plan. In addition, entrepreneurship and preparedness from all employees can only be at their best if FQ skills are considered. Some examples of these skills are financial planning, money-saving, budgeting, negotiating for return on investment, paying and working with debt, investing.

Overall, the resulting typology on competences and skills was synthesized in Table 5.1. The presented list of competences was developed for supporting Human Capital 4.0 amidst Industry 4.0 development and implementation. Such a selected collection of skills and attributes was considered to have the most positive impact on employees and employers during so-called disruptions.

Chapter 6

Holistic Preparation and Development of Human Capital 4.0

If the competence of the Human Capital 4.0 needs to evolve holistically, it is also relevant to consider how this new upskilling can be best allocated and applied to facilitate human preparation and development of such competence. This chapter elaborates on a novel model to assist the presentation and conveyance of the competences found in the previous chapter. In addition, it also works on a framework for an application of the proposed model as a tool to support competence assessment in terms of contemporary challenges affecting the workforce. In this sense, this chapter contributes to answering the third research question: "What is the human-centered model that can best support the allocation of a holistic competence for human capital preparation and development? And what contextual method can be developed from such model with a challenge-based perspective?"

6.1 Introduction

Considerable efforts have been made on the technical side of Industry 4.0 in discussing, developing, and applying tools, technologies, or architectures for mechanical implementations. However, the efforts on the human side and workforce preparation of Industry 4.0 require further attention and action. In today's fast-paced industrial era, social resources, such as employees, are required to adopt and adapt at the same pace as technology. Nevertheless, it has been shown that the lack of preparedness and qualification of the existing workforce is one of the three top challenges that companies face in the paths to embrace Industry 4.0 [208]. As a result, training and continuous development of the workforce is one of the priority areas for research in academia and industry.

The delivery and upskilling of adequate competences are required for students, employees, and even employers, who might want to follow an Industry 4.0 criterion for businesses, i.e. value creation, resource optimization, and future sustainability. This new holistic type of criterion invites novel opportunities and ways of tackling the problem of preparing the workforce.

This section aims to provide a new perspective and approach to the issue of preparedness that will support the development and upskilling of Human Capital 4.0. The inspiration for this perspective came from the consideration and analysis of the existing challenges for the workforce against the breakdown of recent educational efforts found for future employees. In general, according to the literature, it can be noticed that the current efforts on preparation and training development, although considerable, are not robust and compatible enough to address the existing challenges in the workforce. For instance, most of those plans and programs for future labor force preparedness tend to be technology-based (i.e. programming) or subject-based (i.e. mathematics), which keeps an only overall technical competence for human capital. Moreover, it can be perceived that the perspectives behind such efforts are job-based approaches (conservative) rather than challenge-based (disruptive). This, in turn, could lead to the development of application methods that maintain a single-sided perspective (i.e. technology-centric, subject-based), instead of developing strategies with multi-sided perspectives (i.e. human-centric, problem-based).

Therefore, to aid this need, a novel architecture has been proposed. The architecture displays a human-centric approach in its development, along with a challenge-based perspective as a method of application, to offer a disruptive holistic solution.

6.2 The Reference Human-centric Architecture Model (RHAM)

Industry 4.0 has set foot as the next Industrial Revolution, and this new milestone has brought demanding challenges to the labor workforce. Therefore, it would seem productively ideal and fair to face those challenges from a human perspective. As pointed out, most of the emerging endeavors to educate or prepare the future generations of human capital are not very complimentary to address some of the existing challenges. For instance, most preparation efforts, i.e. educational plans or training programs, tend to be technology-based, which keeps a prevailing technical viewpoint. Nevertheless, if the identified challenges were also to be covered and addressed from a skill-based point of view, they would require a more holistic competence and perspective. Thus, this brings an opportunity for a new way to support and enhance the preparation approach for potential workers.

This section elaborates a human-based model, where one of its main pillars is the competence described in the previous chapter. This new architecture was inspired by the established smart grid architecture model for supporting Industry 4.0 production systems, RAMI4.0. However, the proposed architecture aims to support the study and development of more robust upskilling means and tools to prepare the workforce by visualizing and adapting a core competence scenario. As a result, the recommended architecture is to provide a novel approach that is holistic and inclusive in terms of skills. Still, it also offers better flexibility and adaptability to address Industry 4.0 challenges.

Only one recent study was found to present a similar approach for the learning and delivery of some Industry 4.0 competences. The study displayed a case-based approach for supporting the future of production, using the RAMI4.0 model as a reference [209]. However, such effort is solely focused on production processes scenarios and with a limited number of skills into consideration. In other words, the aim and scope of its applicability are restricted to only specific production interests of Industry 4.0, leaving out the bigger picture of additional challenges for Industry 4.0 apart from production.

6.2.1 Smart Models as A Base Reference

The proposed model, RHAM, originates from a Smart Grid Architecture Model (SGAM) that was developed to manage and illustrate complex distributed systems. The term 'Smart Grid' has been used in this case to allude to a true System-of-Systems, which is the representation of a distributed system with certain complexity [210]. The SGAM was a collaborative effort from members of the CEN, ETSI, and CELENEC along with domain models already established from the NIST (National Institute of Standards and Technology), IEC (International Electro-technical Commission), and TOGAF (The Open Group Architecture Framework) [211], [212]. In Figure 6.1, there are three main dimensions, namely domains, zones, and interoperable layers, which are the concepts to express the different axes on the architecture model. The idea is that the intersection among these dimensions will support the assurance of traceability between the architecture components. The SGAM model can be appreciated as a high-level three-dimensional concept.

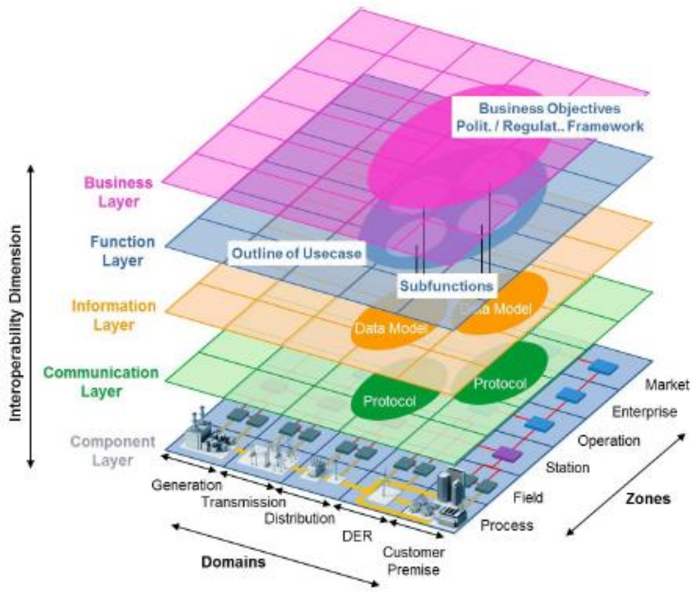


Figure 6.1 The original Smart Grid Architecture Model (SGAM) [210]

Major architectural models have been developed in different disciplines using the SGAM concept. For instance, the Smart City Infrastructure Architecture Model (SCIAM), the Electric Mobility Architecture Model (EMAM), the Home and Building Architecture Model (HBAM), and the Reference Architecture Model for Industry 4.0 (RAMI 4.0), which is considered the most sophisticated one recently developed.

RAMI 4.0 was created by the Chinese-German collaborative group (Working Group) in 2015 [213]. This architecture displays a structure of standards for Industry 4.0 production applications, and it is divided into three dimensions to simplify the system. As noticed in Figure 6.2, the six layers on the vertical axis represent the operational formation within a company. The life cycle & value stream axis represents the stages of product development. The hierarchy level axis represents the distribution of elements and responsibilities of the company's departments.

Part of the primary goal of RAMI 4.0 is to make sure that all those who participate and are involved in the Industry 4.0 integration and implementation understand each other by breaking down a complex system into simpler clusters [214].

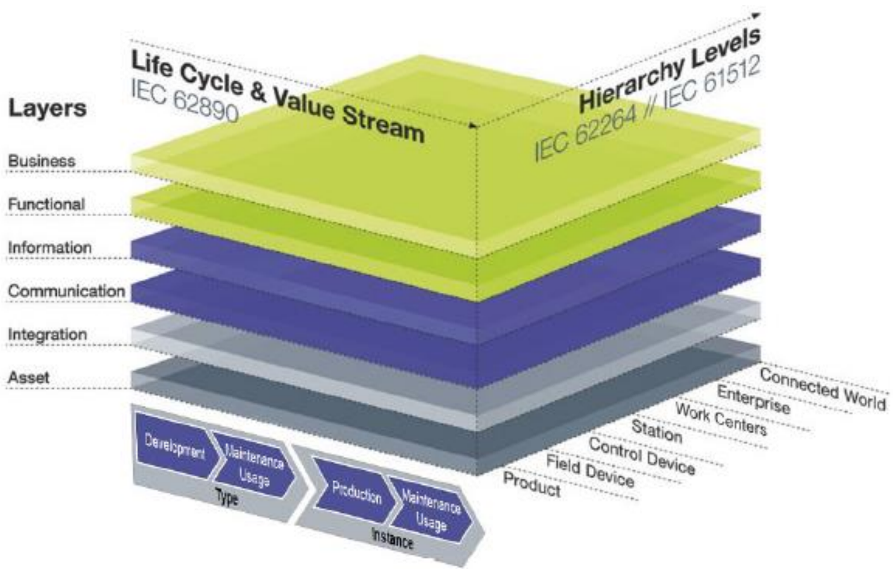


Figure 6.2 The Reference Architecture Model for Industry 4.0 (RAMI 4.0)

6.2.2 RHAM: A Competence-based Model for Human Capital 4.0

As found before, most conventional efforts for future workforce preparation are technology-based (i.e. programming) or subject-based (i.e. maths), which can be translated into hard or cognitive skills primarily. However, this type of approach and competence is limited, or insufficient, to cover and provide development support for a bigger context of human needs, such as Industry 4.0 contemporary challenges.

Moreover, such efforts providing only hard or cognitive skill proficiency may be well described as technological-centric approaches rather than human-centric. Such a technology-driven approach is missing further needs of the labor force into consideration. According to a recent study on assessing and building skills for employees, there is a highlighted need to consider all the worker needs when planning for training and create 'worker-centric' solutions to convey life-long development [215].

In this case, to make our approach human-centered, we have considered keeping the workforce competence typology as the principal constant axis in our model. As a result, the Reference Human-centric Architecture Model (RHAM) can also be seen as the competence-based approach to encourage, guide, and trace human capital preparation and upskilling.

Figure 6.3 displays the proposed architecture RHAM, which is integrated by three main elements across the three axes: the competence layers, the lifetime cycles & value stream, and the ecosystem levels. The purpose of these three axes is to map key aspects and characteristics of human preparation and development, as these three conform to integral elements in a person's life.

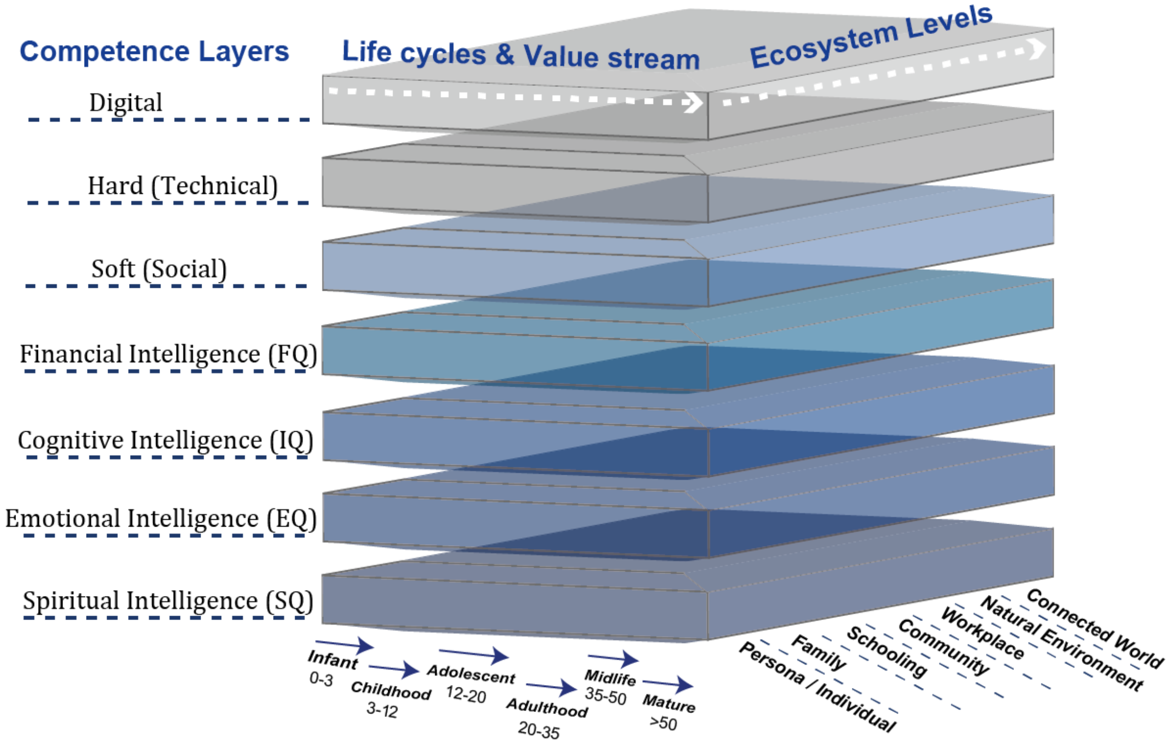


Figure 6.3 The Reference Human-centric Architecture Model (RHAM)

6.2.2.1 The 3D Axes Integration

The 3D axes integration for the RHAM elements is comprised as follows:

The competence layers. This axis is formed by collecting the competences in the Human Capital 4.0 typology. The competences have been ordered according to the depth at which they function to serve the person. In other words, they go from the innermost level (A) to the most superficial level (C). According to their characteristics, the competences were divided into three primary functional levels, A, B, and C. Figure 6.4 shows the level representation at which each of the competences is considered to aid a person in carrying out their activities.

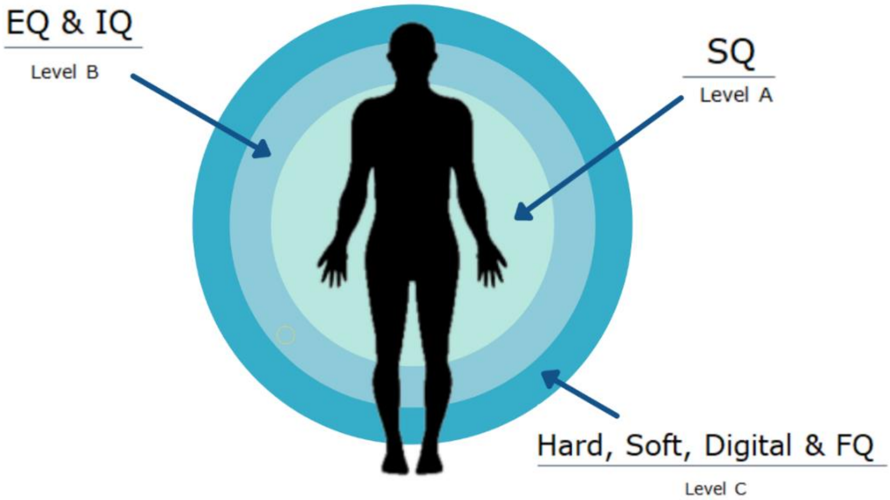


Figure 6.4 The competence axis distribution by functional levels

- *Level A*. The essential characteristic of this level is to be the deepest layer at which a competence or skill can present its functionality. Therefore, the selected competence here should suffice the quality of being paramount and total independent from other competences. According to what has been found in the literature, it can be assumed that the competence of spiritual intelligence (SQ) is the only one that fits in this level since it does not require predecessor competences for its action. Instead, it is understood that other competences rely on SQ for their better discernment and action. In short, SQ is the core competence that offers the capacity to recognize that oneself is conscious of things, and therefore one can control internal thinking and processing.

- *Level B.* This is the middle layer at which competences can present their functionality. The competences selected here are characterized by being dependent on a deeper level and required for the next level. Similarly, according to the literature, it is assumed that emotional intelligence (EQ) and cognitive intelligence (IQ) fall at this level because they both are dependent on SQ, while at the same time, they will influence the application of the other competences. In short, EQ and IQ help to acknowledge thoughts and emotions in a person, which can be managed effectively by SQ. This, in return, supports the capacity for learning other skills or taking external action in other activities.

- *Level C.* This level is the outer layer where the rest of the competences can fit. The competences selected in this level are characterized by being totally dependent on the more internal competences. Moreover, these outer skills are also identified by providing the capacity to interact with the external environment (outside the person), through outputs or actions. Either the person needs to interact with another person or carry out a job or task. Therefore, soft, hard, digital, and financial intelligence (FQ) can be placed at this level according to what they represent in supporting a person. For instance, soft competence, also called social, supports the interaction with other people. Hard competence, also called technical, supports performing a job activity. Digital competence supports the interaction with digital devices. Lastly, the FQ competence supports activities related to managing financial wealth or money.

The lifetime cycles & value stream. This axis is formed by considering the most traditional stages of life for a person during a lifetime. It also considers the continuity of value a person keeps creating and accumulating throughout their life (i.e. experience, accomplishments, knowledge, etc.). Therefore, it is assumed that the impact and value of a person increase along their lifetime.

In this case, since the topic on stages of life is broad and there is no consensus among the literature about the number of life stages, an analysis and average among three sources was considered [216]–[218]. Therefore, the six main stages of life are Infancy (from zero to 3 years old), Childhood (from three to 12 years old), Adolescence (from 12 to 20 years old), Early adulthood (from 20 to 35 years old), Midlife (from 35 to 50 years old), and Mature adulthood (with more than 50 years old). Figure 6.5 illustrates the distribution and representation of this axis.

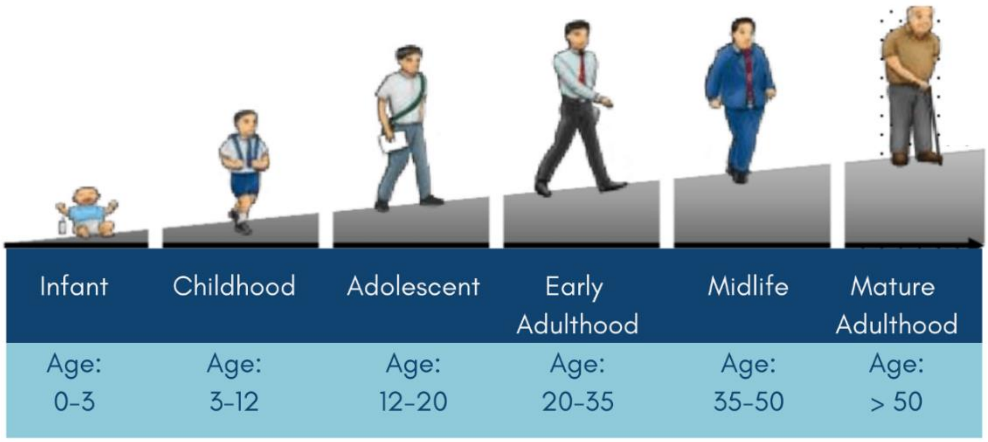


Figure 6.5 The lifetime cycles & value stream axis distribution by stages of life

The ecosystem levels. This axis conforms to the overall collection of ecosystems at which a person can find themselves in any given human situation. Each ecosystem level can involve different conditions that are characteristic to a particular level, i.e. the 'family level' can include activities or interactions with parents and siblings. Similarly, as the ecosystem level changes for different situations, the actions or responsibilities of the person will vary from one to the other. For instance, at the 'family level,' the person may need to cooperate with household chores, whereas at the 'workplace level', the person may need to operate with robots. In other words, this axis represents the different areas at which the person will need to multitask various activities according to the situation or interaction to be analyzed.

For this case, seven well-known ecosystems or environments for human interaction were selected. The 'persona ecosystem' comprehends any activity or interaction at the person's individual level. The 'family ecosystem' involves any activity or interaction at the household level. The 'schooling ecosystem' includes any activity or interaction at the educational place. The 'community ecosystem' covers any activity or interaction in the social surroundings. The 'workplace ecosystem' involves any activity or interaction at the job place. The 'natural environment ecosystem' included any activity or interaction at the nature level. The 'connected world ecosystem' covers any activity or interaction at the national or international level. Figure 6.6 shows the seven common scenarios where a person can interact within the human ecosystem during a lifetime.

Figure 6.6 The ecosystem axis distribution by spheres of interaction

6.3 RHAM: A Tool for Addressing Contemporary Challenges Impacting the Workforce

This section presents an assessment method as an example of how the proposed RHAM model can work as a tool and find application in context to some of the aforementioned challenges. We have developed this framework based on an approach elaborated in another study by W. Patrick Neumann et al. Such a study formulated a form to systematically consider human factor (HF) conceptualizations [161]. However, adequate amendments were required to suit the peculiar concepts, needs, and outputs sought by the RHAM model.

As a result, a systematic framework for assessing skill requirements was created to explore the RHAM model as a tool to tackle existing challenges affecting the workforce. This framework is elaborated in a form or template, which is divided into five main steps: 1) Identification of the problem, 2) Identification of the person, 3) Identification of the scenario and the skill, 4) Assessment of the situation, 5) Outcome of the analysis.

- ***Step one***, *identification of the challenge.* This step refers to identifying the issue or challenge that wants to be addressed or solved. A question such as “what is the challenge that best suits this problem or situation?” is suggested to help fill in this step. In this case, the challenge should be picked from a collection of challenges involving Industry 4.0, which are already known.

- ***Step two**, identification of the person.* In this step, details such as ‘human type’ and ‘age range’ of the impacted or affected person are submitted. A question such as “according to the situation, what is the best type to describe the person, and what is his/her age range?” is suggested to help fill in this step. In this case, this information would be obtained from the information on the lifetime cycles & value stream axis shown on the RHAM model.

- ***Step three**, identification of the scenario and the skill.* This step relates to identifying two specific needs of the situation for the assessment, such as the place or environment being impacted and the competence or abilities that require improvement. Questions such as “what is the affected or involved ecosystem?” and “what is the skill/competence needed or recommended for improving the situation?” are suggested for helping to fill in this step. This information is taken from the competence and ecosystem-level axes shown on the RHAM model.

- ***Step four**, assessment of the situation.* An assessment of the wanted skills is carried out according to the person’s needs, which should allow exploring the requirements for a possible training solution. Here, reasons and further context as to why or how the required skills are needed can be collected for the assessment. For instance, it is essential to explain how a specific skill, or the lack of it, affects the person’s performance, either on themselves or around the area. A key aspect to consider for this assessment is explaining from a skill-based perspective and the person’s perspective to provide the reasons. Therefore, a question such as “From the skills on step3 perspective, what are the reasons for the person to improve such skills?” is suggested to help fill in this step.

- ***Step five**, outcome of the analysis.* This step concerns the resolution from the given assessment. After considering the different needs exposed in the previous step, the data collected from the initial stages, an outcome can be delivered to ensure all the expressed needs were covered. Like step4, the resolution here needs to be presented from a skill-based perspective, using the order or arrangement from the previous step. A question such as "according to the skills mentioned in step4, what is the best-resolved program or teaching action for this case?". It is important to heed that the line of action to solve the skill issue will depend on the assessor, company, or institution's experience and capabilities who do and give the assessment resolution. Hence, this leaves open the way for upskilling accordingly.

Table 6.1 represents the overall view of the assessment framework created. Section 1 requests the challenge's name and its designated number, i.e. 'the skill gap, no. 1'. Section 2 asks the human type and age range assigned to the person under assessment, i.e. 'fresh graduate, adulthood (20-35)'. This section is filled with the lifetime cycles & value stream axis established on the RHAM model. Section 3 requests the name of the ecosystem, i.e. 'workplace' and the skills/competences deemed needed from the situation, i.e. 'teamwork skill = soft competence'. This section is filled from the ecosystem levels axis and the competence layers axis, respectively, as shown on the RHAM model. Section 4 seeks the reasons and the context behind the request for the skills needed or wanted. This section's answers must be elaborated from a skill-needed perspective, using the listed skills in section 3. Lastly, section 5 asks for the resolved outcome from the assessment. This section also must be answered according to the perspective of skills mentioned in section 4.

Table 6.1 Skill-requirement assessing framework based on the RHAM model

RHAM-based Assessment Framework for Industry 4.0 Challenges						
(1)		(2)		(3)		
Challenge number	Challenge type	Human type	Age range	Involved Ecosystem level	Wanted skills	Type of competence
(4) Situation assessment (from the skill-based and person's perspectives)						
From the skills listed on step3, what are the reasons for the person to improve such skills?						
Is there need for considering further skills? Which ones? Why?						
(5) Outcome of the analysis						
According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?						

6.3.1 Self-exploring Scenarios with the Assessment Tool

Although the scope of this research and this chapter is not within the application of case studies, different scenarios have been elaborated for the practicability demonstration of the proposed framework.

Four scenarios have been created, one for each contemporary challenge described in section 2.2.3. However, only one is presented in this part of the thesis. The other three scenarios have been added to 'Appendix section A1'.

Scenario 1, skill gap: A new graduate has entered a company, but the new guy faces difficulties adapting to the new environment. He requires to show an enhanced work performance soon but struggles with colleagues and the social part of his new job place. Therefore, the company carries on an assessment to point out the main concerns of the situation from a skill-needed perspective. Table 6.2 summarizes the application of such evaluation using the standard of the proposed framework. At the end, taken from the outcome of the analysis, the resolution to the fresh graduate's case is to work on four skills (teamwork, programming, empathy, creativity) while providing specific and multiple means to achieve that.

Table 6.2 Example of the assessment framework on scenario 1

<table>
<tr><th colspan="7">RHAM-based Assessment Framework for Industry 4.0 Challenges</th></tr>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="3">(3)</th></tr>
<tr><th>Challenge number</th><th>Challenge type</th><th>Human type</th><th>Age range</th><th>Involved Ecosystem level</th><th>Wanted skills</th><th>Type of competence</th></tr>
<tr><td rowspan="4">1</td><td rowspan="4">Skill gap</td><td rowspan="4">Fresh graduate</td><td rowspan="4">Adulthood (20-35)</td><td rowspan="4">Workplace</td><td>Teamwork</td><td>Soft</td></tr>
<tr><td>Programming</td><td>Technical</td></tr>
<tr><td>Empathy</td><td>EQ</td></tr>
<tr><td>Creativity</td><td>SQ</td></tr>
<tr><th colspan="7">(4) Situation assessment (from the skill-based and person's perspectives)</th></tr>
<tr><td colspan="7">From the skills listed on step3, what are the reasons for the person to improve such skills?
Teamwork: the new guy does not interact and address his colleagues to work together and according to the company's values
Programming: he does not know how to code C++ with advanced commands
Empathy: he does not understand how his impulsive actitud is affecting his teamworkers at the office
Creativity: he wants to enhace his capacity for imagining new software applications</td></tr>
<tr><td colspan="7">Is there need for considering further skills? Which ones? Why? None</td></tr>
<tr><th colspan="7">(5) Outcome of the analysis</th></tr>
<tr><td colspan="7">According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?
For teamwork: he will be taught the company's goals & values, and added to an accountability group within the company
For progamming: he will be enrolled to a technical course on C++ from an outsourced company
For empathy: he will take on an EQ course and small group sessions for therapy and exercises
For creativity: he will take on an SQ course and regular mindfulness meditations</td></tr>
</table>

As observed from the table above, the framework's applicability can help deliver a simple yet informative and direct assessment of the given situation. This is based on the skill(s) found needed to address the issue. Once the problems have been expressed from a skill-based necessity, the solution can also be communicated from the same principle to deliver a comprehensive assessment.

Moreover, for scenario 1, the assessment framework helps to understand and translate common workforce problems that have been found in a company into a specific and structured panorama for possible workforce solutions. Both the assessment of the situation and the analysis outcome have been expressed from a skill-needed perspective, just as the proposed tool aims to do. This is also true for the rest of scenarios 2, 3, and 4, which can be found in the appendix already mentioned.

In general, the assessment tool based on the RHAM model highlights the need and the importance of new holistic human-centric approaches on educational and upskilling issues. With this type of approach, facing Industry 4.0 challenges could find new opportunities to mitigate them.

Ideally, the assessment framework holds the potential to be digitally developed and implemented using programming software for case studies. However, that would have to be part of future endeavors in post-work to this research's scope.

6.4 Key Characteristics and Benefits of the RHAM Model

The RHAM model has been developed as an interconnected architecture that links main elements that support the understanding of a human-centered approach for human preparation and upskilling. As noticed, the model relies on three main components: skills, stages of life, and environments. The notion of holistic integration emphasizes the effort to support the resolution of contemporary challenges from a multi-sided and disruptive perspective while keeping human aspects in the center. Moreover, since human capital preparation and development are the primary reason for the model, the competence layers become the pivotal element of the model to work with. Therefore, the proposed application method was a skill-based assessment framework to address the challenges to be solved.

In alignment with the intelligent architectures that have been recently developed, this model inherits some of the potential benefits that are important for Industry 4.0 and todays' characteristic solutions. Interoperability, interdisciplinarity, customization, flexibility, and digitalization are features and benefits sought by Industry 4.0 environments and applications. The proposed RHAM model pretends to work out these features while keeping a comprehensive human-centric perspective. Advanced benefits of this architecture can be pointed as:

- *Interoperability.* The model interconnects three main aspects of a person's life: the environment, the life stage, and the knowledge or skill. Including these three variables enhances the data for analysis of disruptive problems or situations that require new approach solutions. I.e. a skill assessment for Industry 4.0 challenges.

- *Interdisciplinarity.* The model covers a wide range of competences that are becoming more integrated than ever before. Moreover, each competence is also expanding in several skills. This multidisciplinary yet related list of skills and competences can address any challenge found in todays' concern. I.e. issues like the skill gap, an aging population, compromised wellbeing, etc.

- *Customization.* The model contains divisions or segments within its three elements (the competence, the life stage, and the ecosystem). This type of segmentation and division can facilitate the delivery of a customized solution accordingly. For instance, a personalized program of skills could be delivered according to a specific life stage (i.e. midlife) and a specific ecosystem (i.e. workplace). This interplay of the elements and divisions can allow for combinations of different possible solutions, which helps to meet specific needs accordingly.

- *Flexibility.* Although the model was inspired by an industrial need (Industry 4.0), it can also lend itself to expand to different areas or needs, i.e. social, academic. It is not fixed to an industrial term, model, or usage, but rather it could be adapted to suit particular needs that require a holistic human-centric approach on people upskilling and preparation.

- *Digitalization.* The model offers opportunities for further exploration and practical applications, especially digital ones, e.g., the digital development of an application from the model, such as a digital skill assessment framework. Moreover, the digitalization of the expressed framework with the embedded use of AI and databases could support the emergence of smart digital tools to aid existing and future Industry 4.0 challenges.

6.5 Summary

This chapter elaborated in answering research question number three. The problem addressed was that most recent workforce preparation and development efforts do not fully meet the needs of the existing challenges for industry and employees. For instance, most of such actions tend to focus on traditional approaches, such as job-based preparation. Moreover, their applied methods also keep a conventional perspective, i.e. a technology-based (i.e. programming) or subject-based (i.e. mathematics), which promotes only an overall technical competence for human capital. This compromises the effectiveness and compatibility for addressing Industry 4.0 challenges, as they require a more multi-sided perspective. This chapter aimed to present an alternative to the problem by elaborating on a model that can aid in workforce preparation while meeting the essential needs of a human-based approach and a holistic perspective. This also included a challenge-based method of application.

The Reference Human-centric Architecture Model (RHAM)

The model's design was inspired by a Smart Grid Architecture Model recently developed for Industry 4.0, which is known as the Reference Architecture Model for Industry 4.0 (RAMI 4.0). This type of design supports breaking down complex systems into simpler clusters to allow integration and understanding between the elements in the model. This type of integration became the suitable design for the holistic perspective sought in our new model. RHAM was developed as the model for human-centric and skill-based preparation of Human Capital 4.0 by including three integral parts that form a person's life. These three critical parts were represented by the three axes that shape the model: the competence layers, the lifetime cycles & value stream, and the ecosystem levels. The resulted integration of the model can be visualized in Figure 6.4.

RHAM: a tool for addressing contemporary challenges impacting the workforce

A systematic framework for assessing skill requirements was created to explore the RHAM model to tackle contemporary challenges affecting the workforce. The proposed method was based on an approach presented by another study that devised a template form to include human factor conceptualizations systematically. However, adequate amendments were required to suit the peculiar concepts, needs, and outputs sought by the RHAM model.

The template form of the framework was divided into five main steps of action. Step one, the identification of the challenge to be addressed. Step two, the identification of the person's details, such as 'human type' and 'age range', of whom is impacted by the identified challenge. Step three, the identification of the scenario or environment being affected, along with the recommendation of the skills and competences that are required on the challenge. Step four, the assessment of the situation from a skill-based perspective, according to the skills mentioned in step 3, and considering the overall view of the problem. Step five, the outcome analysis after having considered the needs exposed. This outcome is also given from a skill-based perspective that was used in the previous step 4. The resulted framework was visually summarized in Table 6.1.

Key characteristics and benefits of the RHAM model

The RHAM model was developed as an interconnected architecture that links three main elements that support a human-centered and skill-based approach for human capital preparation and upskilling. This effort emphasized resolving contemporary challenges impacting the workforce from a multi-sided and disruptive perspective while keeping human aspects in the center. Moreover, since workforce skill preparation was the primary reason for the model, the proposed method of application complied as a competence-centric assessment framework to address some of the challenges faced by Human Capital 4.0.

Lastly, due to its origins of being a smart architecture, the RHAM model also inherited advanced benefits that can feature for further solutions and applications. For instance: (a) Interoperability, this allows the model to interconnect three significant aspects of a person's life, which enhances the data to analyze disruptive problems or challenges that require new solution approaches. (b) Interdisciplinarity, this allows the model to cover a wide range of competences that facilitate a multidisciplinary yet related skill set that can better address present or future challenges and concerns. (c) Customization, this allows the model to create customized solutions by considering and combining the various elements and sub-divisions among the three axes. (d) Flexibility, this allows the model to be expandable and malleable to be used onto more than industrial needs (Industry 4.0), but social or academic. (e) Digitalization, this allows the model to become a base for a digital framework for further exploration and application, i.e. an intelligent digital tool for addressing contemporary and Industry 4.0 challenges.

Chapter 7

Manufacturing Workforce Co-evolving with Technology: A Worker-centric Approach

This chapter elaborates on the human and worker perspective for key implications and insights influencing the manufacturing workforce due to technologies and Industry 4.0 drives. It analyses three different forms of shifts where technology has or will be impacting employees working in manufacturing firms, especially those working close to machines. As a result, the chapter unveils subtle human-technology implications and their respective cooperative evolution (co-evolution) occurring at the factory. This chapter addresses research question 4A: "Bearing in mind the latest technological implementations in manufacturing, and keeping a worker-centric perspective, what are the key implications that can contribute to the understanding of the existing workforce?"

7.1 Introduction

Major technological disruptions tend to unleash a chain of new reactions and changes at the industrial and corporative levels. This is especially true for the manufacturing sector, where the implementation of significant disruptors can offer opportunities and challenges to the workforce. Therefore, to mitigate most of the difficulties and clear up most of the possibilities for manufacturing employees, it is required to study and understand such implications from a worker-centric perspective, i.e. human-centered. However, it seems unfortunate that much of the attention of research studies emphasize studying a technological perspective, rather than a human view, to offer solutions and alternatives. In other words, most efforts that try to support the manufacturing workforce focus on the changes in technology to improve it, rather than focusing on the changes on humans to enhance them. As a result, this creates a difference in approaches between the former and the latter.

For example, Human Machine Interface 4.0 (HMI 4.0) is a new concept that describes the evolution of the industrial interfaces that work as tools for the operator to interact with working mechanisms and equipment [219]. Yet the study of such a concept fails to address the upskilling of the operator to adapt to new H-M interfaces. Similarly, another case elaborates in robotic workmates, or human-robot teams, where a virtual reality scenario was built to analyze the interaction between the human and robot [220]. Although the study tries to measure the interaction in terms of performance and stress of the person, it misses out on an initial holistic-based assessment of the operator capabilities. Furthermore, a new view on human resources, Smart Human Resources 4.0 (Smart HR 4.0), highlights some of the significant technological and organizational disruptions the human-resource domain faces [221]. However, the research mainly covered key technologies with few implications that will affect only the company and the human resource department, leaving out the human perspective of the workforce from such technological changes, i.e. workforce interactions, abilities.

Although the mentioned examples are state-of-the-art studies, they still keep a prominent technological viewpoint in their approach to perceive, understand, and aid the workforce on the new manufacturing changes. However, in this chapter, we have identified and analyzed, from a worker or human-centered perspective, three significant manufacturing implications that can influence the understanding and the aid of the workforce: (1) the workforce structure and role interactions, (2) the workforce capability co-evolving with technology, and (3) the human-machine skill collaboration.

The implication on workforce structure and role interaction are chosen because most analyses attention goes to the product, equipment, or shopfloor development, rather than on human roles, structure development in the companies, or peer-to-peer interactions. The implication on workforce capability co-evolution is selected because many studies strongly stress industrial and technological evolution with less attention to human abilities co-evolving across time. The third implication on human-machine competence collaboration is picked since enough work is done into embedding more HMIs or technologies into HCPS. Still, little work is done to bring up and study the human competences embedded and cooperating into these H-M systems.

The subsequent investigation and deep analyses should aid in providing overlooked and comprehensive insights that will promote a more transparent view into the workforce of Industry 4.0 and enhance the possibility for smoother technological application and implications for workers in manufacturing, i.e. the Operator 4.0.

7.2 The Workforce Structure and Role Interactions

Industry 4.0 digital devices, technologies, and applications are changing how manufacturing companies deal and interact with their external stakeholders, i.e. suppliers and customers. However, the same applies to the internal stakeholders, such as operators and managers, who would face changes in their operation structure and interactions among themselves. Therefore, if Operator 4.0 is to be redefined, it is vital to analyze to envision their future working interactions and then provide a better idea of its refinement. This section elaborates on the significant ramifications of those changes at the structural and interactive level while keeping a manufacturing worker perspective.

7.2.1 Industry 4.0-enabled Smart Working Interaction

As denoted in the literature, the commonly known pyramid structure is represented by five different levels that integrate the whole operational facility of most typical companies. However, this famous hierarchy-based accommodation is being reshaped by primary Industry 4.0 technology and requirements, i.e. flexibility, self-organization, and decentralization, throughout all company levels [8]. Therefore, not only the mechanical elements in the five levels of operation will be affected by such technology and features, but also the human element in each level will be influenced to some extent.

Figure 7.1 displays the proposed distribution change from a typical pyramid-based to a future decentralized flow featured by Industry 4.0 features. This type of new distribution could also be referred to as an enterprise social network (ESN) since there is a resemblance [222].

- The pyramid at the left represents a typical rigid ***hierarchy-based interaction*** in a factory, where management and instructions are ***centralized*** and passed on from high to lower levels(***downstream***). For instance, the high management level would be at the top, asking for production outcomes or distributing information about coming plans. The middle management level is in direct contact with their subordinates, requests new information, and delivers further orders. The low management level consequently gives their team members and operators directions. Similarly, but ***upstreaming***, the feedback and outcomes are passed from the bottom to higher levels in the hierarchy. In this pyramid structure, the customer tends to be completely ***disconnected*** from the communication channel of the factory's production process.

- The network at the right summarizes the emerging change own to Industry 4.0. Industry 4.0 is to achieve the personalization of products and services [223]. In return, this will require the reconfiguration of on-demand production systems [81], the adoption of flexible, adaptable, and efficient manufacturing networks, along the integration of communication between producers and customers [82]. Moreover, as intelligent digital factories of the future will be empowered by the Internet of Things [83], it can be suggested that IoT would also allow pervasive computing connection among people, which will give rise to the Internet of People (IoP) [224]. All together will make changes in companies' communication structure and organizational structure. People will become a ***human labor network***, where every node represents a company member, and every dashed line is an accessible ***decentralized interactive communication***. In addition, customers now will become an ***essential part*** of the exchange of information in the manufacturing process [85], where they will have their input in making their personalized products.

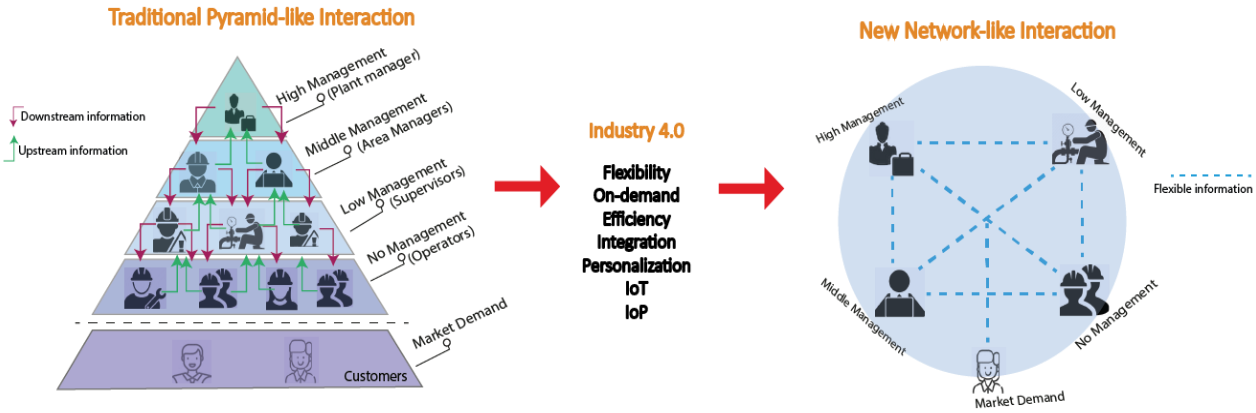


Figure 7.1 Working interactions transformed

Once the company's primary shift interaction has been denoted (Figure 7.1), it is important to identify the critical workforce elements in a manufacturing company. This identification will permit the elaboration of future real-like examples of the new interactions by considering their current interactions. For this, we have considered the already defined architecture for the workforce in manufacturing organizations from R. Goffee and R. Scase [225]. Thus, the considered composition of the workforce is broken down into five main components:

1. **The strategic apex** is the responsible entity for formulating and implementing strategies in the organization, i.e. the plant manager.
2. **The middle line element** links and keeps the information flow, up and down, between the strategic apex and the operating core and directly coordinates subordinates' work, i.e. the production manager.
3. **The operating core** does the essential work of producing goods or providing services, such as securing inputs and distributing materials, i.e. the production operator.
4. **The techno-structure component** is the analysts who provide a service, mainly to the production process, by studying and planning work or even delivering training, i.e. the project engineer.

5. **The support staff element** provides in-house assistance and support to the organization's different areas, i.e. the payroll administrator.

However, such established architecture needs to be updated by adding one more component into the manufacturing plant composition. As previously described, one more element, or stakeholder, will start influencing the production process by the requirement and inputs of their tastes and needs, the customers. Although they are not a worker from the company, their decisions will hugely influence its direction. Therefore, it can be safely assumed that the customer requires inclusion as a component of the manufacturing process. Such denomination is suggested as follows:

6. **The external solicitor** is the buyer that requests the manufactured product, giving voice to their needs and requirements by sharing and submitting their specifications or feedback to the company, i.e. the end-user.

As a result, by combining the 'new interactive network' with the 'new six components' for the manufacturing workforce, it has been possible to propose and depict the Industry 4.0-enabled smart working interaction for future companies in manufacturing. Figure 7.2 illustrates this new innovative type of expected interaction among the key collaborators in manufacturing. This new type of collaboration among workers focuses on and towards the use of Industry 4.0 technologies and the alignment of its goals explained previously.

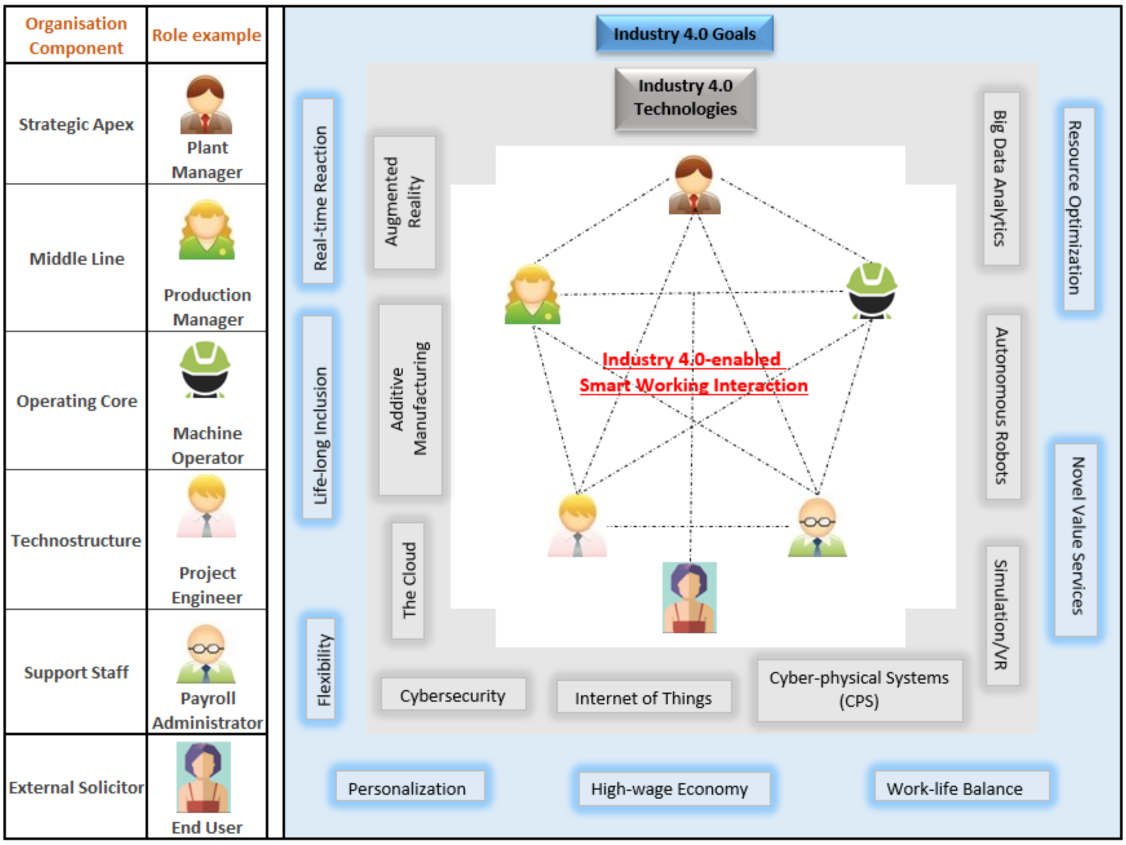


Figure 7.2 Industry 4.0-enabled smart working interaction

7.2.2 Examples and Benefits of the Transformed Interactions

In the new type of interaction achievable by Industry 4.0, each member will have the facility, if required, to directly open channels of communication between each other, regardless of their occupation. For instance, machine operators will have an open opportunity to communicate with plant managers and the other way around, if needed. Using the roles and genders from Figure 7.2, the following envisioned examples are practical applications for key interconnections to be positively affected in manufacturing roles:

At the plant manager level. The company manager will be able to monitor the company's KPIs in real-time, avoiding the need to ask for them due to the digital integration at every level of the company. At the same time, he will receive instant feedback from the sales market, looking at numbers and tendencies, thus encouraging and approving marketing strategies more efficiently. Equally, having first-hand information will make it easier and faster for him to make decisions on where to allocate financial resources more accurately. He will have the option of looking at every member's performance of the company through open individual digital channels of communication with them, either to promote goals and strategies of the company or to offer the company's support to them.

At the middle management-level. The production manager will stop generating manual KPI's of the production department, as digital production systems will generate them automatically. Moreover, by using real-time databases of workers and considering availability, performance, and capabilities, she will be able to arrange her production workers efficiently and accurately. Due to flexible and quick-respondent manufacturing processes, production planning will become easier and automatic, almost removing this task from her duties since customers' orders will be processed similarly. She will be equipped with open instant digital channels of communication with every organization member for different purposes. For instance, she will keep interacting with the project engineer for new production line implementations, the payroll administrator for summary reports of personnel assistance, the machine operator for production line issues, and the plant manager for production department budgeting.

At the operation core level. The machine operator will keep looking after manufacturing parts but through the utilization of Human-Cyber Physical Systems. These systems will allow the operator to carry out his activities smoother because of the augmented technologies, the assistive systems, or the user-experience devices involved. Setting up and monitoring the production process will be guided and shown continuously, troubleshooting malfunctions will be assisted, and quality-product inspections will become efficient. However, communication channels with other company members will also be available among the new features. For example, his communication with the plant manager will allow him to provide open direct feedback on the job environment, while contact with the production manager will be prompted for real-time informative circumstances about the production status. His communication with the project engineer will facilitate the accurate, quick identification and resolution of quality-product issues, while contact with the payroll administrator will facilitate the elaboration of self-generating databases on personal matters, i.e. health, absence.

At the techno-structure level. The project engineer will instantly re-design parts and update production processes according to the feedback obtained from the finished goods located at both ends, the production line, and the field. Spotting continuous improvements in lead times and production processes will become easier due to the real-time monitoring systems implemented. Training the personnel in new job tasks will be more practical and faster to learn using technologies that can embrace a better learning experience, such as AR/VR. His communication with the plant manager will be open to visualizing new product developments and their expected lead times. He will also keep constant interaction with the production manager to monitor and be updated on the performance of new production lines. His direct contact with the machine operator will make it easier and more accurate to follow up with the quality behaviors of manufacturing products. Lastly, his interaction with the payroll administrator will enable him to keep track and easily access his personal archive.

At the support staff level. The payroll administrator will continuously keep liaising with the whole personnel of the company as his duty, yet this will become more efficient due to the digital applications implemented. Maintaining a record of personnel assistance will become fully automatic and traceable. The same will apply to the extra time and bonuses in the system, which will allow the elimination of these tasks in manual form. However, some supervision or approval may still be required for payments. His interaction with the CEO will allow quick approval of the payroll list. At the same time, his connection with the production manager will support the prompt acceptance of working hours and bonuses to the workers. His communication with the machine operator will enhance clarity when abnormal circumstances need clarification, such as unjustified absences, lack of bonuses, or working hours. Lastly, working with the project engineer will support him to rapidly and directly fill in and update the matrix of working competences from training delivered to the operators.

At the external solicitor level. The end-user will continue submitting her requests to the manufacturing company via online processes. However, as customization and personalization will become part of the new services offered by smart companies, the end-user will be able to voice her preferred features and choices based on the company's capabilities. To meet the specific demand, the company will accommodate communication distribution at different departments of its production and service processes to monitor, modify, or inform the status of the production order to the client. In addition, the customer also will support the company's information about the final product and service. She will be able to access the open platform provided by the company to provide her valuable feedback on the product, considering the usage, the appearance, the relation cost-value, the delivery time, among others. All this feedback will give quick, substantial information to internal stakeholders, such as engineers, operators, managers, for constant consideration of the product, process, and services.

In addition to the previous role-specific changes and benefits explained, six critical advantages from the proposed Industry 4.0-enabled smart working interaction can be named. These advantages are listed as follows.

1. It will support the teams in the company to keep flexible, accountable, and transparent means of communicating, broadcasting, and supporting the requirements, plans, events, outcomes, etc. that can cover both professional and social themes of the company.

2. It will promote a decentralized and a flat hierarchy-based approach that helps to reduce communication layers and speed up decision-making [221]. This opens an opportunity to contact and interact with all members in the network mesh in a boundless way. For instance, without being subject to centralized, misinterpreted, or stocked information, requirements, and complaints. This will encourage an equitable, transparent, and accessible environment for collaboration and communication.

3. It will boost 'open innovation' in the company's ecosystem as the mobilization of knowledge will be open from different individuals, places, and departments, whether to address specific issues or create arbitrary new improvements. Open innovation was exemplified during the Covid-19 period. It is defined as the distribution of innovative processes with purposive knowledge that flows

freely across organizational boundaries for financial or non-financial reasons [226].

4. It will aid in the company's ‘re-configurable’ or dynamic capabilities. This will be based on its inherent integrative and quick-adapted interactions and communications, which will allow last-minute notifications and modifications in the system. These changes could be both administrative and operative. Moreover, the reconfigurability will provide production capabilities when needed by characteristics of integration, customization, and convertibility into the manufacturing system [227].

5. It will foster the observations and conclusions of many studies during and after the Covid-19 pandemic in 2020. Such studies’ views on business survival encouraged implementing collaboration, openness, agility, reorganization, reconfiguration, flexibility, and innovation to companies’ structures and strategies [203], [226]–[230]. However, such recommended characteristics cannot be limited only to organizations' physical or digital capability, but they need to be implemented at human capability as well.

6. Lastly, this type of Industry 4.0-enabled smart working interaction will provide employees a continuous experience of connected collaborations at two different levels, the inter-organizational level (inside the company) and the intra-organizational level (outside and among other companies). These can help the worker, professionally and personally. On the one hand, such types of interactions will make it easier for employees to mimic and implement intra-connected collaborations with other companies when needed. For example, when pharmaceutical companies needed to collaborate at different levels to test and find solutions to the same problem of Covid 19, or when car manufacturing companies and medical companies needed to produce respiratory ventilators as teams. On the other hand, such interactions will enhance and boost opportunities for increasing involvement, motivation, responsibility, coordination, creativity, and life-long learning of workers.

7.3 The Workforce Capability Co-evolution with Technology

Although Operator 4.0 has been proposed already, his definition lies merely on his ability and interaction with the different technologies, leaving his human work capabilities unnoticed or less stressed. This section has been elaborated to find out the main workforce capabilities involved in the Industrial Revolutions and their changes throughout time. Having these clear will help to point out such findings into the context of the new Operator 4.0 conception.

7.3.1 Worker-Machine Capability Correlations

Technological advancements have gained more territory in administrative, operative, and productive systems. For instance, artificial intelligence, machine learning, and deep learning are being embedded in advanced HCPS, which can provide a vast territory of application. Moreover, it is understood that some of these technologies have offered possibilities for capabilities and dexterity way better performed than humans [231]. However, individuals such as employees and operators are also understood to be kept as the key actors among such technologies. Therefore, it is necessary to inquire and identify significant capabilities shift and evolution from the first Industrial Revolution involving humans and machines. This type of analysis will help to perceive better and assess the difference between workforce and machine capabilities.

Each of the Industrial Revolutions was characterized by specific sets of significant disruptions and applications in a span of nearly two to three centuries. We have identified and correlated such key disruptions into human-machine capability interplay as follows:

1. In the late 18th and early 19th centuries, the First Industrial Revolution kicked off today's industrialization mechanism. The major technological contributors of that initiation were the steam engine and textile machinery. The creation of this type of prominent machinery removed the need for heavy and exhaustive physical activities done manually by people, i.e. mining.

2. The Second Industrial Revolution took place in the late 19th century, which was possible due to electricity's discovery and industrial application. Some of the characteristic systems empowered from this type of application are the assembly line (production conveyor) and numeric control (NC) machines. This kind of machinery had an exponential improvement in terms of speed over manual activities that people still performed, i.e. assembling, drilling.

3. By the second half of the 20th century, the Third Industrial Revolution emerged. This was possible due to the technical implementation of Information Technologies that occurred in the form of PLCs and computers. These first digital applications had an impactful effect on processing information, doing calculations, and storing data. These technological tools outperformed the mental capabilities of people, i.e. mathematics, memory storage.

4. The Fourth Industrial Revolution has begun in the 21st century with numerous digital technologies, starting the Internet of Things as the major facilitator for this new age. However, AI technology development and implementation play a big stand in terms of human capability domination. Artificial intelligence and deep machine learning are making inroads to outperform human intellect, i.e. analytics, predictions.

Figure 7.3 summarizes the human and machine interaction analysis in terms of capability display. The initial Industrial Revolution brought machinery that removed the need for workers' strength and endurance. The following disruptive machinery took over the need for speed and movement from workers' job activity. The first two industrial disruptions mainly impersonated or replaced human physical capabilities for job activities. The third Industrial Revolution impacted and removed the need for workers' calculations and storing memory. Today, Industry 4.0 is brought by a disruptive technology that mimics and super passes workers' reasoning and intellect. The last two industrial disruptions mainly impersonate, or replace, human mental capabilities for working activities.

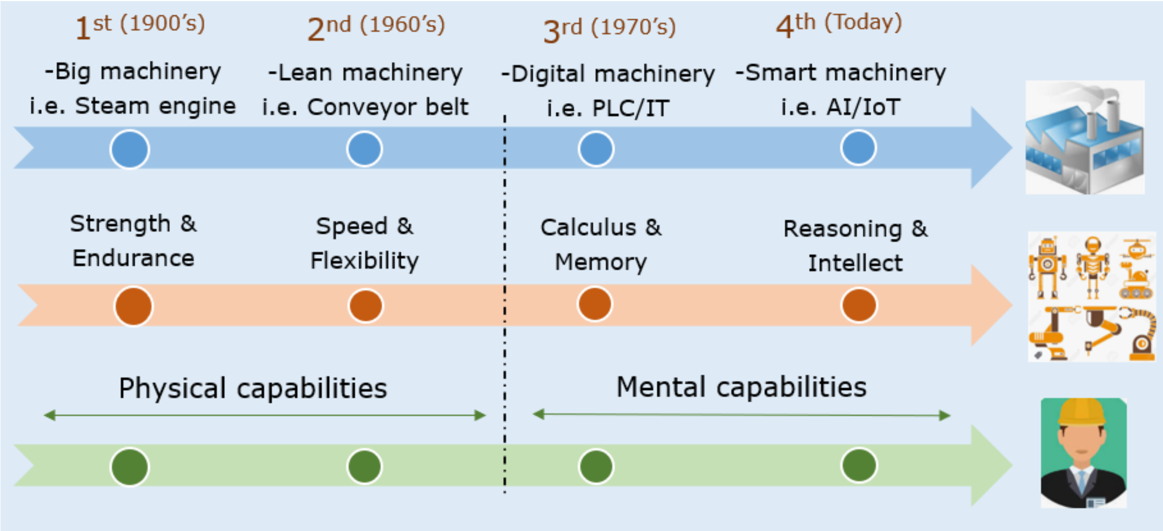


Figure 7.3 Industrial Revolutions by human-machine capabilities

7.3.2 The Capability 'MABA-MABA' List in 21st Century

To be able to understand better and see more precisely the human capabilities in relation to the machine, another short analysis has been done using the so-called MABA-MABA list. This list stands for 'Men Are Better At – Machines Are Better At'. The initial creation of this table was in 1951, and its purpose was to aid with simplicity and comprehension when referring to automation awareness [232], [233]. However, the original table presents an old and obsolete point of view since it has not been updated from its origin.

In this research, we have found the importance and the opportunity to elaborate on the updated version of the MABA-MABA list. This will help cover this gap in academic knowledge and keep the purpose of its origins, which is understanding automation levels simply and comprehensively. Moreover, this should also help to enhance the Operator 4.0 vision while considering these updated differentiations.

Table 7.1 presents the transition from the old version of the MABA-MABA list (on the left) to the new version (on the right). Both versions highlight the main advantages or specific characteristics humans and machines are better at doing. However, in the updated version has been added more capabilities for machines according to the latest possibilities of technology known in the market, i.e. intelligent devices, artificial intelligence. Similarly, capabilities have been placed for humans according to late knowledge in human capacity. This new version focuses on two things, (a) in comparing related capabilities in each row and (b) in stressing the big qualitative difference per capability between the human and the machine.

Table 7.1 The updated version of the MABA-MABA list

The MABA-MABA list (Fitts, 1951)	
Men are better at	**Machines are better at**
Detecting small amount of visual , auditory, or chemical energy	Responding quickly to control signals
Perceiving patterns of light or sound	Applying great force smoothly and precisely
Improvising and using flexible procedures	Storing information briefly, erasing it completely
Storing information for long periods of time and recalling appropriate parts	Reasoning deductively
Reasoning inductively	
Exercising judgment	

The MABA-MABA list (up-to-date version)	
Men are better at	**Machines are better at**
Performing flexible and improvise	Performing faster, stronger, and precise
Understanding the situation and exercising judgment	Sensing and perceiving environmental conditions
Creating solutions (tools or services)	Deliverying options
Noticing patterns and looking at the bigger picture (inductive reasoning)	Reading patterns and doing analytical thinking (deductive reasoning)
Planning	Predicting
Applying intelligence (common sense)	Applying intellect
Experiencing purpose and fulfilment	Storing large amounts of data

7.4 The Workforce Competence Cooperation with HCPS

The previous section worked on analyzing and elaborating on worker-machine capability change throughout time. However, it is equally important to identify and highlight those capabilities in a context for collaboration between the two entities. Moreover, this is a favorable scenario to present an analysis that can use some of the workforce capabilities previously mentioned, along with some of the Human Capital 4.0 competences. This section aims to find out and highlight the human competences or capabilities embedded and collaborating with machines, particularly with CPS, as they are becoming household systems for most applications. This should allow discovering the need for competence from workers, i.e. Operator 4.0, who require to cooperate with such machinery.

7.4.1 Worker-Machine component distribution in HCPS

As learned from the literature review, Cyber-Physical Systems are the technological platform that supports the interaction between the cyber (digital) world and the physical world. However, when these systems are merged with the human element in the loop of their operations, they become a Human Cyber-Physical System. Therefore, this analysis comprises this H-CPS type of system rather than a fully automated CPS system.

In general, all CPS-based systems are conformed by an architecture of five levels of operability. Consequently, for this case, such levels have been broken down into two types of components, the worker component and the CPS component. The worker component represents the human input, which can be a competence, a capability, or an action that the user could contribute to the system. The CPS component exhibits the machine input, which are actions or capabilities that the technology could perform within the system. This type of comparison between the two components at different levels of operability will help to recognize the interplay of related capabilities in the whole HCPS operation. This will facilitate observing how one component might substitute or support the other.

As a result, Figure 7.4 displays the distribution of worker and machine components at the different levels of the HCPS pyramid architecture. The left side of the pyramid shows worker components that participate at the capability of each specific system level. In parallel, the right side of the pyramid shows CPS components that participate in the capability of each particular level of the system. The analysis between both types of elements within each level can be described as follows:

1. **Connection level.** In this phase, the system requires a sensory and connecting capability to start the aimed process of the HCPS. Humans can offer such ability by relying on their cognitive senses, while the machine part of the system might use integrated sensors, servers, or networks, to obtain data from the environment. At this level, accuracy for the acquisition of most data, i.e. weather, temperature, weight, etc. is of high importance for

the proper functioning of the whole process. Therefore, it would be expected that CPS's components take over the worker's components.

2. **Conversion level.** At this stage, the system requires analysis and process power capability. If people were required to analyze and process enormous amounts of data, they would require employing their memory and intellect at high efficiency and accuracy. In other words, remembering and making mental calculations would demand a high degree of mental competence, which has become less reliable. In contrast, these activities have become more reliable to be trusted to the software, programs, or algorithms that come implemented on the machine side.

3. **Cyber level.** In this cyber phase, the system needs to work on historical comparison and current monitoring at the same time. As such, the system depends mainly on digital models, programmable algorithms, and historical data from the machine components to carry out the tasks for this level. Due to the high degree of requirement, the system could hardly get input from the human elements for this level. If people were required to perform these activities, they would need an extraordinary exhibition of storing memory and analytical thinking to achieve a machine-like output.

4. **Cognition level.** After the previous phase, the system needs to prioritize and present the options available for the final execution phase. Since the system represents a HCPS, the activities on this level are most likely to be shared between the two components. On the machine component, the system would require a graphic interface in the form of a program to communicate the evaluation, results, or preferences to be considered by the user. On the human component, once results and options are given from the system, aspects such as experience (memory), emotions, and intelligence play a crucial role in submitting a decision into the system.

5. **Configuration level.** Once a decision is submitted, the system requires (re)adapting the machining process and then executing the order. The machine components at this level mainly rely on in-built physical aspects of the equipment, i.e. controllers, actuators, networks, etc. Meanwhile, for the human element can exist two scenarios. Scenario A): The worker has nothing to do because the final step is automatic. Scenario B): The worker needs to use physiological movement and cognitive senses to complete the last execution in cooperation with the machine.

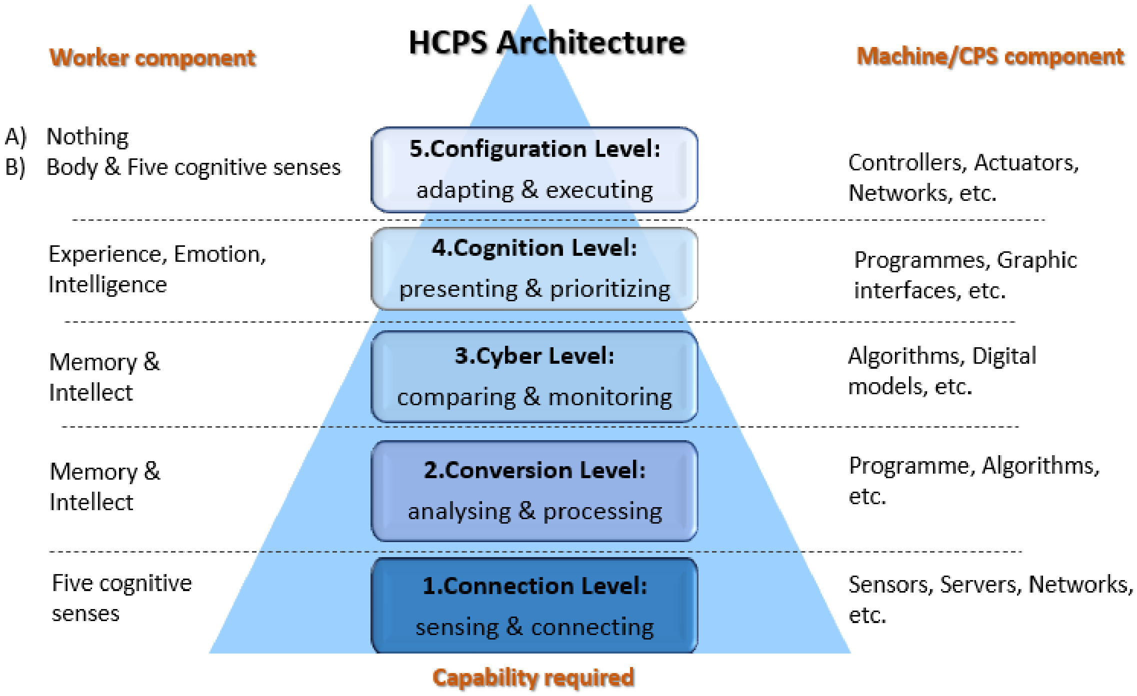


Figure 7.4 Worker-Machine component distribution in the HCPS pyramid architecture

7.4.2 Worker Competence Analysis in HCPS

The acquisition of data, its analysis, the generation of options, the selection of actions, and the execution and implementation of them are the main processes inside of HCPS. In all these processes, the participation of humans and workers is becoming more restricted or limited due to automated systems. Therefore, knowing and identifying what capabilities and competences are being limited and which ones are still relevant and needed from workers is highly important for academic and industrial knowledge. Becoming aware of this should allow the reconsideration for the design of future HCPS and the focus, encouragement, and enhancement on the competences favorable for humans over machine capabilities. The following analysis aims at covering such needs by surfacing the skills involved in a standard HCPS interaction in three short steps.

Step 1

It has been considered the previous H-M component distribution in the HCPS architecture. In addition, the analysis also finds the competence already mentioned in the context of Human Capital 4.0 to create cohesiveness with the results previously found.

Table 7.2 shows a clear distribution of human competences involved in an HCPS system. In summary, there are five instances or moments where cognitive competence (IQ) can occur among the five levels of the system architecture. There is also one instance for emotional intelligence (EQ) and one for spiritual intelligence (SQ) competence. At this stage of the analysis, it is assumed that the system could allow the intervention or input of the user at any moment, hence the need to visualize the main human competence involved.

Table 7.2 Worker competence involved in HCPS

Human Competence in HCPS			
HCPS Level	**Capability per level**	**Worker component**	**Human Capital 4.0 Competency**
1. Connection	Sensing & Connecting	Five cognitive senses	Cognitive (IQ)
2. Conversion	Analysing & Processing	Memory	Cognitive (IQ)
		Intellect	
3. Cyber	Comparing & Monitoring	Memory	Cognitive (IQ)
		Intellect	
4. Cognition	Presenting & Prioritizing	Experience (memory)	Cognitive (IQ)
		Emotion	Emotional Intelligence (EQ)
		Intelligence	Spiritual Intelligence (SQ)
5. Configuration	Adapting & Executing	Five cognitive senses	Cognitive (IQ)

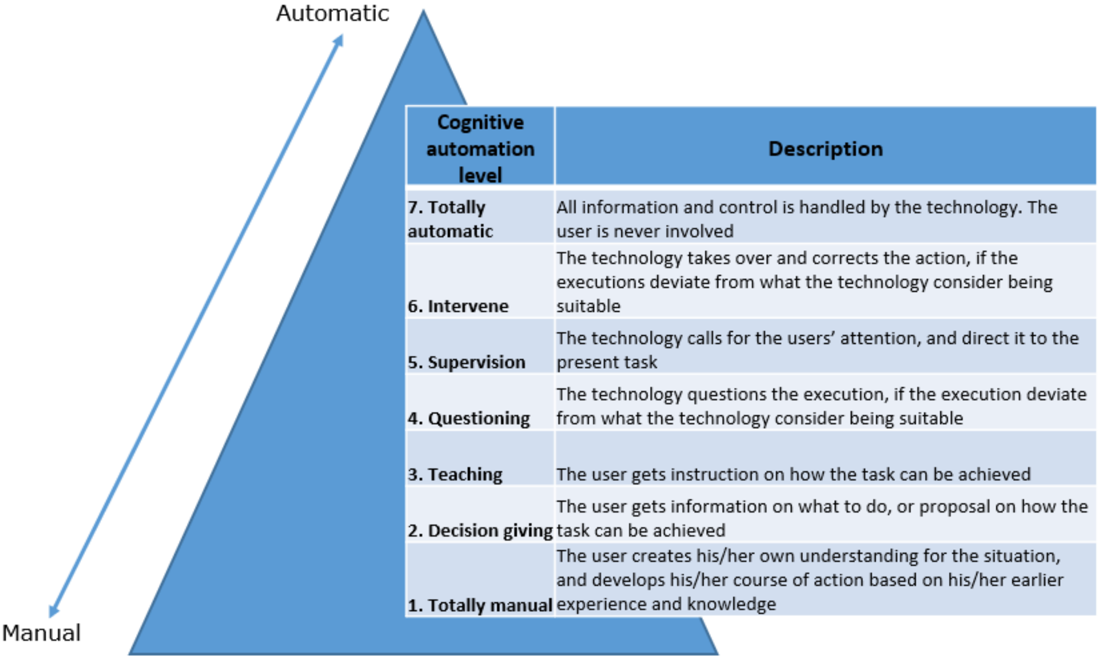
Step 2

However, the cooperation with this machinery will involve certain degrees of automation, depending on the specific system. Therefore, to provide further clarity and advantage to workers, from the human viewpoint, it is relevant to stress what competences are primarily automated and which ones are not. The following points briefly clarify the possibilities of automation for cognitive, emotional, and spiritual competences.

- Cognitive automation is the most common and practical type of automation because of the constant and repeatable factors of the cognitive and physical tasks that concern the operator [234]. In general, there are seven levels of cognitive automation, ranging from 1 (totally manual) to 7 (totally automatic). Figure 7.5 displays the levels known for this type of automation.

- Emotional automation is much less common in implementation than cognitive. This is mainly because the existing models and the science behind still struggle with the reason/bias that could exist behind an emotion, i.e. an old memory of the person or a new intellectual idea [235]. Among the most recent endeavors on emotional automation has been the implementation of deep neural
- networks to predict only image-based emotions with accuracies around the 90% [236]. Therefore, there is no clear and defined automation for this competence as the cognitive one, at least to this time.

- Spiritual intelligence has been clearly stated as a solely characteristic of humans among the living beings [194]. On the one hand, probably this is the main reason no such concept as spiritual automation has been widely tried. On the other hand, this unique attribute of humans would be further complex and time-consuming to handle than emotional automation today. Therefore, it can be safe to assume that there is no automation on this one.



Cognitive automation level	Description
7. Totally automatic	All information and control is handled by the technology. The user is never involved
6. Intervene	The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable
5. Supervision	The technology calls for the users' attention, and direct it to the present task
4. Questioning	The technology questions the execution, if the execution deviate from what the technology consider being suitable
3. Teaching	The user gets instruction on how the task can be achieved
2. Decision giving	The user gets information on what to do, or proposal on how the task can be achieved
1. Totally manual	The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge

Figure 7.5 The seven degrees of cognitive automation, adapted from [234]

Step 3

Based on the previous points of automation, and table 7.1, most of the five levels of HCPS can undergo a certain level of automation since they hold an IQ competence. Cognitive and physical activities are the most suitable for a feasible automation degree. Nevertheless, emotional and spiritual requirements are still distant from being successfully automated in a system. Therefore, these two present zero to low feasibility for achieving an automation degree.

Table 7.3 depicts the summary of the analysis. It considers the possible degrees of machine automation in each HCPS level. It also shows the selection of the preferred two competences as key advantages that a worker can rely on when working with HCPS. In other words, the highlighted section stresses where the most substantial opportunity for humans is to participate, or be involved, during the process of collaborating with human cyber-physical systems.

Table 7.3 Worker competence advantage in HCPS due to machine automation grades

Machine Automation Grades in HCPS				
HCPS Level	**Capability per level**	**Worker component**	**Human Capital 4.0 Competence**	**Possible machine automation**
1. Connection	Sensing & Connecting	Five cognitive senses	Cognitive (IQ)	1 to 7
2. Conversion	Analysing & Processing	Memory Intellect	Cognitive (IQ)	1 to 7
3. Cyber	Comparing & Monitoring	Memory Intellect	Cognitive (IQ)	1 to 7
4. Cognition	Presenting & Prioritizing	Experience (memory)	Cognitive (IQ)	1 to 7
		Emotion	Emotional Intelligence (EQ)	Low
		Intelligence	Spiritual Intelligence (SQ)	0
5. Configuration	Adapting & Executing	Five cognitive senses	Cognitive (IQ)	1 to 7

This type of approach analysis and its results help to see and understand the human competences involved and in cooperation with HCPS in two main ways:

- It can raise attention for the development and enhancement of the identified competences, according to the particular needs of the worker. For instance, it can be noticed that emotional and spiritual intelligence are the most pivotal abilities from a worker's perspective when collaborating with a type of CPS. Nevertheless, cognitive abilities should not be neglected as they also need a level of involvement during the work in the system.
- It can be used when designing future HCPS, i.e. to facilitate adaptation in terms of training needed, according to the level of engagement sought on the user.

7.5 Summary

This chapter contributed to answering the fourth-A question. The problem addressed was that the high focus of the evidence consistently keeps a technological drive and perspective when perceiving, understanding, and aiding the manufacturing workforce with the new industrial changes. For example, there are attempts to implement new

H-M interfaces, new robot collaboration features, or new human-resource technologies. However, most of these study efforts fail to perceive and understand such manufacturing changes from a human or worker perspective, i.e. operator skills, holistic-based capabilities, or workforce interactions. Consequently, the aim was to shed some light on manufacturing implications due to the technology and its collective evolution (co-evolution) with workers while maintaining a human-centered approach. For this, three significant analyses were selected and presented.

The workforce structure and role interactions

It was explained the traditional hierarchy-based structure and interaction among people in the factory. The primary characteristic involves communications and interactions from top positions to low positions, and vice versa. Moreover, in this pyramid-like structure, existing customers do not tend to have ways of influencing the factory production process. However, the interaction structure changes with the foreseen mesh-like network for the future of smart factories. It becomes a human labor network of decentralized interactive communication among all the key levels and members of the factory. Furthermore, the customer becomes an integral part of the manufacturing process as they will have an exchange of information available to put their input while personalizing their products.

To better represent the proposed interactive network, the analysis also considered five manufacturing roles that had been identified as key roles for manufacturing factories in the past. However, an update was needed in the key roles to add on the new vision coming from Industry 4.0, such as having the customer in the loop. As a result, the final proposed structure was formed from two updates, the 'new working network' and the 'new six components' for the manufacturing workforce. These together resulted in the 'Industry 4.0-enabled smart working interaction' for manufacturing, which can be viewed in Figure 7.2.

The workforce capability co-evolution with technology

This analysis was based on a worker-machine skill correlation and comparison. This considered the overview of all four Industrial Revolutions, which helped to point out the human capabilities that have been replaced or outperformed by key technological disruptors at the time. It was denoted that workers' physical abilities, such as strength, endurance, speed, and flexibility, were overtaken by the machinery in the 1st and 2nd Industrial Revolutions. Meanwhile, the subsequent two Industrial Revolutions and their technology have replaced workers' mental capabilities, such as calculus, memory, reasoning, and intellect. This result was summarized in Figure 7.3.

In addition, to further support the aim of the workforce capability investigation, an old list that had been used as a tool to better support the understanding of automation was included. The MABA-MABA list originated in 1951 represented a comparison between men and machine capabilities, where one was better than the other at a specific task or activity. However, since such a list lacked an update since its origin, the notion for the new version was presented in this section. This new version was updated using the original as a reference, but it expanded its capabilities. The resulting version is in Table 7.1.

The workforce competence cooperation with HCPS

The first stage of this analysis broke down the HCPS pyramid architecture into two components: the worker component and the CPS component. These two components were compared and analyzed according to capability needs for each of the five levels in the HCPS architecture. Therefore, the connection level, the conversion level, the cyber level, the cognition level, and the configuration level in such architecture were designated worker and CPS elements according to their functional activity. This resulted in a graphic representation of a worker-machine component distribution in the HCPS pyramid architecture, displayed in Figure 7.4.

The second stage helped to surface both the human competence involved in each level of the HCPS system and the possibility of automation for such competence. As a result, it was found that IQ was the most involved competence since it is present in the five levels of the system. Meanwhile, EQ and SQ competences were found of least involvement, as they are only once in one system level. Furthermore, it was established that IQ has well-known applied levels of automation (1 to 7), while EQ is a work in progress with a low possibility of automation implementation in a system. The SQ competence was clearly stated as a human feature solely with a zero probability for automation in the system. Therefore, EQ and SQ represented the significant advantage points that a worker can rely on when collaborating with HCPS. All together brought the consolidation of the resulting findings to Table 7.3.

Chapter 8

Operator 4.0: Part of the Manufacturing Workforce and Human Capital 4.0

The original concept of Operator 4.0 resulted in a successful effort to bring attention to a human working side involved in Industry 4.0, operators. However, such initial conception came from an analysis primarily based on the technicality of workers. This chapter presents the adjustment of the concept considering not only what has been already established, but more importantly, considering what has been developed and proposed under Human Capital 4.0. It provides the human-based analysis of the working force in the operator, which is missed in the original view. This chapter contributes to answering question 4B: "Considering the factors found until now, what is the updated version of Operator 4.0 that best advocates for a human perspective of Industry 4.0? and what are the distinctions from such updated version?"

8.1 Introduction

General speaking, if we understand and assume that the role 'operator' is taken as a 'person who works in a factory', it is necessary to refer to the operator as a human individual in the first place. Then, we can refer to them as job practitioners. When such obvious oversight distinction is observed and remembered, it becomes easier and feasible to develop profound and insightful human concepts and applications. Accordingly, such concepts and applications can be for industrial, academic, or social practices.

Unfortunately, although the initial Operator 4.0 concept was a considerable effort to look for the human part in Industry 4.0, it missed observing the human aspect in its analysis. It correctly pointed out the machines that the operator has been working with since the First Industrial Revolution. Yet, there was no further analysis at the individual level of the worker. This gap in the worker's conception could lead to half-breed applications and practices. Moreover, industrial, academic, or social efforts based on the concept would be missing the human side aimed for in Industry 4.0. Therefore, this chapter seeks and attempts to present the updated view for the image of Operator 4.0, based on a human side, by implementing the Human Capital 4.0 approach until now.

The approach we have taken to achieve the updated concept with the human side inclusion can be best described with the following wellbeing example. For instance, it is already known that the collective level of the workforce's wellbeing is similarly related to the collective wellbeing of the whole population. Figure 8.1 depicts such an example of the relationship between the entire wellbeing of the population and the employees' wellbeing. It also shows that wellbeing can be reflected in productivity at the enterprise and nation levels. As a result, the complete picture shows the dynamics and interactions of factors influencing or feeding on one side to another in a cyclic way.

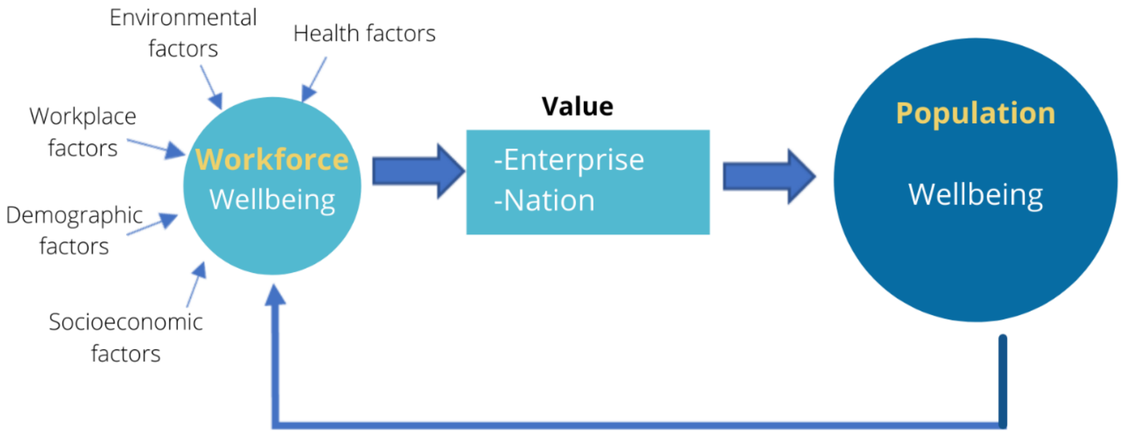


Figure 8.1 Alignment between the wellbeing of the population and the wellbeing of the workforce, adapted from [184].

Similarly, Figure 8.2 depicts the intention of this chapter. The characteristics found and developed around Human Capital 4.0 (chapters 4, 5 & 6) and the manufacturing workforce (chapter 7) will be passed onto the Operator 4.0 perspective elaborated in this chapter. Moreover, the upcoming idea of the operator should expect that the output from such operator shifts from simple local productivity to greater value to impact a bigger population.

Ideally, Operator 4.0 requires coming from a human-centric perspective that somehow covers and considers the human side of the industry in the first place. Just then, the technical side of Industry 4.0 can also be integrated. In the following sections, we have explored and elaborated on the new definition of Operator 4.0 using the existing idea and the study done in the previous chapters. The benefit of this merging is to enhance the current view of the concept to uplift its perception and understanding and smooth the worker's transition to the new expectations brought by the changes in Industry 4.0.

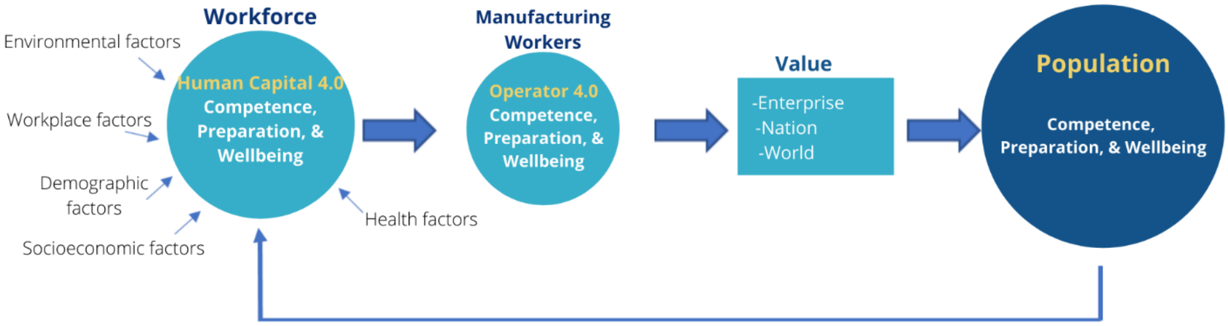


Figure 8.2 Alignment of Operator 4.0 within Human Capital 4.0

8.2 Limitations in the Original View of Operator 4.0

The pioneering papers from Romero et al. have covered the early notion of Operator 4.0 as "the operator of the future, a smart and skilled operator who performs cooperative work with robots and also work aided by machines if and as needed by means of… adaptive automation, human-automation symbiosis" [12], [14]. In short, Operator 4.0 has been described as a worker who is competent and skillful to interact and keep a relationship with state-of-the-art technologies, i.e. HCPS, to perform a specific work. Moreover, this definition has also emphasized that the focus of the given concept is on "automation to enhance the cognitive capabilities" of workers through HCPS integration.

Furthermore, under the same initial sources, different types of operators were suggested based on the use and application of various technologies. Depending on the technology involved, there was a particularly given term for the operator, i.e. 'the augmented operator' for using augmented reality. It was the same case for other seven technologies, such as exoskeletons, VR, wearable trackers, intelligent assistants, collaborative robots, social networks, and big data analytics. As a result of such typology of Operators 4.0, a good number of studies and contributions have been done to explore and explain the applications or benefits of the operator and its respective technological tools [158]–[160], [237], [238].

Although this initial version of the operator has gained popularity and become widely conventional, the rise of awareness for a better or more complete understanding of the operator is in the air. Few studies have raised this concern for a better formation or completion of the Operator 4.0 view. For instance, the idea of the future operator being a standby monitoring techno-augmented operator has been challenged. Instead, this notion supports the idea that an operator should be an imaginative, skillful, teamwork member and maker in the organization [79]. Another work has boldly pointed out that the original view of Operator 4.0 is still blurred since it only considers the cognitive capabilities of humans (sensorial, physical, spatial). This leaves out both a human-centric design and human values into the concept [162].

In general, four relevant limitations can be pointed out in the original idea of Operator 4.0:

1. The analysis only included the evolution of tools interacting with the operator. Hence, it misses other critical human factors and interactions, such as the interaction with team workers or the accountability for human competences.
2. It keeps a sharp focus on automation as the only means for facilitating human work interaction and enhancement of specific capabilities. This poses the danger of assuming an absolute dependence on technology for human work interactions and human capability enhancement.
3. It only considers one type of human capability, cognitive competence. This leaves out most human competences, i.e. emotional, soft, spiritual, etc. Consequently, this shadows essential human traits, such as values, imagination, creativity, or purpose.
4. It is unclear how the operator becomes 'smart and skilled' to perform cooperative work. In other words, it did not cover on which basis (i.e. competences, human development, etc.) is the operator to be upskilled for performing intelligent and skillful work.

In summary, the current view of Operator 4.0 works as a first step to recognizing the operative worker across the Industrial Revolutions. It acknowledges and elaborates on integrating the human side to the Industry 4.0 vision. In addition, it works on the combination of strengths between technological tools with human operators. However, such a concept also bears significant gaps for a more extensive scope of human aspects. These aspects need to be considered for a comprehensive and inclusive term for future operators. In other words, the better the emphasis on the human side of this concept, the better outcome for the original intention.

8.3 Operator 4.0: The Vision on Working Interactions

The early view of Operator 4.0, along with the original picture of Industry 4.0, has put heavy upgraded expectations on the workforce, particularly operators. This new level of expectation on the forthcoming Operator 4.0 will inherently create new responsibilities, communications, and interactions with different key elements in the production plant. Therefore, this section aims to propose activities and interactions that can work as a guided answer from this research to the Industry 4.0 goals and challenges in context to the operator. Moreover, it is expected that this aim can also provide a fair idea of to future needs of the operator in terms of development and upskilling.

Due to Industry 4.0 and the technological tools involved, the forms of interaction within companies are changing. For instance, as pointed out in chapter 7, the Industry 4.0-enabled smart working interaction can result from these changes. This new type of intelligent operating interaction offers many benefits, such as flexible and liable means of communication, decentralized and flat hierarchy approaches, open innovation opportunities, dynamic and adaptable capabilities, and even a company's resilience from unexpected disruptors, i.e. Covid-19.

Operator 4.0 can be positively affected by this new structure and interactions across the manufacturing company. Figure 8.3 displays the Industry 4.0-enabled smart working interaction applicable to the Operator 4.0 perspective. The general perspective of such interaction can be noticed on the left side, whereas the right side shows the same type of interaction but from the operator's perspective. This will mirror some of the mentioned benefits of the intelligent working interaction to the operator. As a result, Operator 4.0 will have inputs (blue arrows) and outputs (green arrows) of communication and interactions between every stakeholder in the organization, including the customer.

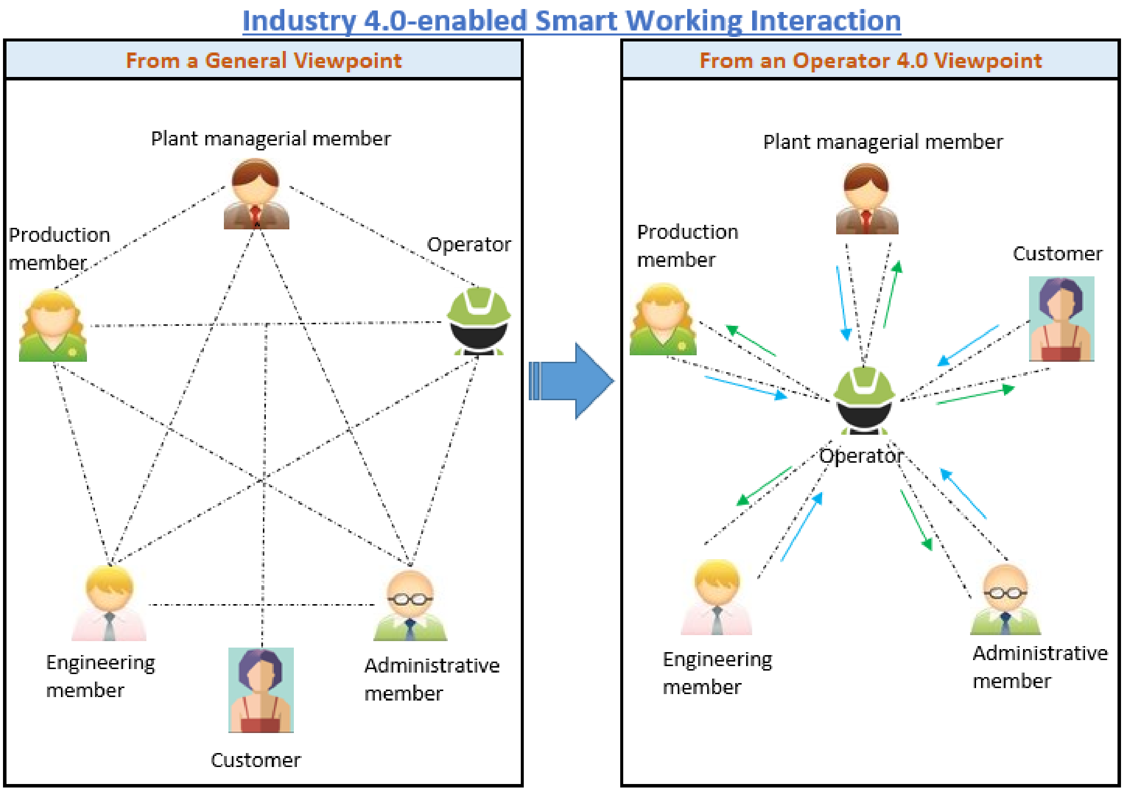


Figure 8.3 The Operator 4.0 perspective in the Industry 4.0-enabled smart working interaction

Although some examples were already presented in section 7.2.2 about these new interactions, this segment provides more specific upcoming changes from the Operator 4.0 point of view. The following responsibilities are a guided answer to the eight Industry 4.0 goals and challenges previously highlighted, such as personalization, resource optimization, flexibility, novel value services, high-wage economy, real-time reaction, life-long inclusion, and work-life balance. These responsibilities represent new organizational activities and interactions that the operator will require to exhibit. Such actions and interactions are assumed by employing different technological advancements, i.e. HCPS, HMI, intelligent personal assistants, etc.

A list of eight envisioned forthcoming responsibilities to tackle some of the Industry 4.0 challenges, from the Operator 4.0 view, is summarized as follows:

1) Personalizing manufactured products.

The operator will access and understand the customer requirements, set up the system accordingly, and manufacture the requirement. This will demand an interface that facilitates the interaction between the customers' orders and the production system of the operator. For instance, the order's acceptance, production status, order modification, or cancelation.

2) **Trouble-shooting production flexibly.**
The operator will solve problems in the production process through a flexible, interdisciplinary, and dynamic approach of knowledge to obtain the expected result. This will require an interface and interaction between the operator and significant supporters, i.e. the engineering and production team, to maintain accountability and expertise exchange while experiencing problem-solving practices.

3) **Overseeing and assuring real-time production feedback.**
The operator will support and confirm real-time and 'real-life' supervision of the production process indicators by feeding the automatic system in addition to their observations on the production needs. This will promote interconnection between the operator and the management level of the department, primarily along with other supporter areas, i.e. the production manager and project engineer.

4) **Achieving sustainable production with resource optimization.**
The operator will work on productivity and efficiency to produce as many goods as possible with a cero, or close to none, faults, waste, and fewer resources. This need will require an interconnection between the operator and the engineering team to learn, confirm, measure, and utilize the resources in the most efficient way possible.

5) **Producing value at the company creatively.**
The operator will look at a whole production context and factory (processes, manufacturing elements, resources, data, tools, etc.) to seek, analyze, or apply new valuable solutions, services, and applications. This will demand an open, transparent, and supportive interconnection between the operator and all the stakeholders, i.e. managers, engineers, the customer.

6) **Life-long learning to stay professionally productive.**
   The operator will become and remain productive in the company, or the market, for long years through regular professional and personal development. This will require the company's support to provide specific training for the job, and it will promote continuous constructive feedback between the operator and most colleague members.

7) **Balancing own workload to reconcile personal and professional life.**
   The operator will achieve self-autonomy (visualization, management, and planning) of tasks by considering the job needs and the personal capabilities (limits and needs). This will demand an open and transparent interconnection between the operator and the production manager and the administrative members, i.e. human resources, to promote self-balancing.

8) **Engaging in a high-wage production economy.**
   The operator will work for, and in alignment with, a competitive production process that generates financial profits that are perceived and recognized by the company and stakeholders. This will demand from the operator and other stakeholders inside the company to maintain an interconnection that supports the knowledge of financial matters behind the production system and the company's gains, i.e. production costs, monthly sales, revenue, etc.

8.4 Operator 4.0: Appreciation of Professional Competence

The operator of the future, known as Operator 4.0, demands competence preparation and upskilling for its personification. Without this competence, the expectations and possibilities of the operator could miss achieving the early bold Industry 4.0 ambitions. Therefore, the attention on competences and skills for future operators in this research is highly relevant. The principal aim of this segment is to carry out an appraisal to facilitate evaluation, review, and inclusion for Operator 4.0 competences and skills in terms of Human Capital 4.0 competence.

In this section, we have divided the professional competence for Operator 4.0 into two types of applicability for a more accessible appraisal of them: the collaborative competences with HCPS and the job skills in role activities.

8.4.1 Collaborative Competences with HCPS

As learned from section 7.4.1, HCPS are a type of CPS, but with the human aspect integrated, in this case the Operator 4.0. As such, HCPS have become one more technological tool for operators to carry out semi-automatic work tasks. The Operator 4.0 component represents the human input, which can be displayed as a competence, a capability, or an action that the worker could contribute to the system. The CPS component exhibits the machine input, which can be displayed as actions or capabilities that the technology could perform within the system. This type of comparison between the two components at different levels of operability should allow to recognize the interplay of related capabilities in the whole HCPS operation. In return, this will facilitate observing how one component (human or machine) might substitute or support the other.

Collaborative competence is a type of professional competence that Operator 4.0 might use to keep constant communication and collaboration with the so-called Human Cyber-Physical Systems. As HCPS becomes more household applications in future factories, Operator 4.0 will need to interact and work close to these mechanical systems.

Therefore, it is required to appraise the most common exchange of competences between these two entities (operator-machine) and perceive their corresponding relation. This type of appraisal should allow for two significant results, the operator's competences involved and the estimated percentage of operator participation in collaboration with the HCPS. Consequently, to achieve the required evaluation, outputs from Chapter 7 have been used, along with a systematic methodology of four steps:

- **Step one.** Creating a table to assign a corresponding cognitive autonomy degree for the operator. This requires using the reference of the cognitive automation degree from the machine.

- **Step two**. Creating a table to identify the operator competences within each architecture level of the HCPS and the parallel grades of cognitive autonomy for the operator.
- **Step three**. Elaborating a method to calculate the operator's competence input percentage in a process or cycle when working with HCPS. This will estimate the amount of involvement of the operator in the system.
- **Step to four**. Providing recommendations to foster the competences where the operator is predominant over the mechanical side of HCPS.

Step one

As previously pointed in Table 7.2, there are three types of Human Capital 4.0 competences involved in a HCPS, the cognitive (IQ), the emotional (EQ), and the spiritual (SQ). Out of these three, only one has been considered capable of automation at different degrees, IQ. However, while the capability of cognitive automation relies on the machine side, it is unclear what would be the cognitive autonomy from the operator's perspective while collaborating with the machine. To cover this need, a table has been elaborated to calculate the degree of autonomy from the operator per the degree of automation from the machine.

Table 8.1 shows the resulting analysis between the grades of cognitive automation and the grades of cognitive autonomy. A corresponding level of autonomy from the operator has been estimated, according to each of the levels of automation from the machine referred to in Figure 7.5. This table displays a number, a reference name, and a description of the operator for each one of the degrees. In addition, two columns about the percentage of contribution to the collaboration have been assigned, one for the machine, one for the operator. This column shows the estimated overall involvement from the cooperation when working with HCPS. Lastly, the last two rows and degrees are grey since they leave out the operator's collaboration.

Table 8.1 Cognitive degrees between HCPS and Operator 4.0

HCPS-Operator 4.0 Cognitive Grades					
Machine			Operator		
Cognitive automation degree	Description	Collaboration (%)	Cognitive autonomy degree	Description	Collaboration (%)
1 (Totally manual)	The user creates his/her own understanding for the situation, and develops his/her course of action based on his/her earlier experience and knowledge	0%	10 (Fully independent operator)	The operator is total skilled and capable to work on the activity by him/her-self and performs the actions autonomously	100%
2 (Decision giving)	The user gets information on what to do, or proposal on how the task can be achieved	20%	8 (Helped operator)	The operator needs help from the technology (i.e. calculations) to proceed and keep up with the activity and processes	80%
3 (Teaching)	The user gets instruction on how the task can be achieved	40%	6 (Learner operator)	The operator needs to follow directions from the technology (i.e. assembly instructions) to be able to finish the activity and process	60%
4 (Questioning)	The technology questions the execution, if the execution deviate from what the technology consider being suitable	60%	4 (Verifier operator)	The operator is asked by the technology to confirm the execution and procedure of the following actions from the technology (i.e. the configuration of a production process)	40%
5 (Supervision)	The technology calls for the users' attention, and direct it to the present task	80%	2 (Spotter operator)	The operator is called up by the technology to check or look at something happening in the process done by the technology (i.e. a faulty product)	20%
6 (Intervene)	The technology takes over and corrects the action, if the executions deviate from what the technology consider being suitable	100%	0 (Overridden operator)	The operator's input is overruled by the technology, as if the technology knows better (i.e. an automatic process)	0%
7 (Totally automatic)	All information and control is handled by the technology. The user is never involved	100%	0 (Absent operator)	There is no operator	0%

Step two

The following Table 8.2 is a similar reflection as Table 7.3. However, Table 8.2 was added a column to reflect the possible degrees of operator autonomy obtained from step one. Such autonomy degree is now parallel with the designated competences in the HCPS architecture. As a result, the table shows each architecture level that requires a cognitive competence (IQ) that the operator could perform. However, this need for cognitive performance will depend upon the system's configuration, which is the trade-off between machine automation and operator autonomy. In other words, the possible cognitive degree from Operator 4.0 into the system will depend on the cognitive degree possible from the machine, going from 0 to 10 (as pointed in table 8.1). Meanwhile, the EQ and SQ competences have been left with a fixed value of 10 because, as mentioned in the previous chapter, they are considered to only be performed by the user.

Table 8.2 Possible autonomy of Operator 4.0 in HCPS

Operator 4.0 Autonomy Grades in HCPS				
HCPS Level	**Capability per level**	**Worker component**	**Human Capital 4.0 Competence**	**Possible operator autonomy grade**
1. Connection	Sensing & Connecting	Five cognitive senses	Cognitive (IQ)	0 to 10
2. Conversion	Analysing & Processing	Memory Intellect	Cognitive (IQ)	0 to 10
3. Cyber	Comparing & Monitoring	Memory Intellect	Cognitive (IQ)	0 to 10
4. Cognition	Presenting & Prioritizing	Experience (memory)	Cognitive (IQ)	0 to 10
		Emotion	Emotional Intelligence (EQ)	10
		Intelligence	Spiritual Intelligence (SQ)	10
5. Configuration	Adapting & Executing	Five cognitive senses	Cognitive (IQ)	0 to 10

Step three

Although the cognitive competence covers most of the architecture levels in HCPS, it is necessary to evaluate all competences involved to estimate the input from the operator in the whole process while working with these systems. This type of analysis and information will support Operator 4.0's preparation and understanding of competence expectations when engaging with HCPS. The following table represents the method summary for this analysis.

Table 8.3 projects a standard method implemented to calculate the Operator 4.0 involvement in the (manufacturing) process while working with HCPS. It contains the five levels of the HCPS architecture, where each one of them makes 20% of the whole 100% for a complete process or cycle. It also shows the competences found in each architecture level, parallel to their respective percentage distribution for each level. The last column presents the estimation for each competence level distribution and the total in the whole cycle or process. This previous column requires the complementary table 8.3.1 to fill in the corresponding cognitive percentage. Sub-table 8.3.1 is a conversion table of percentages that aids in visualizing the operator cognitive input per architecture level, according to the cognitive collaboration percentage with HCPS in Table 8.1.

Table 8.3 also helps to notice that two competences were left with fixed values of 6.66% in the last column. These competences are assumed to be the full responsibility of the operator since such competences are hardly automated. Therefore, the values of EQ and SQ should remain as fixed values, while IQ values will depend upon the level of automation of the HCPS. The last sum of all percentages is translated into a percent of the operator's competence participation in collaboration with a given HCPS.

Table 8.3 Percentage of Operator 4.0 competence involved while working with HCPS

	Operator 4.0 Competence Percentage in HCPS				
	Number of (process) levels	**% per level**	**Competence per level**	**% Competence distribution**	**Operator competence distribution (%)**
	1 (Connection)	20%	Cognitive (IQ)	Up to 20%	According to table 8.3.1
	2 (Conversion)	20%	Cognitive (IQ)	Up to 20%	According to table 8.3.1
	3 (Cyber)	20%	Cognitive (IQ)	Up to 20%	According to table 8.3.1
	4 (Cognition)	20%	Cognitive (IQ)	Up to 6.66%	According to table 8.3.1
			Emotional Intelligence (EQ)	Up to 6.66%	6.66%
			Spiritual Intelligence (SQ)	Up to 6.66%	6.66%
	5 (Configuration)	20%	Cognitive (IQ)	Up to 20%	According to table 8.3.1
Total	5	100%		100%	Sum of the percentages (i.e. 17%)

Sub-table 8.3.1

Operator IQ input		
if % in the whole HCPS		**then % per architecture level**
100%	→	20%
80%	→	16%
60%	→	12%
40%	→	8%
20%	→	4%
0%	→	0%

Step four

Since it is considered that EQ and SQ are the constant percentages needed when collaborating with HCPS, Operator 4.0 should be trained in exercising and displaying skills and capabilities for such competences. To this end, the operator should be trained on capabilities already highlighted in the updated MABA-MABA list (table 7.1). Operator 4.0 needs to excel at those capabilities at which men are still better than machines by integrating them into the basic competence. Therefore, Figure 8.4 depicts seven key capabilities suggested in this research to promote Operator 4.0 development on EQ and SQ competences. We consider that such capabilities foster the upskilling of future operators and their confidence and trust in automated systems. This is especially important because trust in automation can be affected by the self-confidence of operators, which is derived from their skills and capabilities [239].

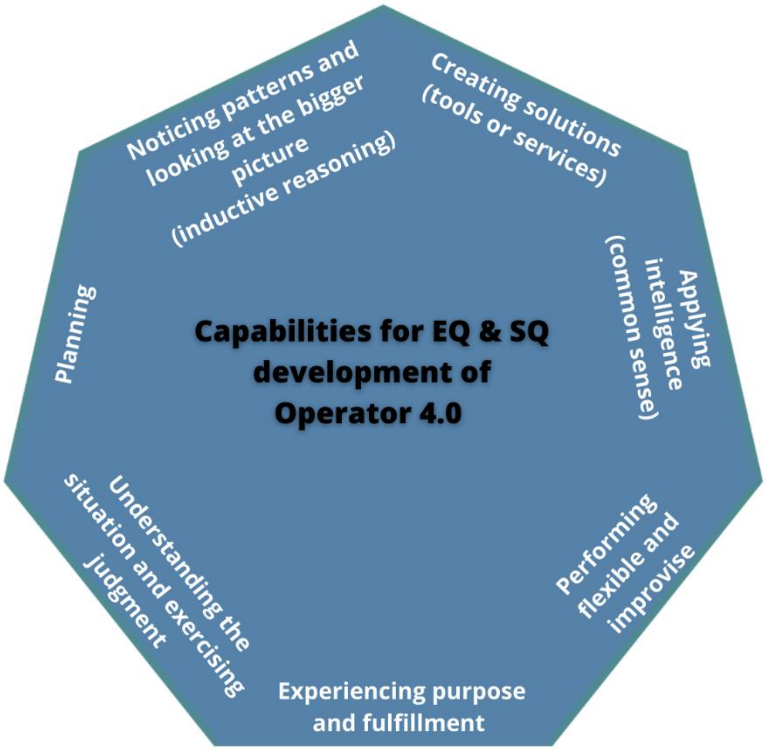


Figure 8.4 Key capabilities for boosting EQ and SQ competences of Operator 4.0

This does not mean that only EQ and SQ competences should be promoted to Operator 4.0. Cognitive intelligence should continue to be trained as well. However, it is uncertain, or irregular, the extension of cognitive involvement from the operator into the production system. Most common cognitive functions are already embedded into automated mechanisms.

8.4.2 Job Skills in Role Activities

This type of professional skill is the one required for Operator 4.0 to carry out multiple and diverse role activities during the working period. The skills and competences of this type may or may not involve HCPS to exhibit or perform the working activity. However, this should depend on the demands from the activity and the actual technology capability of the company. This means that regardless of automation, the future operator must exhibit certain mastery and competence to contribute to the manufacturing company through job tasks.

Therefore, it is required to review most, if not all, job activities needed from Operator 4.0 in terms of skills. This type of appraisal should allow two important results, the overview of the operator role activities and the specific abilities considered for each activity. Consequently, to develop the required evaluation, outputs from Chapter 5 and section 8.3 have been used, along with a standard methodology of three short steps:

- **Step one.** Listing the array of role activities in a column
- **Step two.** Listing the Huma Capital 4.0 competences in a row above the column
- **Step three.** Adding and matching the skills in each cell according to the activity and type of competence. The pool of skills to select from are in the Human Capital 4.0 competence, elaborated in Table 5.1

As mentioned in section 8.3, there are eight activities or responsibilities of Operator 4.0 that are foreseen as a guided answer to some of the Industry 4.0 challenges. Therefore, we have used those same activities to showcase this type of review for this case and practical purposes. As a result, Table 8.4 shows the template of an appraisal for job-task skills of Operator 4.0 according to the demanded activities. It identifies the fit skills for each of the activities and each competence, such as soft, hard, digital, financial, cognitive, emotional, and spiritual. In other words, a diverse pool of skills will be found suitable to support a corresponding job activity of the operator.

There is a couple of benefits that are originated from this assessment template worth mentioning:

- It allows for visibility of the skills needed in an activity before its implementation. This can provide the company with training programs to cover the skills demanded and help prepare the operator accordingly.

- It allows for the expandability of the evaluation into more activities and skills. In other words, the pool skills within each type of competence, and the list of job activities, are not limited to those presented so far. They can be expanded as necessary, fitting the needs of both the company and operators. Nevertheless, if more skills were added, it is essential to include them within the best suitable competence classification to clarify the competences.

Table 8.4 Appraisal of Operator 4.0 skills needed versus the role activities

Operator 4.0 Job-task Skill Review							
Activities 	Human Capital 4.0 competence						
	Soft (Social)	Hard (Technical)	Digital	Financial (FQ)	Cognitive (IQ)	Emotional (EQ)	Spiritual (SQ)
1. Personalizing manufactured products	Cooperation Communication Adaptability	Industrial processes HMI knowledge Digital networks	Digital networks Cloud computing Data-base management Industry 4.0 technology (i.e. AM/AR)	N/A	Depending upon the automation of the system (i.e.HCPS). But minimum: Problem-solving thinking, analytical thinking, verbal aptitudes (i.e. reading)	Self-motivation Empathy	Creativity Value-oriented Trust
2. Trouble-shooting production flexibly	Teamwork Communication Negotiation Adaptability Willingness to learn	Industrial processes Understanding of standards Problem-solving techniques Digital security	Cybersecurity Programming Digital networks Industry 4.0 technology (i.e. AI/VR)	Cost evaluations Money saving Budgeting	Memory Problem-solving thinking, Analytical thinking Coordination, Verbal and Numerical aptitudes	Self-awareness Self-control Self-flexibility Self-motivation Positive outlook Empathy Circumstance awareness Conflict management	Compassion Creativity Wisdom Leadership Accountability
3. Overseeing and assuring real-time production feedback	Cooperation Communication Veracity	Industrial organization Industrial processes HMI knowledge Digital networks	Clould computing Database management Industry 4.0 technoloy (i.e. Big Data analytics)	N/A	Depending upon the automation of the system (i.e.HCPS). But minimum: Analytical thinking, Numerical aptitudes (i.e. maths)	Self-awareness Circumstance awareness	Trust Leadership
4. Achieving sustainable production with resource optimization	Teamwork Communication Negotiation Adaptability Willingness to learn	Industrial processes Understanding of standards Industrial organization Problem-solving techniques	Digital networks Cloud computing Data-base management Industry 4.0 technology (i.e. AM/VR)	Money saving Cost evaluations Budgeting Analysis for ROI	Memory Problem-solving thinking, Analytical thinking Coordination, Verbal and Numerical aptitudes	Self-control Self-flexibility Positive outlook Positive influencing	Creativity Wisdom Purpose-drive Inclusiveness
5. Producing value at the company creatively	Teamwork Communication Negotiation Adaptability Interculture interest	Industrial processes Understanding of standards Industrial organization Problem-solving techniques	Programming Digital networks Cloud computingc Software management Industry 4.0 technology (i.e. AM/AI)	Money saving Cost evaluations Budgeting Analysis for ROI Indentifying assets and liabilities Cash-flow	Memory Problem-solving thinking, Analytical thinking Coordination, Verbal and Numerical aptitudes Abstract reasoning	Self-awareness Self-flexibility Self-motivation Positive outlook Empathy Positive influencing	Generosity Innovation Meaning-drive Value-oriented Inclusiveness Leadership Legacy
6. Life-long learning to stay professionally productive	Cooperation Communication Interculture awareness/interest Negotiation Adaptability Willingness to learn (from others) Veracity	Industrial organization Industrial processes Problem-solving techniques Human-Machine Interface knowledge	Cloud computing Database management	Money saving Cost evaluations Budgeting Identifying assets and liabilities	Verbal aptitudes Numercial aptitudes Problem-solving thinking Abstract reasoning Analytical thinking	Self-awareness Self-control Self-flexibility Self-motivation Positive outlook Empathy Circumstance awareness	Creativity Trust Wisdom Gratitude Value-oriented Inclusiveness Legacy
7. Balancing own workload to reconcile personal and professional life	Teamwork Communication Negotiation Adaptability Veracity	Industrial organization Industrial processes Problem-solving techniques	Digital networks Cloud computing	Money saving Financial planning Budgeting Investing Paying and working with debt Generating cash-flow Analysing balance sheet vs Income statement	Problem-solving thinking Abstract reasoning Analytical thinking	Self-awareness Self-control Self-flexibility Self-motivation Positive outlook Empathy Circumstance awareness	Wisdom Gratitude Meaning-drive Value-oriented Integrity
8. Engaging in a high-wage production economy	Teamwork Communication Negotiation Adaptability	Industrial processes Understanding of standards Industrial organization Problem-solving techniques	Digital networks Cloud computing	Money saving Cost evaluations Budgeting Indentifying assets and liabilities Cash-flow	Depending upon the automation of the system (i.e.HCPS). But minimum: Analytical thinking, Numerical aptitudes (i.e. maths)	Self-awareness Self-motivation	Purpose-drive Value-oriented Inclusiveness Leadership Legacy

8.5 Operator 4.0: Mediation with Contemporary Challenges

As discussed in the literature review and as addressed in Chapter 6, four major challenges are affecting the industry and the workforce today: a skill gap, an ageing population, a compromised wellbeing, and VUCA situations. In this sense, Operator 4.0 is not aloof from these challenges, but rather the operator might be affected to various degrees. This section's aim is twofold. First, to stress the need to support Operator 4.0

for such existing challenges. Second, to promote the skill-needed assessment framework from the RHAM model as an alternative to address this issue from the operator perspective.

In general, the four existing challenges can have an impact on Operator 4.0 in diverse ways. All will depend on the individual state of the operator and the environment or circumstances in the company. However, whether the impact is positive or negative will depend on the operator's capability to cope with the new. Therefore, the assessment for such specific circumstances involving the four challenges needs to be reviewed from a competence-based perspective, just as the previous examples using the RHAM method. This holistic skill-based method of situational evaluation will allow exploring and finding out the type of competences and specific skills needed for Operator 4.0 within existing problems.

This section presents four self-exploring scenarios from the operator's perspective to face each of the identified challenges. Similar to the examples in chapter 6, each of the following scenarios helps understand and translate operator-related problems into a specific and structured panorama for possible operator-related solutions. The situation's assessment and the analysis's outcome are expressed from a skill-based perspective to ease the problem of each scenario.

Scenario 1, a skill gap: a female Operator 4.0 faces difficulties to meet her company requirements in terms of capabilities. Due to her employment as a new recruit, the operator is facing some technical and personal difficulties in her role. She requires to show an enhanced work performance in the technical side of her job and the social part with her colleagues. Therefore, the RHAM method analyzes the case and provides supports for her case.

Table 8.5 presents the summary assessment of the situation in favor of the operator. Four key skills were identified as needed for her situation, where each one of them provides a reason and a prescribed solution for them.

Table 8.5 Mediation scenario for Operator 4.0 on challenge number one

RHAM-based Assessment Framework for Industry 4.0 Challenges						
(1)		(2)		(3)		
Challenge number	Challenge type	Human type	Age range	Involved Ecosystem level	Wanted skills	Type of competence
1	Skill gap	Employee (Operator)	Adulthood (20-35)	Workplace	Teamwork	Soft
					Programming	Technical
					Empathy	EQ
					Creativity	SQ
(4) Situation assessment (from the skill-based and person's perspectives)						
From the skills listed on step3, what are the reasons for the person to improve such skills? Teamwork: the new operator does not interact and address her colleagues according to the company's values to work together Programming: the operator struggles to code C++ with advanced commands Empathy: the operator does not understand how her impulsive actitud is affecting her teamworkers at the floor shop Creativity: the operator needs to enhace her capacity for imagining new shapes of finished products						
Is there need for considering further skills? Which ones? Why? *None at the moment*						
(5) Outcome of the analysis						
According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case? For teamwork: she will be taught the company's goals & values, and be added to an accountability group within the company For progamming: she will be enrolled to an advance technical course on C++ from an outsourced company For empathy: she will take on an EQ course and small group sessions with therapy and exercises For creativity: she will take on SQ course with regular mindfulness meditations						

Scenario 2, aging population: a male Operator 4.0 faces conflict as beliefs of his growing age pose difficulties between his company and personal needs. The company wants to keep and promote the operator due to his knowledge. However, the operator does not feel comfortable with the new changes in digital implementations and his personal capacity to face those changes.

Table 8.6 presents the summary assessment of the situation in favor of the operator. Three critical skills were identified as needed for his case, where each one of them provides a reason and a prescribed solution for them.

Table 8.6 Mediation scenario for Operator 4.0 on challenge number two

RHAM-based Assessment Framework for Industry 4.0 Challenges						
(1)		(2)		(3)		
Challenge number	Challenge type	Human type	Age range	Involved Ecosystem level	Wanted skills	Type of competence
2	Aging population	Senior employee (Operator)	Mature Adulthood (50+)	Workplace	Digital networks	Digital
					Willingness to learn	Soft
					Self-Trust	SQ
(4) Situation assessment (from the skill-based and person's perspectives)						
From the skills listed on step3, what are the reasons for the person to improve such skills? Digital networks: the operator is required to learn this new skill for him because instead of retiring, he has been convinced by the company to continue working with them for longer. Willingness to learn: the operator's attitude towards learning new things is a bit rust since he has not been in teaching/learning lessons for a long time. Self-trust: the operator requires to enhance his trust on himself to take on the coming changes optimistically						
Is there need for considering further skills? Which ones? Why? *None at the moment*						
(5) Outcome of the analysis						
According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case? For digital networks: the operator will be intructed by another member from the IT department for six months For willingness to learn and self-trust: both skills will be imparted by the internal HR department with practices on collaborative teamwork and on self-gain experience/trust.						

Scenario 3, a compromised wellbeing: a female Operator 4.0 due to job and professional stressors faces difficulties in the form of unhealthy mental conditions, which cause problems to keep up with her work professionally. Previously, her job performance was up to the company's standards; however, her attitude at work and her results have been declining since last year.

Table 8.7 presents the summary assessment of the situation in favor of the operator. In total, six critical skills were identified as needed for her situation, where each one of them provides a reason and a prescribed solution for them.

Table 8.7 Mediation scenario for Operator 4.0 on challenge number three

<table>
<tr><th colspan="7">RHAM-based Assessment Framework for Industry 4.0 Challenges</th></tr>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="3">(3)</th></tr>
<tr><th>Challenge number</th><th>Challenge type</th><th>Human type</th><th>Age range</th><th>Involved Ecosystem level</th><th>Wanted skills</th><th>Type of competence</th></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Compromised wellbeing</td><td rowspan="4">Employee (Operator)</td><td rowspan="4">Adulthood (20-35)</td><td rowspan="4">Workplace</td><td>Self-awareness</td><td>EQ</td></tr>
<tr><td>Communication</td><td>Soft</td></tr>
<tr><td>Compassion</td><td>SQ</td></tr>
<tr><td>Purpose</td><td>SQ</td></tr>
<tr><th colspan="7">(4) Situation assessment (from the skill-based and person's perspectives)</th></tr>
<tr><td colspan="7">From the skills listed on step3, what are the reasons for the person to improve such skills?
Self-awareness: the operator keeps externing frustration, stress, and anxious/compulsive behaviours around her job environment
Communication: altough the operator interacts with some of her workmates, she does not communicate effectively and respecfully with most of the company's members
Compassion: the operator tends to be aggressive towards her workmates, and even herself
Purpose: the operator lacks to see meaning or reason for her work</td></tr>
<tr><td colspan="7">Is there need for considering further skills? Which ones? Why? Gratitude and Value-orientation (SQ), as she does not display gratitude and lacks respect</td></tr>
<tr><th colspan="7">(5) Outcome of the analysis</th></tr>
<tr><td colspan="7">According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?
For compassion, purpose, gratitude, and value-orientation: the operator will go through a full course of SQ with practical exercises, such as meditation, yoga, comtemplation by an especialized company.
For self-awareness: she will complete an EQ course with practices of self-management by the HR department
For communication: this skill will be encouraged and addressed throughout the mentioned courses, and will be assessed at different stages in the process</td></tr>
</table>

Scenario 4, a VUCA situation: a male Operator 4.0 faces involvement with volatile, uncertain, and complex situations in his professional life, especially in his new job role. Due to the strategy of cost reductions, the company requires the operator to handle total new responsibilities than previously performed. He is now to become the whole supervision of the production line, which requires using new technology to keep a record of production costs (among other new features).

Table 8.8 presents the summary assessment of the situation in favor of the operator. Six critical skills were identified in total as needed for his case, where each one of them provides a reason and a prescribed solution for them.

Table 8.8 Mediation scenario for Operator 4.0 on challenge number four

<table>
<tr><th colspan="7">RHAM-based Assessment Framework for Industry 4.0 Challenges</th></tr>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="3">(3)</th></tr>
<tr><th>Challenge number</th><th>Challenge type</th><th>Human type</th><th>Age range</th><th>Involved Ecosystem level</th><th>Wanted skills</th><th>Type of competence</th></tr>
<tr><td rowspan="4">4</td><td rowspan="4">VUCA</td><td rowspan="4">Employee (Operator)</td><td rowspan="4">Midlife (36-50)</td><td rowspan="4">Workplace</td><td>Adaptability</td><td>Soft</td></tr>
<tr><td>Digital systems</td><td>Digital</td></tr>
<tr><td>Self-Trust</td><td>SQ</td></tr>
<tr><td>Wisdom</td><td>SQ</td></tr>
<tr><th colspan="7">(4) Situation assessment (from the skill-based and person's perspectives)</th></tr>
<tr><td colspan="7">From the skills listed on step3, what are the reasons for the person to improve such skills?
Adaptability: the operator requires to adapt to the new situation as he is the person in charge of a new system
Digital systems: the operator needs to work with a new digital technology in his daily operations
Self-trust: the operator requires to uplift his own trust to be able to cope with the new responsibilities
Wisdom: it is necessary for the operator to increase his spiritual intelligence and discernment to manage and operate IQ and EQ skills in a balance state</td></tr>
<tr><td colspan="7">Is there need for considering further skills? Which ones? Why? Budgeting and management of costs (FQ): to undertand the basic financial literacy needed to work with the new features of the technology 'the track and management of the production line costs'</td></tr>
<tr><th colspan="7">(5) Outcome of the analysis</th></tr>
<tr><td colspan="7">According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?
For adaptability, self-trust, and wisdom: EQ and SQ competences will be taught and delivered by a programme from the company to the employees facing new positions due to the new changes in the company.
For digital systems: the provider of the technology will be asked to deliver a course to the new operator(s) using their technology, along with continous support from the in-house IT department.
For financial budgeting and management of costs: an introductory seminar will be given to the operator to be able to understand, present, and talk in terms of costs about his production work and relate to the technology's features</td></tr>
</table>

8.6 Operator 4.0: An Updated Definition and View

The early definition of Operator 4.0 is a considerable effort making inroad to the human element for Industry 4.0. Such description heeded the need for human considerations when planning and heading to the next Industrial Revolution, the operators in factories. However, such definition mainly worked on the evolution of the machines or tools utilized by the operator across the different periods. It offered minimum attention to other vital aspects, such as interactions and competences of the future operator. This need for better holistic attention is covered in this section by elaborating on a renewed and more complete definition for Operator 4.0, which keeps a human focus.

Table 8.9 is created from the collection of resources and the outputs that have been put forward in this research study. It summarizes the analysis of the operator's evolution from essential technical and human aspects. This view clearly shows the evolutionary process from Operator 1.0 to Operator 4.0. Although some of the technical aspects had been mentioned before, new ones have been pointed out, i.e. the supporting technology and the work type. Moreover, all the human elements are a novel form of analysis for the operators' characteristics that have sprung from this research work.

Based on the table, it is visible that the job demand on the workers has been increasing until reaching the stage of Operator 4.0. Both expectations and job autonomy have increased proportionally at different stages since the First Industrial Revolution. However, as the demands on the operator increase, the development and upskilling for competence expand. This growth and development on the human side is the key to coping and carrying out the technical side of Industry 4.0. Therefore, the motivation and the basics for the following more applicable definition of Operator 4.0 comprehends all this into perspective.

Table 8.9 Technical and human aspects concerning the operator evolution

		Operator 1.0	Operator 2.0	Operator 3.0	Operator 4.0
	Periods	1700 - 1870	1870 - 1970	1970 - 2000	2000 - Today…
Technical Aspects	Disruptive element(s)	Water, Steam, Fire	Electricity	Microprocessors, Electronics	Internet
	Machinery / Tools	Steam engine, Sewing machines	NC machines, Assembly lines	Computers, PLC's, Robots	Nine pillars (i.e. CPS, IoT, AM, AR, etc.)
	Supporting technology	Mechanically assisted	Electrically assisted	Computer assisted	CPS assisted
	Work type	Repetitive (i.e. un-loading, manipulating, transporting)	Repetitive and Specialized (i.e. assembling, cutting)	Specialized (i.e. programming)	Specialized and Multidisciplinary (i.e. programming, supervising, decision making)
Human Aspects	Role interactions	Static (i.e. only with supervisor)	Semi-dynamic (i.e. with supervisor and HR department)	Dynamic (i.e. with sup, HR department, Engineering department)	Multi-dynamic (i.e. HR, Engineering, Managers, Customer, etc.)
	Competency integration	Hard (1st Ind. Rev.)	Hard, Soft (mid 19th century)	Hard, Soft, IQ (1980's), EQ (1990), Digital (mid 90's)	Hard, Soft, IQ, EQ, Digital, SQ (2000), FQ (2007)
	Job autonomy (i.e. problem-solver, creative, leader, etc.)	Basic (Novice)	Intermediate (Advanced beginner)	Upper (Competent)	Advanced (Proficient)

In this research work, we propose Operator 4.0 as ***"the technology-aided worker who performs in a holistic way to interact and operate with machines and humans as needed, and is supported by approaches of Human Capital 4.0 development, upskilling, and wellbeing while navigating continuous job (changes)"***.

Unlike the pioneering concept with an automation focus on cognitive capabilities, the new proposed engineering philosophy is focused on enhancing more expansive human capabilities, i.e. soft, emotional, spiritual, etc. However, this does not seek to leave aside the technical automation part. Instead, it aims to ease the job adaptation and implementation between automation and operators when required. Moreover, the suggested concept of Operator 4.0 also supports the development of a hybrid type of operators that may arise at the different stages of the company's Industry 4.0 implementations. This will not fix the operator to a particular fit idea of worker, but rather it offers the human flexibility to adapt accordingly. Overall, this term will help emphasize the strengths of the human side of the industry by keeping operators as a key focus rather than a 'nice to have' on automation developments.

Figure 8.5 displays the overall scope found of this research work. This view is a more complete, human-based conception of Operator 4.0, a view of the operator needed for future companies. The competences derived from the holistic approach of Human Capital 4.0 should support and empower the operator. This empowerment is not only on the cooperation with Industry 4.0 technologies but also on the management of regular job changes and coping with existing challenges in the industry.

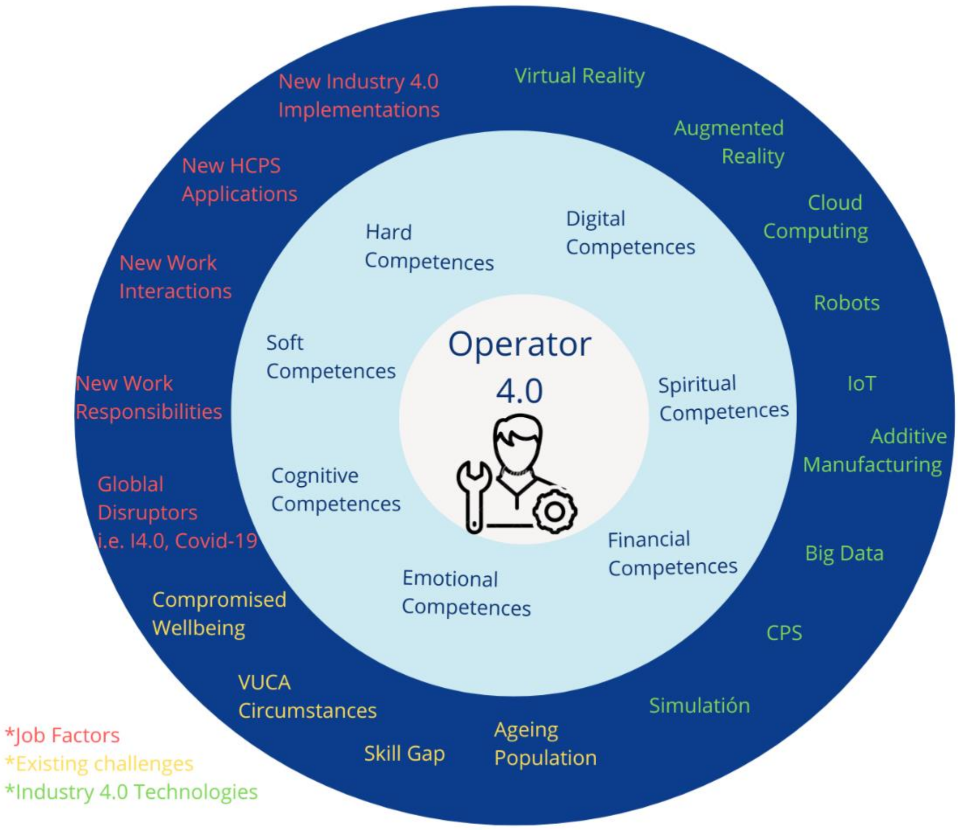


Figure 8.5 The wholesome view of Operator 4.0 capability and engagement

In general, the new vision of Operator 4.0 presented in this study creates a pathway towards a more self-reliable and capable type of manufacturing worker. They will operate at the demanded pace from the situations in their work environment. This does not oppose the original concept, but rather it helps to complement it in a more human-centric perspective while filling for the limitations on the early idea. Operator 4.0 will not stop using mechanical or technological machinery at any time soon. Therefore, the relevance to visualize and study the capability similarities or differences between these two elements (operator-machine). This kind of analysis will provide an understanding of the human strengths that need to be supported at the operator level, not only at the automation level. For this reason, the new concept aims at bridging the gap and balancing between a techno-driven industry and a human-related industry, such as Industry 4.0 could offer.

8.7 Summary

This chapter elaborated on answering the fourth-B question. The problem addressed was that the original concept of Operator 4.0 lacked the human-based analysis required in Industry 4.0 for its conception. Despite being a successful effort to put the labor side into perspective for Industry 4.0, the original view only focused on a technical-based analysis, i.e. machinery used by operators. Therefore, this work aimed at presenting an updated view of the concept of Operator 4.0. Furthermore, this new view was systematically constructed based on the human-sided analysis supported by the Human Capital 4.0 development across the different chapters 4-7, as it was expressed in Figure 8.2.

Limitations in the original view of Operator 4.0. The original conception about Operator 4.0 was discussed while stressing the facts of its technological focus. Moreover, a couple of state-of-the-art studies were found to express their unconformity with such a vague concept of the operator.

In the end, four relevant limitations were found in the original idea of Operator 4.0. (1) It only included the tool evolution interacting with operators while missing out on human factors, i.e. work-team interactions and competences. (2) It kept automation as the only means for human work and capability enhancement, which poses a danger to becoming absolutely dependent on technology for any of those activities. (3) It only considered cognitive capabilities, leaving out most of the other human capabilities (i.e. emotional, spiritual, etc.), which resulted in a shadow on human traits such as values, imagination, or purpose. (4) It left unclear how, or on which basis (i.e. preparation, competences), the operator should become ‘smart and skilled’ to perform intelligent and skillful work.

Operator 4.0: the vision on working interactions. The vision of Operator 4.0 was merged with that of the 'Industry 4.0-enabled smart working interaction' from chapter 7. It aimed at bringing benefits such as flexible means of communication, decentralized flat hierarchies, open innovation, dynamic, adaptable capabilities, and resilience to the operator's view. This perspective was presented in Figure 8.3, where Operator 4.0 will have inputs and outputs of communication and interactions between every organization's stakeholder, including customers.

In addition, due to the new type of interaction, specific upcoming changes in organizational responsibilities were provided as a guided answer to the eight Industry 4.0 goals and challenges previously identified. Therefore, a set of eight envisioned forthcoming activities for Operator 4.0 was listed and described.

Operator 4.0: appreciation of professional competence. Two divisions were created to facilitate the evaluation, review, and inclusion for Operator 4.0 competences and skills, in alignment with Human Capital 4.0 competence.

The first type, collaborative competences with HCPS, referred to the competences for the constant communication and collaboration the operator will need when working with machines, especially HCPS. This appraisal was put together using outputs from Chapter 7 and a four-step systematic methodology. The second type, job skills in role activities, refers to the skills required for Operator 4.0 to carry out multiple and diverse job activities to contribute to the company, regardless of the involvement of machines. This appraisal was elaborated using outputs from previous sections and a three-step standard methodology.

Operator 4.0: mediation with contemporary challenges. It was highlighted the need to support Operator 4.0 with existing challenges expressed in Chapter 6, such as a skill gap, an aging population, compromised wellbeing, and VUCA situations. For achieving this, the holistic skill-based RHAM method was proposed to assess and aid the operator's capability to cope with such circumstances and challenges.

In summary, four self-exploring scenarios were elaborated from an operator perspective to encounter and skill-based assess each identified challenge. Scenario one involved a skill gap issue that an operator could face when she is a new recruit and finds it difficult to adapt to her role and company. Scenario two implicated an aging issue that a senior operator could face when the company wants him to work for longer years and with a promoted position. Scenario three involved a compromised wellbeing issue that an operator could face from unhealthy mental conditions that cause problems to keep up with her work. Scenario four implicated a VUCA situation that an operator could face when new requested responsibilities are different from his previous ones due to adapting to a new role and technology.

Operator 4.0: an updated definition and view. Two main outputs were provided. One is the overview of two key aspects in the study of the operator evolution (1.0 to 4.0), such as the technical and human aspects. Another is the holistic-focused and human-centric definition for Operator 4.0 that was achieved from the complete research on this topic.

The human and technical aspects were divided by periods of time, according to those of Operator 1.0, 2.0, 3.0, and today's Operator 4.0. Such kind of analysis among these aspects resulted in a novel view for the operator characteristics, as shown in Table 8.9. The updated definition of Operator 4.0 was formulated as an engineering philosophy that presented a more complete, human-based view of Operator 4.0, which is needed for future company operators. The resulted scope from this conception was displayed in Figure 8.5 as the wholesome view of Operator 4.0 capability and engagement.

Chapter 9

Conclusions and Future Work

Outlined objectives of this research have been achieved as the previous chapters elaborated. Therefore, this chapter presents the conclusions reached due to this research. First, a study summary is presented to recap the research context and the completed research. Then, the major achievements and contributions of this research are provided. Third, the description of the limitations of this research is indicated. Lastly, an outlook to future research recommendations is outlined.

9.1 Recap of the Research

The main steam and motivation for this research derive from the natural imposition of Industry 4.0 towards the human side of the industry, the workforce. The now 10-year-old paradigm of the Fourth Industrial Revolution is acquiring ever more present in the industrial, engineering, and academic fields. A large amount of work has been done, mainly at the technological and technical aspects of it. It has gone from the inclusion of critical enabling technologies, i.e. VR, AR, AM, CPS, etc., to integrate such technologies with user exploring applications, i.e. data analytics + operator, VR + operator, etc. In time, the engineering concept of Operator 4.0 came to heed a part of the workforce in manufacturing, the operator of Industry 4.0. Such a view of the operator quickly gained attention. It was the first attempt for human participation and inclusion in Industry 4.0, which represented a technological human-machine collaboration concept. However, whether such an ingenious term was robust and resourceful enough to work out the Industry 4.0 challenges and support the operator and human side of the industry demanded questions. Consequently, a study of the phenomenon between Industry 4.0, Operator 4.0, and the labor (human) force appealed to our attention.

In order to identify the research gaps and work towards resourceful and solid answers, it was first necessary to understand the current status and landscape among the involved interactions. Consequently, literature research was conducted to cover these three angles: the Industry 4.0 paradigm and its visionary and technological reach, especially in future smart factories; the working and workforce existing issues, such as competence (competences and skills), challenging contemporary situations, and future preparation; and the Operator 4.0 view and its overall reach. A thorough review of these aspects revealed research gaps that highlighted the lack of support towards the human side of Industry 4.0, which became the key motor for this study. Moreover, the identified gaps were used to underpin the structure for the research questions formulated as part of the methodology followed in the study. Therefore, the answer to these research questions provided a means and a resource to address the corresponding gaps and meet the objectives.

A total of five research questions were investigated, one per identified gap. The first question addressed the need for human-sided terminology that should support the workforce in the advent of Industry 4.0. The second question aided on the need for a workforce competence that should back and prepare for the demands of disruptive challenges, such as Industry 4.0. The third question supported the necessity for an alternative model and method that should aid in human capital preparation and development under the new competence. The fourth question assisted on the need for analyzing and understanding some of the key implications happening within the manufacturing workforce due to technological advancements. Lastly, the fifth question addressed the need to improve and update the Operator 4.0 concept and view, according to the findings and results from the other questions.

To answer the research question number one, it was elaborated the foundation and development of a new term to best represent an inclusive set of future-proofing attributes for the workforce in Industry 4.0. Human Capital 4.0 is the new term developed on an approach different from the traditional term of human capital to support the workforce heading to Industry 4.0 goals and challenges. In principle, the new term suggested a holistic competence instead of technical-based competence and a holistic preparation instead of a job-based preparation for workforce development. This shifted approach was reasoned after considering eight potential goals sought in Industry 4.0, such as personalization, resource optimization, flexibility, novel value services, high-wage economy, real-time reaction, life-long inclusion, and work-life balance. Moreover, to cover for the welfare issue highlighted on the challenges impacting the workforce, the attribute of wellbeing was also added to the new term. For this case, wellbeing was set as the balance between the set of Industry 4.0 challenges and the set of workforce resources to foster human wellbeing as a norm (as a means and as an end) in the whole conception of HC 4.0. Therefore, a total of three future-proof attributes comprises the resulted term, (1) wellbeing, which was further elaborated in this chapter, and (2) holistic competence and (3) holistic preparation, which are elaborated in the following chapters.

The answer for research question number two expanded to identify and describe the competences required for the new paradigm of Industry 4.0, not only from the technical side but, more importantly, from the human side. A holistic typology of seven competences was formed for Human Capital 4.0, and it included pools of the most wanted skills for each category. (1) The soft workforce [adaptable + social] is the competence required for workforce adaptability, interconnectivity, and decentralization needed in Industry 4.0. (2) The hard workforce [technical + dexterous] is the competence required for the technical and technological knowledge of the workforce requested in Industry 4.0. (3) The cognitive workforce [intellectual + analytical] is the competence required for handling complexity expected in Industry 4.0 environments. (4) The emotional workforce [self-aware + empathetic] is the competence required for managing stressful and emotional fatigue circumstances found during Industry 4.0. (5) The digital workforce [digital literate + digital interactive] is the competence required for the basic to advanced digital literacy demanded in this new age. (6) The spiritual workforce [innovative + purposeful] is the competence required for the employees' and employers' creativity and leadership needed in an inclusive Industry 4.0. (7) The financial workforce [financial literate + financial planner] is the competence required for financial wellbeing, financial preparedness, and entrepreneurship necessary in today's disruptive challenges, i.e. Industry 4.0, Covid-19.

To answer the research question number three, it was presented the development of a human-centered model to support the allocation of a holistic competence for workforce preparation and development, along with the development of a method of application for the model. The Reference Human-centric Architecture Model (RHAM) is the model for human-centric and skill-based preparation of Human Capital 4.0, which includes three integral parts that form a person's life. (1) The competence axis, which included the competences found in the previous chapter; (2) The lifetime cycle & value stream axis, which displayed the known stages of life during a person's lifetime; (3) The ecosystem axis, which is considered the aggrupation of human environments for activity and interaction. Different from the traditional approach, the RHAM model offers a human-centric and holistic competence approach, which also permitted the basis for the elaboration of a challenge skill-based framework of the application. This systematic framework was developed to address contemporary challenges impacting the workforce by assessing skill requirements according to the given situation. Four self-exploring scenarios were put forward to showcase its practicability. In the end, the RHAM model was found to inherent similar advanced benefits as the original smart architecture. These benefits are interoperability, interdisciplinarity, customization, flexibility, and digitalization, which can be featured for further solutions and applications.

The answer for research questions number four-A elaborated on a worker-centric perspective of key manufacturing implications due to technology and its co-evolution with workers. It covered three significant analyses. (1) The workforce structure and role interactions in Industry 4.0, which explained and represented a new 'Industry 4.0-enabled smart working interaction' for the manufacturing workforce. Such a new type of interaction maintains a mesh-like decentralized and flexible human labor network, which further benefits were explained. (2) The workforce capability co-evolution with technology, which elaborated on the human capabilities cooperating and evolving with technologies. The first part of the analysis covered workforce capabilities that have been outperformed or replaced by key technological disruptors. The second part presented the update of the MABA-MABA list to highlight the comparison between the capabilities of men and machines. (3) The workforce competence cooperation with HCPS, which surfaced and highlighted the human competences embedded and collaborating with the HCPS system. The first stage created the worker-machine component distribution in the HCPS pyramid architecture by designating human and machine elements to each of the five levels of the architecture. The second stage revealed the analysis for the IQ, EQ, and SQ competences involved in HCPS, along with their possible level of automation.

Finally, to answer research question number four-B, it was developed the expansion and the update of Operator 4.0 by integrating the factors and human-sided perspective of Human Capital 4.0 generated across the different chapters 4-7. Such development and integration were delivered in five sections. (1) Limitations in the original view of Operator 4.0, which discussed and presented four significant limitations in the original concept. (a) It missed human factors, such as work-team interactions and competences; (b) It kept automation as the only means for human work and capability enhancement; (c) It left out most human capabilities, i.e. emotional or spiritual, and other human traits, i.e. values, imagination, or purpose; (d) It was unclear the basis, or development, on which the operator should become 'smart and skilled' to perform intelligent and skillful work. (2) The vision of Operator 4.0 on working interactions integrated the view of the 'Industry 4.0-enabled smart working interaction' to the Operator 4.0 perspective to bring new benefits to the working structure and interaction, i.e. flexibility, decentralization, innovation, adaptability, and resilience. As a result, new foreseen responsibilities were put forward to answer some of the challenges of Industry 4.0 from the Operator 4.0 point of view. (3) The appreciation of Operator 4.0 professional competence divided the operator's competences and skills into two divisions to facilitate evaluation, review, and inclusion. (a) The collaborative competences with HCPS, and (b) The job skills in role activities. Each type of division carried out a particular set of steps to analyze and present the competence for the operator. (4) The mediation of Operator 4.0 with contemporary challenges highlighted the need for supporting Operator 4.0 with existing challenges, such as a skill gap, an aging population, compromised wellbeing, and VUCA situations. Therefore, a total of four self-exploring scenarios showcased the application of the holistic skill-based RHAM method to assess and aid the operator's capability to cope with those circumstances. (5) The updated definition and view of Operator 4.0 offered two main outputs. First, the overview of key technical and human aspects for the operator evolution from the First to the Fourth Industrial Revolution. Lastly, it provided the proposed updated definition about Operator 4.0 achieved from the complete research on this topic. Such engineering philosophy kept a more comprehensive, human-based view of operators for future companies.

9.2 Research Contributions

Human Capital 4.0 and its associated components were developed, along with the updated overview of Operator 4.0, to enable the infusion of the human and workforce side into the technicality of Industry 4.0. The scientific contributions made through the course of this Ph.D. are highlighted as follows:

Contribution 1: A holistic interconnected human-based model for the Fourth Industrial Revolution and its disruptions. To date, little research has been done on developing human-centric approaches to technological advancements and foreseeable changes in the industry, primarily Industry 4.0. This research proposed a systematically structured terminology, based on an early term, to provide guidelines for human inclusion while moving forward with the Industry 4.0 contemporary industrial changes. Human Capital 4.0 was proposed as one of the most significant conceptions to lead towards the human side of Industry 4.0, as it keeps a holistic and comprehensive approach. HC 4.0 allows to identify and visualize the attributes that can function for the workforce as compelling supporters to navigate the Industry 4.0 wave successfully. The vital enabling characteristics for a successful workforce in Industry 4.0 were identified based on recent outputs in wellbeing, competence, and preparation. The proposed methodology is believed to be pioneering work that provides a practical solution to the basics for human labor considerations in today and near-future industrial challenges.

Contribution 2: A competence typology as a resource for Industry 4.0 engagement. Most of the competences or skills research reported in the literature fails to facilitate and cover a comprehensive competence set for existing and future needs of the general workforce heading to Industry 4.0. A holistic competence typology was developed in this research, which is at this moment the most thorough and extensive resource for human capital competence. The proposed model, based on seven competences, offers an exhaustive skill set of the most commonly discussed skills and the insight of those barely emerging from other needs to bring them together on the same purpose of workforce readiness for Industry 4.0 implementation. The model also clarifies and recommends how to identify each competence category best and how a particular group of skills might benefit Industry 4.0 adaptation by supporting the workforce or mitigating some of the challenges.

Contribution 3: A reference architecture model as a resource for human capital preparation in Industry 4.0. There is limited research and methodologies available to provide an alternative to Industry 4.0 workforce upskilling and development, especially with a more expansive and human-centric perspective. This research proposed the Reference Human-centric Architecture Model as a smart model resource to facilitate the holistic human-centered visualization and preparation of Human Capital 4.0. The RHAM model was inspired by an original Smart Grid Architecture Model. Such design allowed the inclusion of three vital elements for human preparation and development, such as competence, age, and the environment of involvement. The model was used and explored as a base for a tool method to address some of the contemporary challenges impacting the workforce. Besides the model being a multi-sided disruptive approach to aid existing challenges for human capital, the model also offers inherent benefits sought in Industry 4.0 applications, such as interoperability, interdisciplinarity, customization, flexibility, and digitalization.

Contribution 4: A worker-centric overview for manufacturing workforce implication and engagement with technology. Few studies have been found to be able to provide a human-centric perspective on technology advancement co-evolving with workers since most approaches take on technical views. This research produced a series of three different scenarios to highlight and analyze manufacturing workforce implications due to technology, yet with a worker, or human-based, perspective. The scenarios covered different needs on human factors, such as role interactions, capability changes, and competence involvement, while keeping in mind the influence of working structures, the co-evolution with technology, and the cooperation with HCPS. It is believed that the implemented approach to board and display the implications proposed is novel, and it helps to widen insights that will promote a more precise view into the workforce of Industry 4.0, i.e. Operator 4.0.

Contribution 5: A consolidated Operator 4.0 definition for Industry 4.0. The original view of Operator 4.0 has gained attention for exploring its conception, which is a technical implementation. However, only a limited number of studies have challenged such a view, while minimal efforts have attempted to upgrade it. This research structured a wholesome updated version of Operator 4.0. The new definition was built on the foundation of the holistic human-centric approach throughout the development of Human Capital 4.0. This allowed integrating a few more different angles, or aspects, into the vision of the future operator, such as working interactions, professional competence, and mediation with challenges. Compared to the original engineering philosophy, the proposed version of Operator 4.0 covers a more resourceful and interdisciplinary overview to support the proposed definition. Nevertheless, such an updated version intends to add on, not to dimmish, the original effort.

Overall, the significance of the proposed approach and terminology lays a foundation upon developing a new conceptualization for the understanding and analysis of the workforce in engagement with disruptive (technological) challenges, such as Industry 4.0. One key aspect of this research is the amalgamation of interconnected concepts, theories, methodologies, and models of different fields, along with novel approaches and methods applied, to produce the synergy among such developed components.

9.3 Research Limitations

As pioneering work concerning an interconnected holistic human-centered approach for Industry 4.0, a fair number of limitations and opportunities for improvement still exist:

- Implementation of the developed framework. This research strongly focused on the development of new theory based on known data through answering the research questions. However, due to the timing constrains of the project, an implementation section of the developed model was not achievable within the scope. It should be understood that before a practical implementation there should be a solid background theory underpinning it, which was the main focus on this research. Nevertheless, ideas of implementation are discussed in the ’future work’ section.

- Wellbeing measurement. Although the wellbeing attribute is reasoned and explained in the new term of Human Capital 4.0, this research did not consider a measuring or estimating method. Hence, a method could be integrated where its estimation is also synchronized and resultant from the relation of the other two attributes, the holistic competence, and the holistic preparation.

- Competence typology assessment. This research presented a set of competences and skills for Human Capital 4.0. However, it did not include an assessment method for such a pool of attributes and abilities. Hence, a process could be developed either with multiple sub-methods for each competence or with a nominal value for all the competences.
- Experimental results for the RHAM method. The proposed tool method for addressing challenges was systematically elaborated and explored to demonstrate its functionality. Nevertheless, this research did not cover case studies or experiments to further exhibit such a method's applicability. Hence, case studies could be elaborated to detailly explore the skill-based assessment framework for tackling challenges in terms of different aspects, i.e. effectiveness and flexibility.

- Physical and psychological conditions implicated in the workforce and Operator 4.0. Although the research covered human factors involved and influencing the manufacturing workforce such as working interactions, competence, capability, or challenge mediation, it did not consider other human factors such as physical or psychological conditions. These two conditions are of high importance for the workforce, particularly in today's times with the global pandemic. Hence, a research section could be added to bring the interconnection of these two conditions with other factors, i.e. the competence, and elaborate on the resulted effects on the workforce and even Operator 4.0.

9.4 Recommendations for future work

Since the topic of Industry 4.0 becoming more human-centric is just gaining popularity among the industry and academics, some recommendations for future research have been identified using the presented study as a reference. These suggestions are:

1. Implementation and utilization of Human Capital 4.0. One company needs to be picked to run a pilot test on basis of HC 4.0. A selected number of employees need to be evaluated at different levels regarding their current experience with each one of the competences and skills enclosed in HC 4.0. In parallel with that, another subarea of the future work needs to find some best practices, exercises, or programs to boost such competences and skills. In this sense, the pilot test should consist of the evaluation of employees before and after the training on the required competences. The test should be able to measure, either qualitative or quantitative, the practical experience of employees in their work-related tasks, environment, and even wellbeing/satisfaction.

2. Design and tailor HCPS according to the Operator 4.0 needs and job requirements. Recent work has ignited the interest and needs to add human values when designing smart tools for future operators [162]. However, this type of technology for Operator 4.0, such as HCPS, could also benefit their design when considering the analysis of competence and capabilities

embedded in these systems. In other words, the future design of HCPS could potentially consider human values, capabilities, and competence as a reference in their implementations.

3. Digital implementation of the RHAM model and the tool framework. Although RHAM is not a highly complex Smart Grid Architecture Model (SGAM), such as RAMI 4.0 or SCIAM, it still holds potential in terms of development and applicability, especially being the first with a human approach instead of technological. Therefore, further research should explore RHAM as a smart grid in general, along with developing the smart digital version of the proposed method of application for aiding human capital with challenges. For instance, SGAMs can be tested and validated using software tools, co-simulation, and scenarios [240], [241].

4. Implementation of the updated Operator 4.0 definition for aiding Industry 5.0. The presented upgraded definition will require further presence and consideration into the industrial and academic literature, particularly with the now fresh conception of Industry 5.0. The brand-new concept has brought together three core emphases into the industry's future, such as human-centric approaches, sustainability, and resilience [242]. Therefore, the presented overview of Operator 4.0 could be embedded as a conceptual ally for the idea of Industry 5.0, considering that the presented work covers a robust human-centric approach to the current and future needs of the workforce.

9.4.1 Industry 5.0 and Operator 4.0 – a postface for the research

In 2021, the European Commission formally called for the Fifth Industrial Revolution (Industry 5.0) by the formal release of the document titled “Industry 5.0: Towards a Sustainable, Human-centric, and Resilient European Industry” [243]. This is a top-down initiative in response to the changing societal and geopolitical landscape. Industry 5.0 recognizes the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the center of the production process. Industry 5.0 centers around three interconnected core values: human-centricity, sustainability, and resilience. The human-centric approach puts core human needs and interests at the heart of the production process, shifting from technology-driven progress to a thoroughly human-centric and society-centric approach. A safe and inclusive work environment is to be created to prioritize physical health, mental health and wellbeing, and ultimately safeguard worker's fundamental rights, i.e., autonomy, human dignity and privacy. Industrial workers need to keep upskilling and re-skilling themselves for better career opportunities and work-life balance [243].

The discussions about Industry 4.0 and Industry 5.0 are still ongoing [242]. The research work in this thesis on Human Capital 4.0 and Operator 4.0 clearly addresses one of the three core values of Industry 5.0, such as human-centricity.

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Appendix A

Second Part of Self-exploring Scenarios with the Assessment tool (section 6.3.1)

Scenario 2, aging population: After some convincing talk from the company, an employee of retirement age has decided to continue working for the same company for a longer time. However, she has some self-doubts about the requirements needed for her role in the company's new vision, as it involves working with digital technology. Therefore, the company carries on an assessment to point out the main concerns of the situation from a skill-needed perspective. Table A.1 summarizes the application of such assessment using the proposed assessment tool.

Table A.1 Example of the assessment framework for scenario 2

<table>
<tr><th colspan="7">RHAM-based Assessment Framework for Industry 4.0 Challenges</th></tr>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="3">(3)</th></tr>
<tr><th>Challenge number</th><th>Challenge type</th><th>Human type</th><th>Age range</th><th>Involved Ecosystem level</th><th>Wanted skills</th><th>Type of competence</th></tr>
<tr><td rowspan="4">2</td><td rowspan="4">Aging population</td><td rowspan="4">Senior employee</td><td rowspan="4">Mature Adulthood (50+)</td><td rowspan="4">Workplace</td><td>Digital networks</td><td>Digital</td></tr>
<tr><td>Willingness to learn</td><td>Soft</td></tr>
<tr><td>Self-Trust</td><td>SQ</td></tr>
<tr><td></td><td></td></tr>
<tr><th colspan="7">(4) Situation assessment (from the skill-based and person's perspectives)</th></tr>
<tr><td colspan="7">From the skills listed on step3, what are the reasons for the person to improve such skills?
Digital networks: the member is required to learn this new skill because instead of retiring, she has decided to continue working with the company for a bit longer.
Willingness to learn: depite her willingness to keep working, her willingness to learn is a bit rust since she has not been in teaching/learning lessons for long time.
Self-trust: she requires to enhance her own trust for her to take on the new change/challenge optimistically</td></tr>
<tr><td colspan="7">Is there need for considering further skills? Which ones? Why? N/A</td></tr>
<tr><th colspan="7">(5) Outcome of the analysis</th></tr>
<tr><td colspan="7">According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?
For digital networks: she will be guided by another team member from the IT department for a period of 4-6 months
For willingness to learn and self-trust: both skills will be covered and imparted by an internal HR-department seminar with practices on collaborative teamwork and self-gain experience/trust.</td></tr>
</table>

From the assessment above, the resolution to the senior employee’s case is to work on three skills (digital networks, willingness to learn, and self-trust) while providing specific and multiple means to achieve that.

Scenario 3, compromised wellbeing: a high-school student has been sent to see the principal, as his behavior inside the classroom and with his classmates has presented some issues. The student has expressed the frustration and pressure he feels about his present and future studies. He feels hopeless, and that angers him. Therefore, the school decides to carry an assessment to name the critical concerns of the situation from a skill-based necessity for the student. Table A.2 shows the application of the proposed tool for such a case.

Table A.2 Example of the assessment framework for scenario 3

<table>
<tr><th colspan="7">`</th></tr>
<tr><th colspan="2">(1)</th><th colspan="2">(2)</th><th colspan="3">(3)</th></tr>
<tr><th>Challenge number</th><th>Challenge type</th><th>Human type</th><th>Age range</th><th>Involved Ecosystem level</th><th>Wanted skills</th><th>Type of competence</th></tr>
<tr><td rowspan="4">3</td><td rowspan="4">Compromised wellbeing</td><td rowspan="4">High school student</td><td rowspan="4">Adolescence (12-20)</td><td rowspan="4">Schooling</td><td>Positive outlook</td><td>EQ</td></tr>
<tr><td>Communication</td><td>Soft</td></tr>
<tr><td>Compassion</td><td>SQ</td></tr>
<tr><td>Purpose</td><td>SQ</td></tr>
<tr><th colspan="7">(4) Situation assessment (from the skill-based and person's perspectives)</th></tr>
<tr><td colspan="7">From the skills listed on step3, what are the reasons for the person to improve such skills?
Positive outlook: the student keeps externing angry and frustated outlooks and situations among his peers in school
Communication: altough he talks to his classmates, he does not communicate clearly with teachers nor parents
Compassion: he tends to be aggressive towards some of his classmates and even himself
Purpose: the student has expressed that he fails to see meaning and reason for his activities and studies</td></tr>
<tr><td colspan="7">Is there need for considering further skills? Which ones? Why? Gratitude and value-orientation (SQ), as he does not display gratitude and lacks respect in most of his classes</td></tr>
<tr><th colspan="7">(5) Outcome of the analysis</th></tr>
<tr><td colspan="7">According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case?
For compassion, purpose, gratitude, and value-orientation: the student will go through a complete course on spiritual intelligence with practical exercises, i.e. meditation, yoga, comtemplation, by an especialized institute.
For positive outlook: a emotional intelligence seminar will be taught by internal school department.
For communication: this skill will be encouraged and addressed throughout the just mentioned programmes, to be assessed at different stages in the process</td></tr>
</table>

From the assessment above, the outcome has provided the need to work on a total of 6 skills for the student's case (positive outlook, communication, compassion, purpose, gratitude, and value-orientation) while providing specific and multiple means to achieve that.

Scenario 4, VUCA situation: a parent has visited a social institution to ask for help with her situation at home. She struggles to manage and keep up with the expenses to maintain her household. She has acknowledged that probably, it is not a lack of a job or money coming in, but rather the way of managing it, which could compromise her volatile and ambiguous situation. Therefore, the social institution runs an assessment on the main concerns from a skill-needed perspective. Table A.3 summarizes the application of such evaluation using the proposed assessment tool.

Table A.3 Example of the assessment framework for scenario 4

RHAM-based Assessment Framework for Industry 4.0 Challenges						
(1)		(2)		(3)		
Challenge number	Challenge type	Human type	Age range	Involved Ecosystem level	Wanted skills	Type of competence
4	VUCA	Parent	Midlife (36-50)	Family	Money saving	FQ
					Mathematics	IQ
					Self-control	EQ
					Wisdom	SQ
(4) Situation assessment (from the skill-based and person's perspectives)						
From the skills listed on step3, what are the reasons for the person to improve such skills? Money saving: the parent struggles to keep savings for the monthly expenses of her family Mathematics: she needs to understand facts and topics that require numeric proficiency and calculation Self-control: she requires to remove emotional/compulsive behaviour for purchasing and unnecessary shopping Wisdom: it is necessary for her to increase her spiritual intelligence and discernment to manage and operate IQ and EQ for an efficient financial management						
Is there need for considering further skills? Which ones? Why? ***Budgeting (FQ) to manage income and expenses accordingly, and Legacy (SQ) to become aware and visionary to look after her children and their future***						
(5) Outcome of the analysis						
According to the skills mentioned on step4, what is the best resolved programme or teaching action for this case? For money saving and budgeting: a basic to middle level course on financial intelligence will support the parent with theoretical and practical methods. For self-control, wisdom, legacy: they can be provided by private counselling for her, and perhaps for the family, if needed, to engage family member's support. For mathematics: this will be also covered while doing the FQ course						

From the assessment above, the parent's case resolution is to work on six important skills (money-saving, mathematics, self-control, wisdom, budgeting, and legacy) while providing specific and multiple means to achieve that.

Appendix B

Current Outputs of the Research

- **Flores, E., Xu, X., & Lu, Y. (2020).** Human Capital 4.0: a workforce competence typology for Industry 4.0. Journal of Manufacturing Technology Management.

Human Capital 4.0: a workforce competence typology for Industry 4.0

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Abstract

Purpose – The purpose of this paper is twofold: to raise and address an important change for the human capital in the future of Industry 4.0, and to propose a human-focused perspective for companies underneath the new Industrial Revolution.

Design/methodology/approach – The research study follows a state-of-the-art literature review process. The nature of the selected approach enables to cover the extensive aim of the paper with sufficient scientific solidity that should support the understanding of every topic.

Findings – This work has presented three relevant aspects for Industry 4.0 and its human labour force: a workforce architecture with new interactions, a term to embrace the human capital of the future and a typology for referencing the required competences for Industry 4.0.

Research limitations/implications – The paper sheds light on an important aspect for the emerging Industrial Revolution, the human force. The result and conclusion sections suggest future implications for academia and the private sector, due to changes at the conceptual and practical levels of human operation in the industry – for example, new structural interactions among employees, additional qualities to human capital and different ways to identify the competences for the workforce.

Originality/value – This is an interdisciplinary study that tries to bring together a modern industrial term, a social focus and a company scenario. From this, it was possible to obtain a new social term, a novel typology of competences and a new company-scenario interaction.

Keywords Human capital 4.0, Competences and skills, Typology, Workforce architecture, Industry 4.0-enabled interaction, Industry 4.0

Paper type Research paper

1. Introduction and motivation

The new paradigm of Industry 4.0 is rapidly spreading worldwide. This revolutionary concept offers the story of the next Industrial Revolution as a flexible platform where technologies and the Internet are pervasive means to do businesses and manufacturing.

Efforts have been made to propose future tendencies and shifts in terms of technologies, systems and tools. However, there still seems to be a lack of considerations for future workers, especially at a holistic view. In other words, there is a need for a corresponding term and scenario for humans in parallel to Industry 4.0. To address this need, the following questions demand an answer:

RQ1. How does the future interaction and communication look like for employees in a manufacturing company? What type of new structure and activities may arise from such new interactions?

RQ2. What is the best term to represent an inclusive set of future-proofing attributes of the workforce?

RQ3. What are the competences required for this new paradigm shift?

The research reported in this paper attempts to answer these questions by having carried out a state-of-the-art review. This methodology allows both to address a wide literature and topic, and to highlight perspectives for further research (Grant and Booth, 2009), which resonates with the aim of this paper.

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CIE48 Proceedings, 2-5 December 2018, The University of Auckland

OPERATOR 4.0: THE HUMAN FACTOR IN THE NEW ERA OF MANUFACTURING

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ABSTRACT

The Industry 4.0 wave is capturing the attention of many as it bears some promises that appeal to industries and academics. One of those promises is not just the inclusion of human, but also the well-being of workforce. This paper briefly mentions the view of such promises, but makes special emphasis on how this new paradigm is expected to affect the human factor, Operator 4.0. The document gives a general review on the inclusion of Operator 4.0: past and present perspective, concept and classification, skills, aiding systems and technologies to support the workforce. Lastly, it gives thoughts on how the presence of the human should continue in the future.

Keywords: Operator 4.0, Assistance Systems (AS), Human-Machine Interaction (HMI), Cyber-Physical Human Systems (CPHS), Cognition, Situation Awareness (SA), Digital Skills

- **Flores, E., Xu, X., & Lu, Y. (2020).** Human Cyber-Physical Systems: A skill-based correlation between humans and machines. In 2020 IEEE 16th International Conference on Automation Science and Engineering (CASE) (pp. 1313-1318). IEEE.

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August 20-21, 2020, Online Zoom Meeting

Human Cyber-Physical Systems: A skill-based correlation between humans and machines

Emmanuel Flores, Xun Xu, Yuqian Lu

***Abstract*— Cyber-Physical Systems (CPS) are an integral element of Industry 4.0, and these systems are said to have become gradually more intelligent throughout the years. Moreover, as technologies such as Artificial Intelligence and Internet of Things evolve, the suspicion arises on whether machines and humans could cohesively share control in the system. Despite efforts in the literature regarding the architecture and the implementation of CPS and Human Cyber-Physical Systems (HCPS), more work needs to be done to highlight the similarities and strengths between people and machines. In this work, we take on the challenge to show that comparison from a human-skill perspective. This analysis highlights some of the human capabilities that have been moved to technologies. It also presents an updated list of human-machine capability differences. Besides, it identifies the human elements involved in HCPS as well as the skills included and required while working with HCPS.**

I. Introduction

The rapid development of industrialization is brewing all types of digitized and automated technologies as well as processes. The 4th Industrial Revolution is bringing together different technologies, such as the Internet of Things (IoT), Cypher-Physical Systems (CPS), Digital Twin (DT), Artificial Intelligence (AI) and Augmented/Virtual Reality (AR/VR), among the most commonly discussed in the literature. It is expected that these technologies will help to boost economic and social wellbeing.

Along with technology, humans are also expected to perform at higher levels of competence. The development of technology is a synonym for people to upgrade their skills, type of work, and responsibility. In addition, people will be surrounded by a growing set of automated systems, i.e., CPSs. Such systems can be implemented to either substitute human input or collaborate with it. In general, when a system replaces human participation, it is regarded as full automation. Meanwhile, a system that considers human insights in the control loop is seeing as semi-automation [1]. conflict or fear of automation. To this end, this study aims to shed some light on the topic by employing a human focus perspective. This research aims to present an architecture of HCPS based on people skills and their importance of collaboration within the system. For this, three research questions have been pondered:

1. What is a human viewpoint of capabilities regarding the four Industrial Revolutions, and what is its current human-machine relation and comparison?
2. What are the human elements that can be involved in HCPS, and what are their relationships with machines?
3. What are the people skills involved in HCPS, and which one(s) is the key differentiator?

This study addresses these questions in a novel way, as no similar work has been found yet, to the best knowledge of the authors. The rest of the paper is divided into the following sections. Sections 2 and 3 present a state-of-the-art view on CPS and HCPS, pointing out their architecture and elements. Section 4 elaborates on the answer to each research question within each subsection, respectively. Part 5 draws the discussion and conclusions in the study. The last section gives a hint of future work to pursue.

II. Analysis of Cyber-Physical Systems Composition

The term CPS, or any derived name (i.e., CPHS or CPPS), is becoming stable around the Industry 4.0 literature. For instance, nearly 2000 publications were found between 2010-2015 on CPS, regarding just the manufacturing industry alone [2]. CPS's are thought to be a pivotal foundation for the New Industrial Revolution and forthcoming smart enterprises [3]. Therefore, these views bring strong attention to the study and work evolving around this technology, regardless of it not being a new concept.

From its conception in 2006 [4] to this date, the CPS concept has been evolving according to the latest technological capability. CPS's are engineering systems that monitor,

- **Flores, E., Xu, X., & Lu, Y. (2020).** A Reference Human-centric Architecture Model: a skill-based approach for education of future workforce. Procedia Manufacturing, 48, 1094-1101.

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A Reference Human-centric Architecture Model: a skill-based approach for education of future workforce

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Abstract

As Industry 4.0 sets foot as the next Industrial Revolution, it is necessary to bear in mind the new challenges from the human workforce perspective. There is a need for such challenges to inform educational and training programs, for them to enable skill development from a holistic viewpoint. Yet, most of the educational programs seem to be technological or subject-based, i.e. not skilled-based. There is an opportunity for a new approach to support and create educational programs and training for both university graduates and industry workers. This paper presents a human-centric model based on competences, age groups, and environment scenarios. The proposal supports the development of more robust means to look at educational gaps by visualizing and adapting a competency-based scenario. The aim is to provide a novel approach that is holistic, inclusive, and flexible in better preparing the future workforce.

Peer review under the responsibility of the scientific committee of NAMRI/SME

Keywords: Industry 4.0, Reference Architecture Model, Human-centric, Education, Workforce, Competences

1. Background

From its conception in 2011, and then its recommendations for implementation in 2013, Industry 4.0 has become a must researched and discussed topic globally. The vision of Industry 4.0 brings together the opportunity for many design principles, such as service-oriented architectures, decentralization of decision-making, interoperability of cyber-physical systems, virtualization of the physical world, real-time accessibility, and flexibility or cross-discipline for adaptation [1].

architectures for implementing Industry 4.0 (i.e. Internet of Things (IoT), Cyber-Physical Systems (CPS), Cloud computing, Big data, Information and Communication Technologies (ICT), Service-Oriented Architectures, etc.), yet there is a need for further aspects to take into consideration, i.e. the social consideration and preparation.

Human resources need to adopt and adapt themselves to this fast-paced Industrial Era. A study shows that the lack of qualified human workforce is among the top three challenges for companies to adopt Industry 4.0 [3]. Moreover, it has

- **Flores, E., Xu, X. (2019).** Operator 4.0: A human perspective for Industry 4.0. Manufacturing & Design 2019 (MAD2019), Auckland, NZ

Operator 4.0: A human perspective for Industry 4.0

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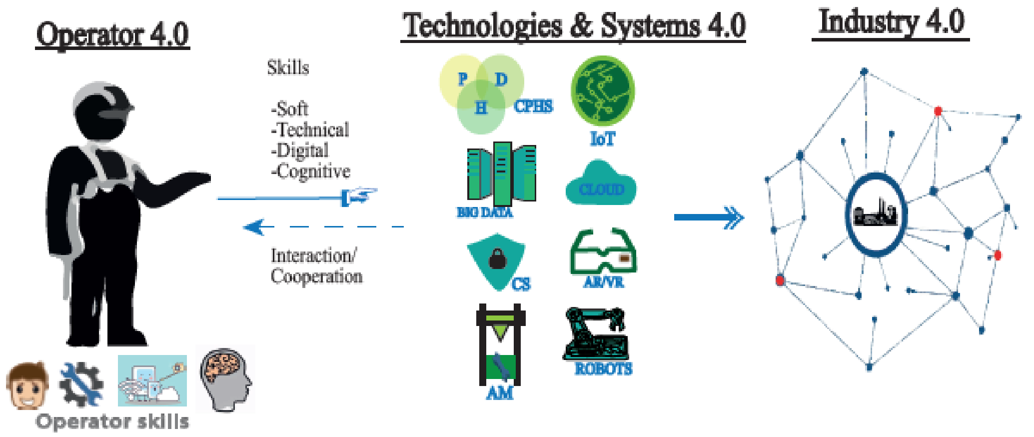


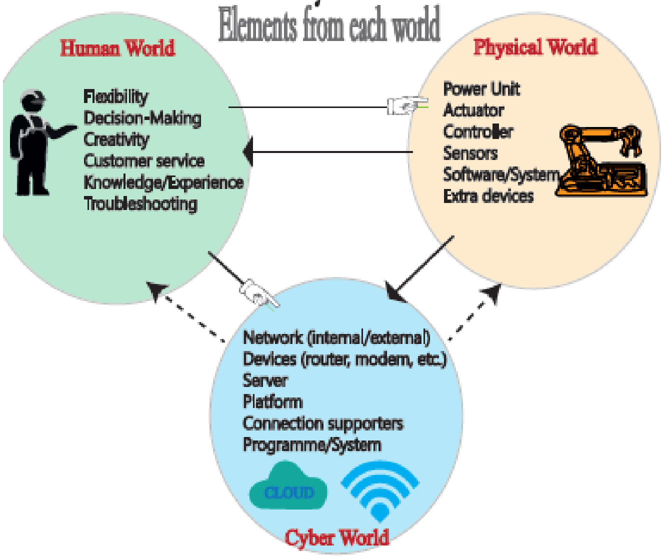
Background

Industry 4.0 promises a better inclusion of workforce aspects, such as better job satisfaction, longer career development and a balance between personal and professional lives. However, for this commitment there is still ambiguity on how to achieve such challenge of human working inclusion with a seemingly technology-driven drive.

This research sheds some light on the first steps to be considered to appreciate the need of, and understand the true meaning of, Operator 4.0, the human aspect in this new Industrial Revolution. This comprises the identification of a skill-set required from the workforce, plus the identification of systems working with humans in context of Operator 4.0, and then support how technologies on manufacturing systems could be implemented in order to allow a harmonious integration among the two entities, human work and Industry 4.0 systems.

Human-System Model

Elements from each world



Systems in Context of Operator 4.0

- Assistance Systems (AS)
- Human-Machine Interaction (HMI)
- Cyber-Physical Human Systems (CPHS)

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- **Flores, E., Xu, X., & Lu, Y. (2020).** Human Capital 4.0: competences and skills for disruptive challenges. Manufacturing, Design & Entrepreneurship 2020 (MADE2020), Auckland, NZ.

HUMAN CAPITAL 4.0. COMPETENCES AND SKILLS FOR DISRUPTIVE CHALLENGES

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NOW MORE THAN EVER BEFORE, THERE IS A NEED TO LOOK DEEP INTO THE STUDY AND RESEARCH OF HUMAN COMPETENCES, FOR THEY ARE THE UNDERPINNING KEYSTONES FOR HUMAN PERFORMANCE. THE CURRENT DISRUPTIVE TIME (AKA INDUSTRY 4.0, COVID) FORCES SOCIETY AND COMPANIES TO LEARN TO ADAPT NOT ONLY TO SURVIVAL BUT ALSO FOR FUTURE THRIVING. THUS, IN THIS POSTER, WE WILL PRESENT IN THREE SUMMARIZED WAYS OUR RESEARCH RESULTS SO FAR:

1. Human Capital 4.0: appeals for the future-proofing set of competences, education, wellbeing, and innovation that may support the workforce to cope with the Industry 4.0 paradigm. In addition, a typology of enabling competences for such workforce is required to support the visualization and classification of skill (see figures below).

Scan QR code to read/request complete paper

HUMAN CAPITAL 4.0.

(MAIN COMPONENTS FROM HUMAN CAPITAL FOR INDUSTRY 4.0)

(FIVE ENABLING COMPETENCES)

2. RHAM (Reference Human-centric Architecture Model) is a skill-based approach for the education of future workforce. This is a new approach to support educational or training programs based on competences, age groups, and evironment scenarios, as most common programs are technological or subjec-based, not skilled-based. The aim of the proposal is to provide a holistic, integrated, and flexible model for better preparing the future workforce (see figures below).

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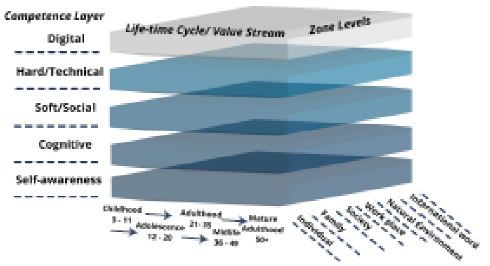

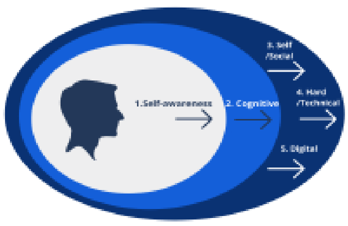

COMPETENCES FROM A PERSON TO PERFORM AN ACTIVITY

3. A skill-based analysis has been done to highlight an updated comparison between human and machine capabilities. In addition, it was also identified the humans elements and skills involved in HCPS (Human Cyber-Physical Systems), in which case helps to point out the key differentiator between the two, people and systems (see tables below). workforce (see figures below).

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The MABA-MABA list (Fitts, 1951)	
Men are better at	Machines are better at
Detecting small amount of visual, auditory, or chemical energy	Responding quickly to control signals
Perceiving patterns of light or sound	Applying great force smoothly and precisely
Improvising and using flexible procedures	Storing information briefly, erasing it completely
Storing information for long periods of time and recalling appropriate parts	Reasoning deductively
Reasoning inductively	
Exercising judgment	

The MABA-MABA list (up-to-date version)	
Men are better at	Machines are better at
Performing flexible and improvised procedures	Performing faster, stronger, and precisely
Understanding the situation and exercising judgment	Storing large amounts information
Creating solutions (tools or services)	Sensing and perceiving environmental conditions
Perceiving patterns, planning, and looking at the bigger picture	Analytical thinking and prediction
Exercising and applying common sense/intelligence	Generating data base of knowledge
Experiencing purpose and fulfilment	

HUMAN SKILLS CONCERNING THE 5-LEVEL ARCHITECTURE OF HCPS

HCPS Levels	Human elements	Category element	Human skills	Automation likelihood
1. Connection	- Five senses	Physical	- Sensation	Medium - High
2. Conversion	- Memory - Intellect	Intellectual	- Cognitive (IQ)	Medium - High
3. Cyber	- Memory - Intellect	Intellectual	- Cognitive (IQ)	Medium - High
4. Cognition	- Intelligence - Experience - Emotion	Conscious	- Consciousness - Emotional Intelligence (EQ)	Low - Medium
5. Configuration	- Bodily action	Physical	- Hard	Medium - High