SYSTEMS AND INDUSTRIAL ENGINEERING SERIES

From Industry 4.0 to Industry 6.0

Edited by
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First published 2025 in Great Britain and the United States by ISTE Ltd and John Wiley & Sons, Inc.

ISTE Ltd
27-37 St George's Road
London SW19 4EU
UK

www.iste.co.uk

John Wiley & Sons, Inc.
111 River Street
Hoboken, NJ 07030
USA

www.wiley.com

Library of Congress Control Number: 2025932523

British Library Cataloguing-in-Publication Data
A CIP record for this book is available from the British Library
ISBN 978-1-83669-029-0

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Preface

Industry 4.0 marked a revolution in industrial processes, introducing connectivity and digitalization as key elements to improve efficiency and productivity. However, technological evolution moves ever forward, and now the prospect of Industry 6.0 has emerged, a new era that promises to radically transform the way we view industrial production. Industry 4.0 was characterized by the integration of cyber-physical systems, the Internet of Things (IoT), artificial intelligence (AI) and data analysis to create smarter and more efficient factories. Connected sensors, autonomous machines and predictive analytics have become the norm, enabling process optimization and more informed decision-making. However, Industry 6.0 looks to go further, introducing revolutionary concepts that will redefine how we view industrial production. One of the pillars of Industry 6.0 is the complete integration of advanced artificial intelligence into all aspects of production. This implies systems that not only collect and analyze data but also continually learn and adapt. Autonomous machines will be able to not only follow predefined schedules but also make complex decisions in real time, adjusting to constantly changing scenarios. This will increase efficiency and reduce the need for human intervention in routine tasks. Another crucial element of Industry 6.0 is augmented reality (AR) and virtual reality (VR), which will be integrated more deeply into production processes. This will open doors to virtual work environments where engineers and operators can interact with complex machines and processes in an immersive and remote manner. Predictive maintenance will also benefit from augmented reality, allowing technicians to view crucial information about equipment in real time, facilitating faster diagnoses and repairs. Cybersecurity becomes even more pressing in the transition to Industry 6.0, as increasing interconnection and dependence on intelligent systems increase the risks of cyberattacks. New security protocols and advanced algorithms will be essential to protect sensitive data and maintain the integrity of industrial processes. Confidence in emerging technologies will largely depend on the ability to implement robust cybersecurity measures. Sustainability also becomes a central focus in Industry 6.0. The search for more ecological and efficient production processes is gaining prominence, driven by growing environmental awareness and stricter regulations. Technologies such as the Environmental Internet of Things (EIoT) and AI-based energy optimization will be key to reducing the environmental impact of industrial production, promoting more responsible and eco-efficient practices. Furthermore, Industry 6.0 not only transforms production processes, but also redefines the relationship between companies and consumers. Mass customization, driven by advanced data analysis algorithms, allows products to be tailored to individual consumer preferences. This not only meets the growing demand for personalized products but also promotes a more engaging and satisfying experience for customers. In short, the evolution from Industry 4.0 to Industry 6.0 represents a significant advancement in how we conceive production and the interaction between machines, humans and systems. Integrating advanced artificial intelligence, augmented reality, enhanced cybersecurity and a renewed commitment to sustainability redefines the limits of what is possible. As we embrace this new industrial era, it is imperative to not only keep up with technological innovations but also embrace a mindset of constant adaptation to maximize the benefits of this ever-evolving industrial revolution. This transition not only increases operational efficiency but also paves the way for new business models, improved sustainability and a more connected and aware society.

Conscious of this reality, *From Industry 4.0 to Industry 6.0* highlights the importance and impact this technological evolution will have on the way today's organizations develop into proactive, innovative and competitive agents.

Organized into eight chapters, this book looks to discuss in Chapter 1, *From Industry 4.0 Onward: Is There a Need for* "*Industry 6.0?*", while Chapter 2 highlights *Industry 6.0 Transformation: Conceptual Transition Framework, Opportunities and a Research Agenda*. Chapter 3 focuses on the *Impact of Industry 6.0 on Human Cognitive Behavior*. Chapter 4 speaks about *Understanding the Metaverse – A Holistic Approach of a Rapprochement with the Marketing Domain*, Chapter 5 focuses on *Model-Based Management – A Safari of Essential Business Models*, Chapter 6 is entitled *Approaching the Portuguese Labor Market From a Gender and Generational Perspective in the Era of Industry 4.0, Robotization and Artificial Intelligence*, Chapter 7 covers *Add More Marketing to Marketing Doctoral Programs – Answering Hunt and Yadav's Calls* and, finally, Chapter 8 looks to discuss *Industry 6.0: Why Talk About It Now?*.

From Industry 4.0 to Industry 6.0 can be used by various potential stakeholders, not only academics and researchers, but managers, engineers, practitioners and other professionals who develop their professional activity in different areas of management and engineering. It is also relevant to emphasize that experts who contributed with a chapter were encouraged to identify the theoretical and practical implications of the different aspects that define the evolution from Industry 4.0 to

Industry 6.0 to provide a more effective understanding and implementation of these issues in different types of organizations.

The present book, organized in eight chapters, can serve as a valuable reference for academics, lecturers, researchers, graduated and postgraduate students, managers, engineers and other professionals in related matters with Industry 4.0 and 6.0.

The editors acknowledge their gratitude to ISTE-Wiley for this opportunity and their professional support. Finally, we would like to thank all chapter authors for their interest and availability to work on this project.

Carolina MACHADO
J. Paulo DAVIM
February 2025

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From Industry 4.0 Onward: Is There a Need for "Industry 6.0"?

The process of industrialization – as a sustained trend in history and developing new socio-economic concepts – presuposes higher rates of growth of the economy and a structural change. It is on this basis diverse concepts of industrial revolutions have been accepted. These concepts have been coherent to reveal singular developments. Recently, the accepted concept of Industry 4.0 (i4.0) has shown some limitations regarding the need to develop automation technology in an anthropocentric orientation. This is why Industry 5.0 has two orientations: either the experiences that adopt this concept seek solutions to adapt the human factor to the features of the technology or, knowing the social and organizational requirements, look for solutions to develop this technology in accordance with these requirements. The debate is still developing. There is not yet conceptual maturity to propose a new topic that would be based in a new eventual structural change observed like a possible "Industry 6.0" era. Most arguments for an Industry 6.0 are still those which have been discussed for Industry 4.0, since they are mostly based on eventual not yet ready developments of technology. That is why we should continue the debate on the late developments of industrialization and its social and economic conditions.

1.1. Introduction

When invited to write about the concept "Industry 6.0", I was curious about its novelty. I have been working for more than a decade on the topic of Industry 4.0, and more recently on Industry 5.0. These last concepts integrate all of the dimensions related with the technological development in the manufacturing industry, and they especially integrate options on company management strategies.

Chapter written by António Brandão MONIZ.

The case for Industry 5.0 is even more advanced: it integrates the older debate on the new organizational options and design and sustainability criteria for management. "Integrates" means that, at the end of the day, the forefront manufacturing technology must be designed considering organizational criteria. Therefore, these criteria have to be consistent with the circular economy and sustainable factors. In this sense, new ideas are completely new according to scientific literature. They have been recently compartmented: technology development and its readiness levels, for one side, and new organizational design, social partners involvement and management strategies, for another side. Now, what is proposed, is for a new joint concept to become debated, leading to more advanced standards. The interdisciplinary scientific community has not yet completely involved with this discussion. There are still few case studies and successful benchmarks. We are still in the early phases of the debate.

To my surprise, some authors are starting to speak about Industry 6.0. My curiosity led me to research the relevant literature, wide discussions and experiments, but unfortunately, I did not find enough evidence. The published literature is mostly conjectural, based on impressive scenarios, and tries to push for a concept that is not yet consistent in terms of novelty and based on any evidence. It is also revealing that most scholars involved in the debate on Industry 4.0 and Industry 5.0 are not discussing Industry 6.0. Why? My answer would be that there is not yet conceptual maturity to propose a new topic that would be based in a new eventual structural change observed – even in few cases – in the manufacturing industry. Most arguments for an Industry 6.0 are still those that have been discussed for Industry 4.0, once they are mostly based on eventual not yet ready developments of technology.

Instead of being disturbing, these facts can also contribute to the rediscussion of these concepts on structural changes concerning how products are manufactured, as well as how the conventional sector and labor markets may change during the next few years. They can also contribute to making these types of scenarios more accurate, ensuring certain elements of evidence are relevant to companies and policymakers. If this is not the case, they can become useless, a simple playground for conceptual flags that do not consider the previous steps explaining the emergent changes or social needs. In the following sections, we will demonstrate this.

1.2. From Industry 4.0 toward Industry 5.0

The concept of Industry 5.0 (i5.0) aims to place workers' well-being at the center of the production process [BRE 21]. This concept is centered on the idea of anthropocentric technology, which implies that technology, organizations and workplaces must be adapted to human and social needs. There are, however, still unclear problems regarding this concept. Knowing that the Industry 4.0 (i4.0) concept has significant limitations regarding the need to develop automation technology in an anthropocentric orientation, Industry 5.0 has two orientations: either the experiences that adopt this concept seek solutions to adapt the human factor to the characteristics of the technology or, knowing the social and organizational requirements, look for solutions to develop this technology in accordance with these requirements [MON 23; CAN 23b]. This is a problem that is unlikely to be resolved.

i5.0 is a concept that arises as an evolution of the industry and human–machine interaction. While i4.0 is focused on automation and scanning production processes, i5.0 search to integrate more harmoniously and collaboratively humans and machines on the desktop [BRE 21].

It seems, however, that a sound i4.0 concept-centric concept still cannot include the perspective and experience of the ethical sciences, sustainability and social and human science. In other words, the concept of i4.0 has been almost exclusively focused on technology development, despite also discussing the need to include the human factor [BUT 18]. However, in reality, it has not happened. We continue to see a prevalence in technology development and not in the development of working conditions where technology could be designed for this development [CIM 20]. For this reason, the idea of i5.0 is focused on this concept of anthropocentric technology and implies that technology, organizations and workplaces should be tailored to human and social needs. For this reason, a potential concept of Industry 6.0 (i6.0) completely focused on future advances on computing technologies and manufacturing systems seems unclear as of yet. In fact, there is still room to develop i4.0 based on experiments of technology development, such as cloud computing, cyber-physical systems (CPS), Internet of Things (IoT) and the interconnection of these with intelligent robotics, or with additive manufacturing [ELH 21; HIR 16; KRI 21; THU 19].

1.2.1. *Limits of the technological developments*

The focus on technological achievements and the articulation between artificial intelligence with new manufacturing technologies have shown many dilemmas and difficulties. Since the technical system is the more advanced, the decision loop must involve human input. In practical terms, machine learning still has too many limitations to enable direct substitution by humans.

If this is true for the moment, will it still be true in the next decade? What about in two decades? These questions bring us to two types of reasoning: on the one hand, we will need more complete and critical knowledge on the possible trends and roadmaps needed; on the other hand, we still must think about the role of humans in a more complex environment with increased capacities in terms of artificial intelligence. What are the limits? Are they known? Do we know the technology limits well enough, or do they have to be imposed by laws and regulations? Do we know the human limits? These are the essential questions on the possible transitions of industrial revolutions.

Thus, i5.0 should recognize the importance of unique human skills such as creativity, empathy, critical thinking and social qualifications, and therefore seek to combine them with the efficiency and accuracy of machines [ELH 21]. In principle, the concept does not seek human replacement with machines in repetitive tasks as a competitive advantage. This concept points closer toward cooperation between humans and machines, harnessing the best of each.

The transition from i4.0 to i5.0 would have to be done by evaluating the nature of the transformation of jobs, future professions and reduced skill gaps in order to address possible unemployment effects (especially the derivatives of technological unemployment) and promote industrial competitiveness and innovation by simultaneously reinforcing inclusion [CAN 23b].

The most recent commitment to i5.0, especially made by the European Commission, includes an interest in “responsible innovation”. This commitment “not only or mainly aims to increase cost efficiency or maximize profit, but also increases prosperity for all those involved: investors, workers, consumers, society and environmental environment” [BRE 21].

In effect, industries can play an active role in providing solutions to society’s challenges, including resource preservation, climate change and social stability. But, if the approach of i4.0, or Industry of the Future, has benefits for the industry, its development in the “anthropocentric” sense allows for advantages benefiting both workers and society [KRI 21]. Therefore, i5.0 should empower workers, because the evolution of the skills and training needs of workers emerges. In other words, with the application of the technological concepts associated with i4.0, new skills emerge, and in view of this, new training needs are sought.

1.2.2. *Discussions on the concept of i4.0*

The anthropocentric concept of i4.0 would then imply that association between the development of intelligent technologies in manufacturing and the needs of its workers. At the same time, with this empowerment, it should increase industry competitiveness [KRU 09; LU 20; NEU 21]. With some principles defined for i6.0, the possibilities would be completely different. We will come back to this later on.

However, thinking of the human first in the productive, more complex and intelligent systems process has not been the central concern in the academic and industrial environment. Only when productive processes have been developed is an attempt made to adapt humans to these technologies.

There is therefore still a long way to go in this conceptual development. In recent years, the concept of i4.0 has been widely based on technology-driven experiences, allowing important steps in the areas of machine learning, cyber-physical systems, development of IoT devices and integration at the industrial factory floor level [MAD 15]. However, new organizational concepts and innovation processes have been secondary. Some production efficiencies, cost reductions and business model adaptations were achieved with i4.0 [THU 19].

With advanced automation, intelligent machines and systems can perform complex tasks autonomously by reducing human intervention dependence on repetitive and routine activities. However, in most cases where the concept of i4.0 has been introduced, it is not possible to demonstrate the advantages of job substitution, or there are no demonstrable gains with the exclusion of operators from interaction processes with these equipment [ROM 16; NEU 21]. Of all modes, the implementation of automated systems aims to increase production cadences using mechanical media and information systems that improve the technical performance. Therefore, although biased, it would be preferable to displace human jobs, making their tasks more creative and less routine [MON 22a].

With IoT, which plays a key role in i4.0, the connection between machines, devices and sensors in a smart network is established. This allows for real-time data collection and sharing, enabling higher visibility and control over production processes [MAD 15]. However, the operation and control of these intelligent networks are, still, always performed by human beings, especially by those with the technical competence and responsibility of the control of these processes.

Virtual and increased reality technologies are used in human–machine interaction in i4.0. They allow for the overlay of digital information in the physical environment by offering visual guidance and real-time instructions for workers, facilitating training, maintenance and problem solution. These technologies have been disseminated in many industries of manufacturing. Only the issues of usability and acceptance can be raised so that this technology does not encounter application limits [THU 19].

1.3. Arguments for "Industry 6.0"

Industry 6.0 is not just about automating factories, but rather transforming entire industries through the integration of advanced technologies, enabling smarter decision-making, higher productivity and unprecedented levels of customization. i6.0 represents the next phase of industrialization, which is focused on creating fully integrated, intelligent manufacturing systems that can operate with minimal human intervention. It combines human intelligence, artificial intelligence, cloud computing energy, human–robot working big data and quantum computing [CHA 23].

With such phrasings, it is possible to find comments where articles like these, framed as the next industrial revolution, are an utter waste. In fact, they even suggest that the author does not understand the principles of the 4th Industrial Revolution (or i4.0) or any industrial generational leap. Comments such as "such articles are only intended to inject unnecessary information (not even knowledge)", can be understood.

1.3.1. *The Finnish white paper on i6.0*

Other statements are produced at the level of white papers. The main referenced one is the one produced by the Innovation Funding Agency Business Finland (AIF) in 2021. There, they underline the following:

> [Industry 6.0] is characterized on one hand by customer-centric, highly customized lot-size-1 thinking, on the other hand by hyper-connected factories, with dynamic supply chains, were data flows across domains. These also change the role of human as a production worker, as they become part of the interconnected environment and need to handle the digital, optimized production [KUO 21, p.2 and 38].

From such feature, a group of suggestions and proposals are established. The main ones are:

– hyperconnected factories in complex, dynamic supply chains and value networks, where data flows across different administration domains. Requires a common data model;

– human digital twin connects manufacturing;

– the role of human dramatically changes in manufacturing;

– AI optimization of production to obtain sustainability and antifragility;

– lot-size-1 made economically feasible;

– antifragility obtained via the design of systems relying on non-functional requirements (NFR).

The motivation is clear. For the organizers of this white paper:

> Thanks to disruptive technologies such as 3D/4D printing and artificial intelligence (AI), Finland can make the most of localization as an opportunity to bring more manufacturing back to Finland. The small size of the local market and the future needs for increased personalization pose the fundamental question and opportunity for Finland: how to make the lot-size-1 economically feasible [KUO 21, p. 10 and 38].

The focus was mainly on the hyperconnectivity, dynamic supply chains, nonfunctional requirements or digital twins. However, the phrase the "role of human dramatically changes" almost says nothing. It is not clear which "changes" or "dramatic roles" can be expected. For something that could be a structural change forward i5.0, the explanation is scarce. It should be fundamental to have clear ideas and proposals on that direction. They are, however, not present in the document.

1.3.2. *New inputs for this concept*

Other articles published in more referenced journals however take the same type of direction.

For example, Chourasia et al. [CHO 22] start their abstract stating that:

> The sole aim of industry 6.0 is to seize the new technologies, which can be applied worldwide and deliver wealth, prosperity away from the job and provide growth to nations across all planetary boundaries. This revolution would promote living harmony with nature, support the principle of sustainability where technology would not be a thing, and promote the human virtual digital twin where all can simultaneously see physical goods and virtual product information (p. 443).

In other words, the authors continue stating that:

> Industry 6.0 is the one-step further than industry 4.0 and industry 5.0, where every operation would be controlled by human minds and performed by automated robots by covering all the planetary

> boundaries. It combines human intelligence, artificial intelligence, cloud computing energy, human–robot working big data, quantum computing (p. 444).

The Duggal et al. [DUG 22] article starts with the mention that:

> The ideological concept of Industry 6.0 encompasses adjustments and advancements in virtually all domains. To perform an intensive categorical analysis, the advancements have been classified into 4 major sectors; robotic automation, society and policies, and lastly, intelligent manufacturing (p. 522).

With this focus, the authors confuse the concepts of Society 5.0 and Industry 5.0, and go on to define Industry 6.0 in a vague way, concluding that:

> The prime focus of the sixth industrial revolution would be on medical technology with multi-dimensional printed controlled release medicine, automated medical diagnostics entirely, removing any extra burden from practitioners, leaving them to focus on critical cases [DUG 22, p. 529–530].

Other authors, such as Almusaed et al. [ALM 23], make a clearer definition:

> Industry 6.0 pioneers advancements in quantum computing, nanotechnology, artificial intelligence and cloud-based energy solutions. Harmonization facilitates design, building, and maintenance processes, improving efficiency, accuracy, and sustainability (p. 1).

They finalize their article by concluding that:

> Industry 6.0 could bring transformative changes to industries. While it promises virtualized, antifragile manufacturing and services emphasizing customer-centric strategies, dynamic supply chains and automation-driven flexibility, job displacement due to increased automation is the primary concern. Future industrial revolutions should prioritize job creation to avoid socioeconomic discontent [ALM 23, p. 22].

This and the previous articles only reproduce simple approaches, repeating arguments and bring no evidence to support their conclusions and assessments.

1.3.3. *Possible outcomes on i6.0*

The arguments for "Industry 6.0" are not convincing. The technological upgrading of production systems including AI systems, even based on quantum computing or nanotechnologies are just a step forward the Industry 4.0 concept. It is not, in fact, an industrial revolution. We can argue in the same direction that the concept of Industry 3.0 is basically the development of automation (that already existed in Industry 2.0), but with digitalization. Digitalization represented a real revolution. Therefore, we can talk about an Industry 3.0 stage. The digitalized automation from the last decades of the 20th century went through several upgrades and developments, from numerical control, to robotics, and from flexible manufacturing systems to computer-integrated manufacturing. We had the integration of product design (CAD) into automated manufacturing (CAM), and later the concept of "production islands" and flexible systems (FMS). The integration of different functions through computerized systems (CIM) represented even a further step in this revolutionary process of manufacturing [HIR 16; CAN 23a].

From the early second decade of the 21st century, the new concept of Industry 4.0 became accepted because the needs of the industrial sector became different. The advances of digitalization and artificial intelligence enabled new forms of production [PFE 16]. This became a new revolution, changing the ways of organizing the sector and opening new doors for possibilities of technological development.

However, the very recent concept of "Industry 5.0" has surged to reveal the need of a necessary development of industry that should respond to present human needs: the consideration of a sustainable strategy of technology development, and the need to consider the role of humans in an increased automated process [SOW 16].

We can conclude that the proposed concept of "Industry 6.0" is by now very poor in terms of revealing new trends of radical development of the process of manufacturing. The debate on the new possibilities for Industry 4.0 is still present among industrialists, social partners and academics. Industry 5.0 emerges as a new future step that will change the way we consider the role of humans in a process that tries to substitute the involvement of human operators in the sophisticated technology system. With such state of the art on the debate about the future of work and the future of industry, is there a place for a new concept? I don't think so. This new concept only refers to potential technological developments that do not represent a new manufacturing process. They are only a possible development of present trends.

1.4. Is there a new industrial revolution?

To answer this question, and considering all of the arguments of the different proposals for the concept of a new industrial revolution, I would answer, no. The definitions of the industrial revolution consider a radical change based on a specific technology or energy source.

> Industrial revolutions are the transformation from old practices of powering and managing of "workplace" into new and sophisticated structures that meet the goals of modern development in order to serve better the needs of the society [GRO 21, p. 467].

Mathias and Davis raised the discussion in a more correct fashion in 1989, when they stated that:

> We must specify criteria and meaning if we are to locate the phenomenon in time and context. It is not until a term or concept can be identified, with criteria assessed, that it is possible to begin to test the reality of historical change in the light of the concept. It is both a conceptual and an operational problem: one must distinguish between the definitional and conceptual identification and the narrative of empirical change deployed to describe and embody (and also to test) the assumption contained in the concept.

They continue by saying that "conceptual identity is thus intimately involved in a potentially infinite enquiry into the facts of change and the inter-relationships of growth" [MAT 89, p. 2].

1.4.1. *What is an Industrial Revolution?*

These historians are referring to the First Industrial Revolution, or Industry 1.0, when they say that "the two main criteria which are central to the definition of the industrial revolution (or the onset of the process of industrialization as a sustained trend in history) are first, higher rates of growth of the economy as a whole and second (closely linked to the first), structural change)" [MAT 89, p. 3]. These criteria can be empirically verified in all of the industrial transitions that we are referring to.

Steam power enabled the powering of the first automatic machines which increased the production of basic needs, such as textiles, food products and metal products. Moreover, these machines allowed for a quick increase in productivity and economic growth and meant that manufacturing systems in different sectors could be available. It implied a multiplication of factories and an increase in the number of jobs. The employment structure changed quickly, conditioning social change and the emergence of social conflicts. The distribution of welfare was not balanced and it quickly became understood that novel technological developments implied the emergence of new tensions in society and economy.

From the First Industrial Revolution of the late 18th century to the novel Second Industrial Revolution characterized by the increased sophistication of new machinery based on electric energy source, it was needed for more than a century. Fifty years went by with an immense increase of productivity due to the application of engineering management principles of Frederick Taylor in the early 20th century, and few years later, the application of the revolutionary assembly lines proposed by Henry Ford, and later adopted by all industries. But this increased capacity was possible with the new electric machineries.

A third industrial revolution was possible with the introduction of numerical control (NC) machine tools, invented during World War II and applied a few years later. It became a standard of a radical change in industry since the 1950s. It even enabled the development of robotics for manufacturing operations. From the 1970s, industry was quickly introducing flexible manufacturing systems (FMS) that connected the different machines with digital systems through microprocessors. In parallel, the Third Industrial Revolution also included the emergence of computer-aided design (CAD) and manufacturing (CAM) equipment, and its integration with CAD/CAM systems. Automation even could be increased into the so-called "computer integrated manufacturing" (CIM) systems, which represent a further advanced stage of automation [HIR 16].

1.4.2. *The debate on sociology of work*

The debate among labor experts and social scientists went through different stages too. Until the 1950s, most studies concerned working conditions under increased automation, especially in the automotive industry. These conditions were usually related to physical dimensions through the interaction with machinery, the speed of operations and the potential danger of accidents due to repetitive tasks with automatic machinery. By that time, studies were considering the psychological effects of mental stress derived of these interactions. Increased attention toward manufacturing operations was demanded by the firms, and in some cases, the need for further control was also a source for mental strain. Other studies considered the social impact of isolation of working positions and the problems induced by the lack of direct communication [KRU 09; LU 20; CIM 20; CAN 23a].

In the 1970s, new social science studies were pointing to the potential loss of qualification derived of increased automated systems, especially those enhanced by digitalized control processes. The direct connection between operator and machine was becoming loose and just possible through numerical control programming tasks. The discussion was again on the potential unemployment or deskilling provoked by computerized numerical control (CNC) systems, and later by robotics as well [KRI 21].

By the end of the 20th century, some visions on the "unmanned factory" became possible. Technological capacities were increasing and the possibility to develop manufacturing without workers became a vision for some commercial advocates and for some industrialists [BUT 18]. Soon it became clear that whenever more complex technology is used, the need to get humans involved in the decision-making process is higher. "Unexpected" events regularly happen when technology density and complexity are high. Minor connectivity problems can quickly cause major breakdowns and problems at production lines or on the whole shop floor.

The lower acceptance of the "unmanned factory" vision became clear not only at the union and workers councils' positions but also among managers and employers. It became clear that those breakdowns, even for short time, or during setting up phases, had high costs and could be avoided maintaining human competences available at the shop floor. Other organizational concepts could be possible. New management concepts argued and demonstrated that the investment on "human capital" could be an answer for such problems and limitations of the advancements of production technology.

1.4.3. *The emergence of the concept of Work 4.0: toward i5.0?*

But the debate over the concept of i5.0 has its roots in the anti-determinist discussion and in the possibilities of designing automated systems with anthropocentric purposes, in other words, allowing human operators to participate in the decision process. Just like with the discussion over i4.0, the topic regained its fundaments.

In Germany, a dialogue process the Federal Ministry of Labor and Social Affairs launched in April 2015 with the publication of a Green Paper. On that occasion, the concept of "Work 4.0" became a necessary extension of the debate concerning the digitalization of the economy, or i4.0. In this respect, the German Ministry of Labor and Social Affairs "invited associations, trade unions and businesses to submit responses, held numerous specialized workshops and events, commissioned academic studies, and obtained a picture of public opinion, including by engaging in dialogue directly with members of the public at local level" [BMA 16, p. 9]. As the German former Minister Nahles stated:

> Work 4.0 stands for the changes taking place in the whole of the working world and their implications for society. Rather than describing the normal status quo today, Work 4.0 is about future prospects, scenarios and opportunities to shape developments – to shape work in a way which benefits people and advances our economy [BMA 16, p. 6].

Some of the questions are still to be answered to today:

> The relationship between humans and machines is also changing: what will the computers and robots of the future be able to do, and what human capabilities are irreplaceable? Who will give instructions to whom in future? What requirements do companies have in terms of flexibility? How can we use flexibility in working time and location to develop new solutions for a work-life balance and achieve a fairer distribution of paid and unpaid work between men and women, while at the same time avoiding overwork caused by a breakdown of the boundaries on work? [BMA 16, p. 41–42].

In fact, these questions, and the grounded debate that support scientifically different answers were the base to starting process to establish programs and fix a concept around the item i5.0.

The discussion of impacts of increased developments of technology, and specifically on i4.0, have raised puzzling outcomes in terms of future trends on employment structure, labor market and skill needs. If we go back to the German Ministry of Labor, they mention that:

> The question of whether far-reaching automation processes could result in employment and wage polarization is also being hotly debated. Employment polarization would occur if middle-skilled employment were hit particularly hard by job losses while the employment of low- and high-skilled individuals simultaneously increased. This shift in demand would also lead to a polarization of wages. To date, however, there is no evidence of this in Germany, or of any collapse in middle-skilled employment [BMA 16, p. 53].

This was based on the assumptions of Dustmann et al. [DUS 09] and Antonczyk et al. [ANT 10], among others.

The Work 4.0 study continues to conclude that the forecasts about the future of work emphasize that action must be taken to avoid a scenario of employment and wage polarization in future. This should be considered, particularly in the areas of safeguarding employment, securing incomes and skills development. However, it is easily understood that these areas can also be considered as strategic policies for an economic development focused more on the welfare and not just on liberal competition.

There are, nevertheless, areas of tension that are recognized by the document produced by the German Ministry. They can be identified as follows: a) the possibilities of upskilling and deskilling with the new range of tasks made possible with the new technologies; b) the growing importance of experience at the workplace; and c) the need to weigh the possibilities for individual support and behavioral monitoring against each other. The tension identified in a) is basically a nondeterministic perspective. This means that a new technology can be designed or used is such a way that it promotes upskilling of their users. But it can also deskill them. The focus is then on the way technology is used, in other words, on organizational factors. The tensions identified in b) and c) are mostly related to social factors: job experience and interrelations at the workplace. There are organizations where the job experience is valued, but others do not. Similarly, in some, there are measures to support and train workers continuously due to the characteristics of new technologies, whereas in others, workers are left alone. Thus, for the same technology, it is always possible to find different organizational and managerial solutions.

This pivotal document from the German BMAS even clarifies that the irony of automation is evident when it recognized that:

> Problems which, while increasingly rare, continue to occur. And yet it is precisely when something goes wrong that people are needed who know from experience how to deal with problems in autonomous systems [BMA 16, p. 71].

This becomes the ground justification for the need of a radical change on the way we can understand the possibilities of technological changes and evolution for productive activities. And this change is the basis for an i5.0 concept.

The basic structure of the relation between the main elements of Work 4.0 is presented in Figure 1.1. They are one of the main vectors of the i5.0 concept.