NOVA SCHOOL OF SCIENCE & TECHNOLOGY

DEPARTAMENT OF
MECHANICAL AND INDUSTRIAL ENGINEERING

DRIVING MANUFACTURING SYSTEMS FOR THE FOURTH INDUSTRIAL REVOLUTION

VÍTOR MANUEL CAETANO ALCÁCER

Master in production engineering

DOCTORATE IN INDUSTRIAL ENGINEERING

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Driving Manufacturing Systems for the Fourth Industrial Revolution

Dedicate this work to the loves of my life.

Acknowledgments

At the beginning of this journey, I did not have any idea about any kind of direction for my Ph.D. research. I just wanted to work with the Industry 4.0 topic and as time went by, more questions without answers arose. A few months later, I realized that my research will never end and what was important at the beginning of this journey was to find the focus of my Ph.D. research. My advisor Professor Virgilio Cruz-Machado encouraged me to set my focus and start to find the light at the end of this tunnel.

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"You cannot teach a man anything; you can only help him discover it in himself." (Galileo).

ABSTRACT

It has been a long way since the aroused of the Industry 4.0 and the companies' reality is not already align with this new concept. Industry 4.0 is ongoing slowly as it was expected that its maturity level should be higher. The companies´ managers should have a different approach to the adoption of the industry 4.0 enabling technologies on their manufacturing systems to create smart nets along all production process with the connection of elements on the manufacturing system such as machines, employees, and systems. These smart nets can control and make autonomous decisions efficiently. Moreover, in the industry 4.0 environment, companies can predict problems and failures along all production process and react sooner regarding maintenance or production changes for instance. The industry 4.0 environment is a challenging area because changes the relation between humans and machines. In this way, the scope of this thesis is to contribute to companies adopting the industry 4.0 enabling technologies in their manufacturing systems to improve their competitiveness to face the incoming future. For this purpose, this thesis integrates a research line oriented to i) the understanding of the industry 4.0 concepts, and its enabling technologies to perform the vision of the smart factory, ii) the analysis of the industry 4.0 maturity level on a regional industrial sector and to understand how companies are facing the digital transformation challenges and its barriers, iii) to analyze in deep the industry 4.0 adoption in a company and understand how this company can reach higher maturity levels, and iv) the development of strategic scenarios to help companies on the digital transition, proposing risk mitigations plans and a methodology to develop strategic scenarios. This thesis highlights several barriers to industry 4.0 adoption and also brings new ones to academic and practitioner discussion. The companies' perception related to these barriers Is also discussed in this thesis. The findings of this thesis are of significant interest to companies and managers as they can position themselves along this research line and take advantage of it using all phases of this thesis to perform a better knowledge of this industrial revolution, how to perform better industry 4.0 maturity levels and they can position themselves in the proposed strategic scenarios to take the necessary actions to better face this industrial revolution. In this way, it is proposed this research line for companies to accelerate their digital transformation.

Keywords: Industry 4.0, Maturity Levels, Companies' Perception, Strategic Scenarios, Risk Management.

Resumo

Já existe um longo percurso desde o aparecimento da indústria 4.0 e a realidade das empresas ainda não está alinhada com este novo conceito. A indústria 4.0 está em andamento lento, pois era esperado que o seu nível de maturidade fosse maior. Os gestores das empresas devem ter uma abordagem diferente na adoção das tecnologias facilitadoras da indústria 4.0 nos seus sistemas produtivos para criar redes inteligentes ao longo de todo o processo produtivo com a conexão de elementos do sistema produtivo como máquinas, operários e sistemas. Estas redes inteligentes podem controlar e tomar decisões autónomas com eficiência. Além disso, no ambiente da indústria 4.0, as empresas podem prever problemas e falhas ao longo de todo o processo produtivo e reagir mais cedo em relação a manutenções ou mudanças de produção, por exemplo. O ambiente da indústria 4.0 é uma área desafiadora devido às mudanças na relação entre humanos e máquinas. Desta forma, o objetivo desta tese é contribuir para que as empresas adotem as tecnologias facilitadoras das indústria 4.0 nos seus sistemas produtivos por forma a melhorar sua competitividade para enfrentar o futuro que se aproxima. Para isso, esta tese integra uma linha de investigação orientada para i) a compreensão dos conceitos da indústria 4.0, e suas tecnologias facilitadores para realizar a visão da fábrica inteligente, ii) a análise do nível de maturidade da indústria 4.0 num setor industrial regional e entender como as empresas estão enfrentando os desafios da transformação digital e suas barreiras, iii) analisar a fundo a adoção da indústria 4.0 numa empresa e entender como essa empresa pode atingir níveis mais elevados de maturidade, e iv) o desenvolvimento de cenários estratégicos para ajudar as empresas na transição digital, propondo planos de mitigação de riscos e uma metodologia para desenvolver cenários estratégicos. Esta tese destaca várias barreiras à adoção da indústria 4.0 e também traz novas barreiras para a discussão acadêmica e profissional. A perceção das empresas em relação a essas barreiras também é discutida nesta tese. As descobertas nesta tese são de grande interesse para empresas e gestores, pois podem-se posicionar ao longo desta linha de investigação e aproveitá-la utilizando todas as fases desta tese para obter um melhor conhecimento desta revolução industrial, como obter melhores níveis de maturidade da indústria 4.0 e possam posicionar-se nos cenários estratégicos propostos por forma a tomar as ações necessárias para melhorar o envolvimento nesta revolução industrial. Desta forma, propõe-se esta linha de investigação para que as empresas acelerem a sua transformação digital.

Palavas chave: Indústria 4.0, Níveis de Maturidade, Perceção das Empresas, Cenários Estratégicos, Gestão de Riscos.

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Acronyms

AM	Additive Manufacturing
AR	Augment Reality
BD	Big Data
BITKOM	Germany's digital association
CC	Cloud Computing
CMMI	Capability Maturity Model Integration
CPPS	Cyber-Physical Production Systems
CPS	Cyber-Physical Systems
CS	Cybersecurity
D4I	Digital4Industry
DREAMY	Digital REadiness Assessment MaturitY model
GE	General Electric
HVMC	High-Value Manufacturing Centers
I4.0	Industry 4.0
i4.0	*Indústria 4.0* (Portuguese Industry 4.0)
IoS	Internet of Services
IoT	Internet of Things
IT	Information Technologies
IVI	Industrial Value Chain Initiative

MADE	Manufacturing Academy of Denmark
NDS	National Digital Strategy
OT	Operation Technologies
PI4.0	Platform *Industrie 4.0*
PwC	PricewaterhouseCoopers
R&D	Research and Development
RoI	Return of Investment
RWTH	*Rheinisch-Westfälische Technische Hochschule* (Aachen University in Germany)
SF	Smart Factory
SIMMI 4.0	System Integration Maturity Model Industry 4.0
SPICE	Software Process Improvement and Capability dEtermination
TUBITAK	Turkish Science and Technology Research Council
USA	United States of America
VDMA	*Verband Deutscher Maschinen - und Anlagenbau e.V.* (German Mechanical Engineering Industry Association)
ZVEI	*Zentralverband Elektrotechnik- und Elektronikindustrie e.V.* (Germany's Electrical Industry)

1

INTRODUCTION

This chapter introduces the context and the focus of this thesis aiming its foundations, presents the problem area, the main motivations and objectives of this research, the research question and the general approach to this research. It concludes with an outline of this thesis contents.

1.1 Aim

The buzz word "Industry 4.0" has been announced and with it arises big promises to face the latest challenges in manufacturing systems. The impeller Industry 4.0 (I4.0) is enabling and reinforcing this trend using its technologies, changing the way of living, creating new business models and new ways of manufacturing, renewing the industrial sector for the so-called digital transformation.
The I4.0 is the driver of digitalization of the industrial sector. I4.0 concept was first appeared in a German government article in November 2011 and was entitled as the High-Tech strategy for 2020. The fourth stage of industrialization was called "Industry 4.0". I4.0 term will appear again in Germany at Hannover industrial fair in 2013 and rapidly emerged as the German national strategy. As one of the most competitive global manufacturing industries, Germany developed a strategic plan to implement I4.0, helping on the transformation from the Industry 3.0 (Zhou et al., 2015), with the heading of " Industrie 4.0" (Zhou et al., 2018).
Around the world, all industrialized countries have the I4.0 topic highlighted at the horizon of their political agenda and be aware of its disruptive effects. The I4.0 is also affecting general society, its economics, its human values and relationships, the social networks or digital platforms. Without no definition of a starting point, the fourth revolution is ongoing. As a normal, way, the largest technology developed countries are the main actors of this transformation era;

they are investing huge amounts of money of their governments and private companies on technology and R&D as showed in Table 1.1. Nowadays, with the support of multinational companies there is a quicker spread of advanced technologies. To boost the I4.0 adoption, industrialized countries worldwide (including technology manufacturers countries) are taking actively actions such as public policies, launching innovation strategies.

The Europe Horizon 2020 research program is also present outside borders. Legal entities from associated countries are participating with the same conditions of the European Member States. In January 2017, the following countries associated to Horizon 2020 was: Armenia, Georgia, Tunisia, Ukraine, Faroe Islands, Switzerland, Moldova, Israel, Turkey, Serbia, Montenegro, the former Yugoslav Republic of Macedonia, Bosnia and Herzegovina, Albania, Norway and Iceland (European Commission, 2018).

Some countries listed in Table 1.1 has or had other national initiatives and this fact shows there is a huge effort to support companies in their digital transition along with their competitiveness improvements. In the last years, the I4.0 thematic has been widely studied so companies can be more efficient and reduce their time to market. Currently, the COVID pandemic and the war in middle Europe are examples that disturbs companies' time to market that the world is facing. The I4.0 enabling technologies will improve companies' time to market by affecting all value chain not only inside company but also outside company, creating an integrated environment where everyone and anything are connected. Challenges and opportunities of this ongoing thematic are of great relevance as today the fourth industrial revolution is being designed.

Table 1.1 - I4.0 initiatives worldwide.

Country and Company (ies)	Initiative Name(s) and Starting Dates	Initiative(s) objectives	References
United States of America and General Electric company	Advanced Strategic Manufacturing Partnership (2011); A National Strategic Plan for Advance (2012)	Revitalizing real manufacturing industry economy to maintain their world leading position.	(Tao et al., 2018a); (Zhong et al., 2017); (Bortolini et al., (2017)
Canada	Industrie 2030 (2016)	Manufacturing growth, innovation and prosperity for Canada.	(Liao et al., 2018)
Mexico	Crafting the Future (2016)	A Roadmap for I4.0 in Mexico.	(Liao et al., 2018)
Brazil	Towards Industry 4.0 (2017)	Enhance the adoption and development of I4.0.	(Dalenogare 2t al., 2018)
Japan and thirty Japanese companies such as Nissan Motors, Fujitsu or Mitsubishi	Industrial Value Chain Initiative (IVI) (2015)	Similar to Industrie 4.0 in Germany, using internet to connect business.	(Zhong et al., 2017); (Sun et al., 2018); (Zhou et al., 2018)
China	China Manufacturing 2025 (2015)	Ten-year plan to improve manufacturing capabilities to reach German or United states of America powerhouses.	(Zhong et al., 2017); (Lin et al., 2017); (Zhou et al., 2018)
Malaysia	Eleventh Malaysia Plan (2015)	Transformation of its three main manufacturing subsectors (Electrical and Electronics, Chemicals, Machinery and Equipment) towards more high-value, diverse and complex products.	(Bahrin et al., 2016); (Liao et al., 2018)
South Korea	Manufacturing Innovation 3.0 (2014)	Gain advantage from the manufacturing of Korea. creating a new king of industry.	(Zhou et al., 2018); (Kang & Kim, 2016); (Oztemel & Gursey, 2020)

Table 1.1 - I4.0 initiatives worldwide (continuation).

Country and Company (ies)	Initiative Name(s) and Starting Dates	Initiative(s) objectives	References
Taiwan	Taiwan Productivity 4.0 (2015)	Development of smart manufacturing based on three kins of connections such as: 1) to the local, 2) to the future, and 3) to the world.	(Liao et al., 2018); (Lin et al., 2017)
Singapore	Research, Innovation and Enterprise 2020 (2016)	Increase industry research and development capabilities, nurture innovative enterprises and meet its national needs.	(Liao et al., 2018)
India	Make in India (2014)	Transform India into a global design and manufacturing hub.	(Liao et al., 2018)
Thailand	Thailand 4.0 (2016)	Align the country with the new digital age.	(Desatanova, 20198), (Wonglimpiyarat, 2018)
Turkey	TUBITAK (2016)	Promote intelligent manufacturing systems on related sectors	(Oztemel & Gursev, 2020)
Australia	Emulated the German agenda	Boost innovation in the digital age.	(Dean & Spoehr, 2018)
Lithuania	*Pramoné 4.0* (2017)	Strengthen and increase the Lithuanian's competitiveness and productivity, through the integration of new technologies;	(European Commission, 2018)
Poland	Future Industry Platform (2016)	Act as an integrator and accelerator for the digital transformation.	(European Commission, 2018)
Sweden	*Produktion 2030* (2013)	Put Sweden in the front-runner in investments in sustainable production by 2030.	(European Commission, 2018); (Liao et al., 2018)
Hungary	Industry 4.0 National Technology Platform (2016)	Boost the transformation industry and manufacturing in Hungary guided by I4.0.	(European Commission, 2018)
Czech Republic	*Průmysl 4.0* (2016)	Maintain and enhance the competitiveness of the Czech Republic guided by the I4.0.	(European Commission, 2018); (Basl, 2017)

Table 1.1 - I4.0 initiatives worldwide (continuation).

Country and Company (ies)	Initiative Name(s) and Starting Dates	Initiative(s) objectives	References
Denmark	Manufacturing Academy of Denmark (MADE) (2013)	Apply research in Danish manufacturing with innovation and improving competitiveness.	(European Commission, 2018)
Germany	*Plattform Industrie 4.0* (2013)	Promote the digital transformation of manufacturing in Germany.	(European Commission, 2018)
Netherlands	Smart Industry (2014)	Fit the future with the strengthens of the Dutch manufacturing industry.	(European Commission, 2018); (Liao et al., 2018)
Belgium	Made Different (2013)	Increase the competitiveness of the manufacturing industries.	(European Commission, 2018)
Luxemburg	Digital4Industry (2016)	Targets the local manufacturing industry, SME's as well as large enterprises.	(European Commission, 2018)
France	New Industrial France Program (2013)	Leading of innovation by pushing the technological boundaries for a step further to enable the creation of future products.	(Liao et al., 2018); (Sun et al., 2018); (Tao et al., 2018a); (Zhou et al., 2018)
Austria	Platform *Industrie 4.0* (2014)	Secure and create highly innovative industrial production and to boost quality employment, thus strengthening Austria's future competitiveness.	(European Commission, 2018)
Portugal	*Indústria 4.0* (2017)	Putting Portugal in the forefront of the I4.0 with three focus: 1) digitalization, 2) innovation, and 3) training.	(European Commission, 2018)
Spain	*Industria Conectada 4.0* (2014)	Digitizing and enhancing the Spanish competitiveness of the industrial sector.	(European Commission, 2018); (Liao et al., 2018)

Table 1.1 - I4.0 initiatives worldwide (continuation).

Country and Company (ies)	Initiative Name(s) and Starting Dates	Initiative(s) objectives	References
Italy	*Piano Nazionale Industria 4.0* (2017)	Affect the lifecycle of the companies providing a wide set of measures in order to improve their innovations and competitiveness.	(Liao et al., 2018); (Mazali, 2018); (Bortolini et al., 2017); (Zangiacomi et al., 2018)
United Kingdom	UK Industry 2050 (2013)	Accelerate the transformation of the equipment industry.	(Tao et al., 2018a); (Zhou et al., 2018)
Ireland	National Digital Strategy (2013)	Focus of doing more with digital.	(Department of Communications, 2019); (European Commission, 2018)
Latvia	National Policy Guidelines (2014)	Integration of Digital Technology by businesses.	(European Commission, 2018)
Romania	Manifesto for Digital Romania (2016)	Alignment of the digital future, bringing the information and communication technologies as well as creative industries.	(European Commission, 2018)
Slovenia	Digital Coalition (2016)	Accelerate the digital transformation in Slovenia.	(European Commission, 2018)
Slovakia	Smart Industry Platform (2016)	Acting as a central authority coordinating efforts.	(European Commission, 2018)
Bulgaria	The National Program "Digital Bulgaria 2025" (2018)	Development and widespread use of ICT as well as the commitment of the different institutions within their sectoral policies.	(European Commission, 2018)

Table 1.1 - I4.0 initiatives worldwide (continuation).

Country and Company (ies)	Initiative Name(s) and Starting Dates	Initiative(s) objectives	References
Finland	Digital Finland Framework (2018)	Short timeframe: Recognized global markets needs; Medium timeframe: Renewal of key domains such as health, transport, mobility, energy and manufacturing, based on digital innovations; Long timeframe: Global challenges - climate action, resource sufficiency, safety and security, industrial renewal.	(European Commission, 2018)
Cyprus	The Cyprus New Industrial Strategy Policy 2019-2030 (2019)	Industrial sector to account for 15% of GDP by 2030, doubling its current contribution.	(European Commission, 2018)
Croatia	Digitizing Impulse 2020 (under preparation)	Networking and digital connectivity, Education of workforce for I4.0.	(European Commission, 2018)

1.2 The Problem Area

Delloite Insights (2018) launched the Delloite Global Survey entitled "The Fourth Industrial Revolution is here - are you ready?" to explore the question of I4.0 readiness on the industrial sector, conducted by Forbes Insights during the second half of 2017 and based in 1603 global executives (C-levels executives) from 19 countries from America, Asia and Europe. The overall landscape shows an optimistic scenario related to the I4.0 potential but there's a concern with the investment on I4.0 technologies.

This survey reveals that almost 87 percent of executives are hoping that I4.0 will create equality, social and economic stability to their companies. In other way, many companies are not ready to embrace these new challenges. One-third of executives are confident about the management of their companies within the connected world but only 14 percent admitted their readiness to implement the I4.0 technologies. At the same time, executives are not confident about having the needed talent within their human resources to build the team to face this revolution, however, they are working on it.

The overall insight of this survey shows that executives are aware about the needed investments in I4.0 technologies to be succeeded in an increasing connected world. Most of the executives have some difficulties on rebuilding their business model due to the lack of strategies to enable the adoption of this enabling technologies. At this end, the executives' points lack of confidence and lack of human resources.

Geissbauer et al. (2018) in the Strategy & PwC launched the report "Global Digital Operations Study 2018 - Digital Champions: How industry leaders build integrated operations ecosystems to deliver end-to-end customer solutions", based on a surveyed 1155 executives at global manufacturing companies, in 26 countries.

According to PwC's Industry 4.0 maturity model, the higher maturity stage is the entitled "Digital Champion". In this 2018 survey, 10 percent of the manufacturing companies are "Digital Champions" and two-thirds have not started the digital journey. An interesting finding is that the Asia Pacific is leading the digital journeys, with 19 percent of "Digital Champions" status contrasting with 11 percent in America and 5 percent in Europe, Middle East and Africa.

This 2018 PwC's survey shows 20 percent of the automotive and 14 percent of the electronic industries sharing the "Digital Champion" status. Consumer goods with 6 percent, the industrial manufacturing with 6 percent and process industries also with 6 percent have not the same status.

The overall insight of this survey is that two-thirds of all companies do not have a clear vision and consequently a strategy to support the digital journey and digital culture.

Peti et al. (2018) in Capgemin Research Institute launched a survey entitled "Digital Engineering: The new growth engine for discrete manufacturers" to explore how enabling technologies are being used to transform the manufacturing landscape. This survey was conducted within 1000 senior executives from global manufacturing segmented in industrial manufacturing, high tech (semiconductor/electronics), automotive and transportation, aerospace and defense, medical devices and industrial agricultural equipment.

These surveyed segments belong to United States, Germany, India, China, United Kingdom, France, Italy, Netherlands and Sweden. According to Capgemin study, only 21 percent of the companies considers in an advance stage regarding to innovation and engineering transformation and almost one-third remains at the pilot stage of this journey. Just 16 percent of companies admit the fully commitment on the implementation of Digital Twins (Digital Twins is a digital representation of physical entities) and 45 percent are in the pilot stage. Only 17 percent of companies have made substantial progress across the transformation maturity due to the adoption of digital technologies.

Having introduced above the focus, the context of the problem, and looking back to the three reports above, it's clear that the adoption of the I4.0 on companies is not the expected all over the world and there are still open issues needing to be solved. This thesis aims to contribute to close open issues in a way to accelerate the adoption of the I4.0 enabling technologies on companies.

1.3 Research Questions

The urgent need for the I4.0 implementation leads to a growing demand for this research topic in order to provide insights into the issues, challenges, and solutions for the design and implementation of the I4.0 (Xu et al., 2018). Also, this demand is reflected on the acceptance among industry that I4.0 paradigm is an indispensable concept to shift manufacturing environments into a valuable asset and that there is no way to survive without I4.0 implementation. Up to date, I4.0 is on the early stage of implementation in industry, human environment and scientific research (Roblek et al., 2016). This makes I4.0 a no longer "future trend" (Xu et al., 2016).

Having these challenges into account, the first Research Question (RQ) selected for this thesis is the following:

- (RQ1) How can companies create the I4.0 environment over its manufacturing systems?

By reaching the RQ1, it was important to understand, to date, how is the I4.0 maturity since its announcement in 2012. By this, the following RQ was drawn up:

- (RQ2) What is the I4.0 maturity evolution considering an industrial regional sector?

Expecting the answer of the RQ2, it was also important to understand in deep the 4.0 adoption using the following RQ:

- (RQ3) What is the I4.0 adoption so far on an manufacturing company?

After obtaining the answers to the research questions above regarding the lack of I4.0 adoption over the companies, it was necessary to look further and project scenarios for 2030-time horizon due to the support of European founds to help the digital transformation on companies. Therefore, to finally assess which scenarios and mitigation plans should be implemented to tackle this lack of I4.0 implementation on manufacturing systems, the following RQ was prepared:

- (RQ4) What will be the I4.0 future strategic scenarios on 2030-time horizon? and what will be the risk mitigation plans on 2030-time horizon due to I4.0 implementation?

1.4 Research Objectives

The importance of I4.0 it's clearly assumed around the world. The Fourth Industrial Revolution is the essential path for the industrial sector. The impact of I4.0 on industry is evident: the competitive advantage due to the systems information integration, with a quick time to market and all this with a lower cost. Having this into account, companies who will not follow this trend are doomed to have severe problems on the industrial environment. Moreover, companies must have to be aware about their technological path, must evaluate the I4.0 adoption through the assess of the impact of the enabling technologies into their business model. There is a clear need to supply knowledge on I4.0 thematic and help companies to find their current technological stage and predict the potential of their manufacturing systems technology on shifting to future models of smart environments.
The research of manufacturing systems development for optimal levels of production is challenging and therefore an area of interest. The opportunity to investigate real scenarios and

share findings on how manufacturing systems are being evaluating is challenging. The development of contributions to improve manufacturing systems is part of the goal of this research project and its main objective is to be a fundamental contribution to the development of the I4.0 implementation. In addition, the multidisciplinary area of I4.0 is very enriching and interesting not only for academia, but also to widen knowledge of general community. Moreover, I4.0 has the potential to shift industrial competitiveness and create new products, business and services, in addition to existing products. Following the aforenoted, the main objective of this thesis as the following focus:

- Contribute to manufacturing systems digital transformation regarding the I4.0 technologies adoption, project future strategic scenarios for 2030 and its risk mitigations plans in order to influence, enable, and fasten the I4.0 adoption over manufacturing systems.

To address the main objective of this thesis, there are some specific objectives that this research is intended to clarify as the following:

- Investigate the I4.0 state of the art concepts and technologies over the I4.0 implementation on manufacturing systems to clarify this digital environment to companies;
- Investigate the impact of the I4.0 implementation on manufacturing systems and how I4.0 enabling technologies can be adopted into manufacturing systems;
- Investigate the I4.0 implementation barriers, the maturity levels of the I4.0 adoption on different manufacturing systems and it's overall on an important Portuguese regional sector in Setubal peninsula;
- Investigate the I4.0 enabling technologies adoption into an manufacturing company leader on electronic components in Setubal peninsula;
- Project and discuss future strategic scenarios for 2030 looking to evaluate the future I4.0 adoption to engage practitioners on this discussion;
- Propose risk mitigation plans to enable the I4.0 enabling technologies adoption into manufacturing systems.

1.5 Methodology

By following the research questions of this thesis there was a need to have a clear vision of the I4.0 concepts and enabling technologies, a perception on how manufacturing systems have been evaluated so far, bring to academic discussion the in deep analysis of the I4.0 implementation and think further about the I4.0 implantation. It was important to investigate the I4.0 development over the manufacturing systems.

Figure 1.1 presents the main phases of this research and its locations on the thesis structure, showing the relevant aspects in each phase and its methodological characteristics.

Looking into the research objectives, this thesis started with the I4.0 topic background, to understand the smart factory vision and its enabling technologies with the use of an extensive literature review.

As the outcome of this thesis is to look further to 2030, it was important to surveying how companies were adopting the I4.0 enabling technologies as the next step, after concluding the smart factory vision of the I4.0. This was possible due to the support of AISET (*Associação da Indústria da Península de Setúbal*), an industrial association who represents companies in the Setubal peninsula, the industrial regional sector under analysis. The next phase was to survey how an manufacturing company, belonging to this industrial regional sector, was dealing with the I4.0 adoption and suggest solutions for better performances. The last phase, also with the support of AISET, surveying and interviewing companies belonging also to this industrial regional sector, discuss the projection of future scenarios for 2030 and propose risk mitigation plans on the adoption of the I4.0 enabling technologies over manufacturing systems.

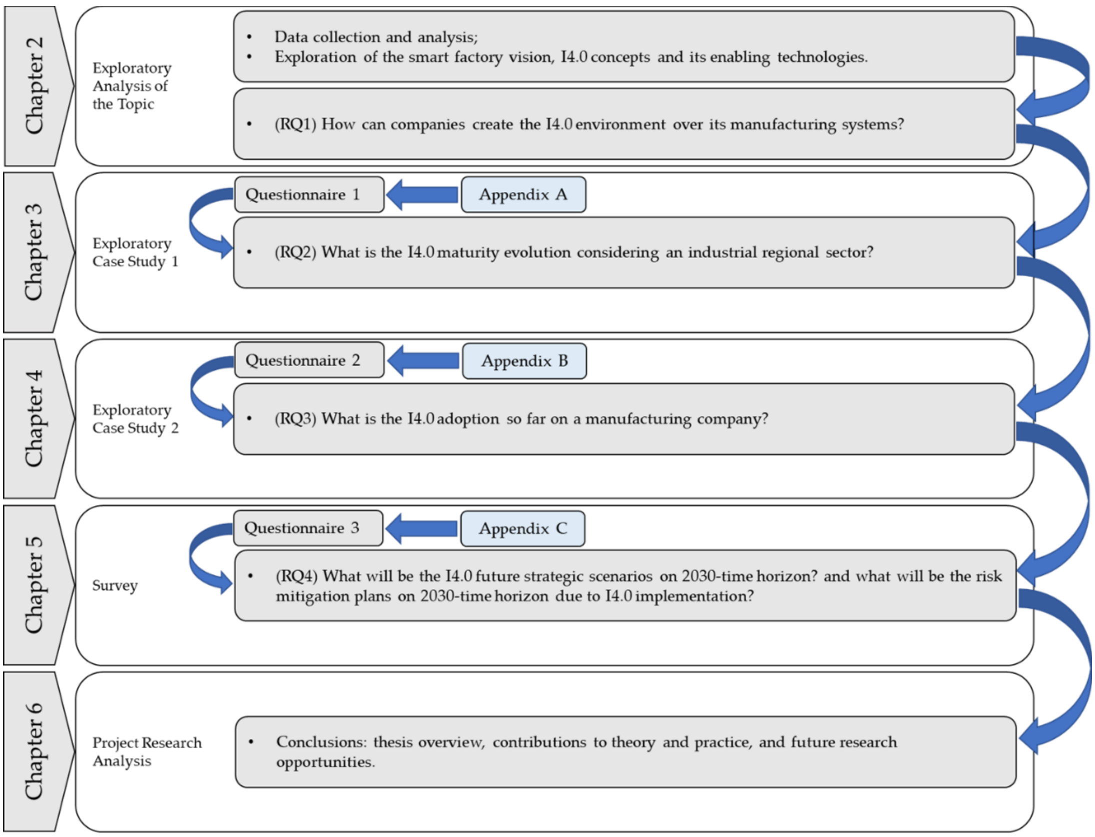


Figure 1.1 - Main phases of thesis development.

The case study presented in chapter 3 is composed by two phases. The first phase was carried out with a survey to measure the I4.0 maturity level, using the IMPULS model. This survey was made online with the use of the LIMESURVEY and data was treated with EXCEL document. The second phase was carried out with semi-structured interviews to assess the perception about the barriers to the I4.0 adoption of the enabling technologies.

The case study of the chapter 4 is composed by a survey, also using the IMPULS model to measure the I4.0 maturity level of the companies' departments. This survey was carried out in in a form of interview.

The chapter 5 considered two phases. The first phase was carried out with a two stages survey: a literature review to identity and analyze risks on the I4.0 enabling technologies implementation and it was used a SWOT analysis to make assessments of each identified risk. A brainstorm session was proposed between researchers to reflect on the type of influence of each risk. The second phase was composed by interviews to collect information using the panel of key-experts to validate SWOT analysis and risks according to risk parameters.

1.6 Thesis Outline

This thesis document is structured in six chapters. It is organized sequentially to better present the research developed. Chapters are linked for ease of reading. All chapters begin with a brief summary and the chapters' development are divided into sections. Chapters are explained further as the following:

- Chapter 1 – Introduction – it's the research setting. It introduces the focus and the research context of this thesis targeting the foundations, the problem area, the motivations and objectives, the research question and methodology to the research project;
- Chapter 2 – The Novel Industrial Revolution - presents a literature review related to the problem area conducting to the concepts and key technologies used to build the I4.0 environment into the manufacturing systems;
- Chapter 3 - Tracking the maturity of the Industry 4.0 - after understanding the vision of the smart factory of the Industry 4.0, it was important to analyze and industrial regional sector regarding the I4.0 maturity. This chapter also brings new barriers on I4.0 to academic discussion and leads to the next chapter;
- Chapter 4 – Industry 4.0 maturity follow-up - analyze the adoption of I4.0 technologies in deep in a manufacturing company. This chapter brings insights of the I4.0 maturity and presents some solutions to increase the I4.0 maturity level in a company;
- Chapter 5 - Industry 4.0 strategic scenarios for 2030 - the chapter 3 and chapter 4 were the starting points to look further. Thus, the chapter 5 discuss strategic scenarios for

2030 regarding the I4.0 adoption and propose risk mitigation plans to face the I4.0 implementation;

- Chapter 6 - Conclusions - presents the main conclusions of this research, reflections to look further and propose future research.

1.7 Concluding Remarks

This chapter served as the introduction to this thesis. The aim of this research and the problem area were launched leading to the drawn of the research objectives and research questions. The general approach presents the structure and methodology of this thesis as also the dissemination channels of the intermediate results. The current thesis fits its research on the I4.0 topic exploring its concepts, enabling technologies, analyzing the I4.0 maturity so far and propose risk mitigations plans to help the I4.0 Implementation.

2

The Novel Industrial Revolution

This chapter is built with the use of a shorter version of the peer-review manuscript version published as: Alcácer, V., Cruz-Machado, V. (2019). Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems. Engineering Science and Technology, an International Journal 22 (3), 899-919. https://doi.org/10.1016/j.jestch.2019.01.006, (Q1; H-Index = 62; Impact Factor = 5.155 (2021); Citations = 561, Captures = 1804).

Summary: Industry 4.0 leads to the digitalization era. Everything is digital; business models, environments, production systems, machines, operators, products and services. It's all inter-connected inside the digital scene with the corresponding virtual representation. The physical flows will be mapped on digital platforms in a continuous manner. On a higher level of automation, many systems and software are enabling factory communications with the latest trends of information and communication technologies leading to the state-of-the-art factory, not only inside but also outside factory, achieving all elements of the value chain on a real-time engagement. Everything is smart. This disruptive impact on manufacturing companies will allow the smart manufacturing ecosystem paradigm. Industry 4.0 is the turning point to the end of the conventional centralized applications. The relevant review of the Industry 4.0 environment is scanned on this chapter.

2.1 Introduction to the Industry 4.0

Global recession over the last years changed the overview on the industrial sector, now looking at the real value-added that it creates. Companies that followed the trend to relocate activities by looking for low-cost labor, are now committed to recover their competitiveness.

German manufacturing strategy played a key role on this shifting, launching initiatives to maintaining and promoting its importance as a ''forerunner" in the industrial sector (Hofmann & Rüsch, 2017). The buzz word ''Industry 4.0" has been presented and with-it big promises arose to face the latest challenges in manufacturing systems. The impeller Industry 4.0 (I4.0) is enabling and reinforcing this trend using its technologies, changing the way of living, creating new business models and new ways of manufacturing, renewing the industry for the so-called digital transformation.

In 2011, the German government have brought into the world a new heading called Industrie 4.0 (I4.0), assumed as the fourth industrial revolution (Wagner et al., 2017; Lu, 2017; Grieco et al, 2017; Motyl et al., 2017; Weyer et al., 2015). I4.0 aim is to work with a higher level of automatization achieving a higher level of operational productivity and efficiency (Lu, 2017; Peruzzini et al., 2017), connecting the physical to the virtual world (Leyh et al., 2017; Baena et al. 2017). It will bring computerization and inter-connection into the traditional industry (Lu, 2017). According to several authors (Lu, 2017; Motyl et al., 2017; Weyer et al., 2015), I4.0 can be assumed as Cyber-Physical Systems (CPS) production, based on heterogeneous data and knowledge integration and it can be summed up as an interoperable manufacturing process, integrated, adapted, optimized, service-oriented which is correlated with algorithms, Big Data (BD) and high technologies such as the Internet of Things (IoT) and Services (IoS), Industrial Automation, Cybersecurity (CS), Cloud Computing (CC) or Intelligent Robotics (Lu, 2017; Peruzzini et al., 2017; Baena et al. 2017). From the production approach, (Leyh et al. (2017) define I4.0 as the intelligent flow of the workpieces machine-by-machine in a factory, on a real-time communication between machines. On this environment, I4.0 will make manufacturing become smart and adaptive using flexible and collaborative systems to solve problems and make the best decisions (Peruzzini et al., 2017). It brings a good development for the industrial scenario focusing on creating smart products, smart processes and smart procedures (Motyl et al., 2017). Companies expected to increase the level of digitalization, working together in digital ecosystems with customers and suppliers (Tupa et al., 2017).

Since I4.0 boom, the research community has experienced different approaches to I4.0 concept; however, the general society may be confused based on the lack of understanding on this area. There is a need for clarification of I4.0 related concepts and technologies.
This chapter deals with the research of I4.0 in manufacturing environments on a literature review over the enabling technologies, focusing on the state-of-the-art and future trends. The approach of I4.0 for manufacturing systems in this chapter is based on the Smart Factory (SF) concept. The SF concept makes use of components such as IoT, IoS, the systems integration and Cyber-Physical Production System (CPPS) that is formed by several linked CPS (CPS may use up until nine key enabling technologies, widely assumed by research community).

2.2. The Key Technologies of the Industry 4.0

I4.0 is characterized on manufacturing and services by highly developed automation and digitalization processes, electronics and IT (Lu, 2017)). From the production and service management perspective, I4.0 focus on establish intelligent and communicative systems such as Machine-to-Machine and Human-Machine Interaction, dealing with the data flow from intelligent and distributed system interaction (Salkin et al., 2018). Among other features, I4.0 promotes autonomous interoperability, agility, flexibility, decision-making, efficiency or cost reductions (Perales et al., 2018).
The I4.0 implementation should be interdisciplinary in a closely between different key areas. Several authors (Motyl et al., 2017; Saucedo-Martinez et al., 2018; Gilchrist, 2106a) described nine pillars (also called the building blocks) of the I4.0 framework as follows in the subsections. A fundamental key point to achieve the integration of I4.0 framework is the human contribution that will be improved with the development of professional skills of the stakeholders.

2.1.1 Vertical and Horizontal Systems Integration

Engineering, production, marketing, suppliers, and supply chain operations, everything connected must create a collaborative scenario of systems integration, according to the information flow and considering the levels of automation (Saucedo-Martinez et al., 2018; Suri et al., 2017). In general, the systems integration of I4.0 has two approaches: horizontal and vertical integrations (Tupa et al., 2017; Suri et al., 2017). Real-time data sharing is enabled by these two types of integration (Salkin et al., 2018).
Horizontal integration is the inter-company integration (Suri et al., 2017) and is the foundation for a close and high-level collaboration between several companies, using information systems

to enrich product lifecycle (Salkin et al., 2018), creating an inter-connected ecosystem within the same value creation network (Tupa et al., 2017; Suri et al., 2017). It is necessary an independent platform to achieve interoperability on the development of these systems, based on industrial standards, enabling exchanging data or information (Suri et al., 2017).

Vertical integration is a networked manufacturing system (Foidl & Felderer, 2016), the intra-company integration (Suri et al., 2017) and is the foundation for exchanging information and collaboration among the different levels of the enterprise's hierarchy such as corporate planning, production scheduling or management (Tupa et al., 2017; Foidl & Felderer, 2016). Vertical integration "digitizes" all the process within entire organization, considering all data from the manufacturing processes, e.g., quality management, process efficiency or operations planning that are available on real-time. By this, in a high level and flexible way, providing the small lot sizes production and customized products, the vertical integration enables the transformation to SF (Salkin et al., 2018). It's important to refer that standards must be the bases of the vertical integration (Suri et al., 2107).

According to several authors (Suri et al., 2017; Foidl & Felderer, 216; Posada et al., 2015; Stock & Seliger, 2016; Wang et al., 2016), the paradigm of I4.0 in manufacturing systems has another dimension between horizontal and vertical integration considering the entire product lifecycle. This kind of integration is based on vertical and horizontal integrations (Foidl & Felderer, 216). In a vision of holistic digital engineering, as the natural flow of a persistent and interactive digital model, the scope of the end-to-end digital integration is on closing gaps between product design and manufacturing and the customer (Posada et al., 2015), e.g., from the acquisition of raw material for the manufacturing system, product use and its end-of-life. The phase of end-of-life product contains reusing, remanufacturing, recovery and disposal, recycling, and the transport between all phases (Stock & Seliger, 2016)). Figure 2.1 shows the relationship between the three types of integration on a manufacturing system, considering vertical integration as the corporation(s), horizontal integration between corporations, and end-to-end integration linking design, production and logistics as an example.

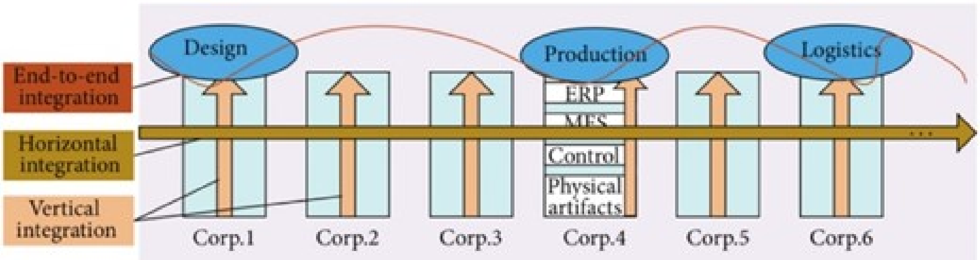


Figure 2.1 - Types of integrations in the manufacturing system (Monostori et al., 2016).

2.1.2 Internet of Things

On the IT (Information Technologies), the IoT (Internet of Things) is the connection of two words i.e., “internet” and “things”. "Internet" as the network of the networks. A global system serving users worldwide with interconnected computer networks using Standard Internet Protocol suit (TCP/IP). As individually distinguishable by the real world, the "things" can be anything like an object or a person (Madakam et al., 2015). Today, IoT is widely used for instance, in transportation, healthcare or utilities (Sezer et al., 2018). Thing-to-Thing, Thing-to-Human and Human-to-Human form a network inside IoT, connected to the internet. Individually identifiable objects exchange information inside this network (Choi & Chung, 2017; Sadiku et al., 2017).

IoT has been increase with the advancement of mobile devices. IoT can be achieved with connected RFID, Wireless Sensor Networks (WSN), middleware, CC, IoT application software and Software Defined Networking (SDN) as the key enabling technologies (Sadiku et al., 2017). Figure 2.2 presents the associated technologies in IoT.

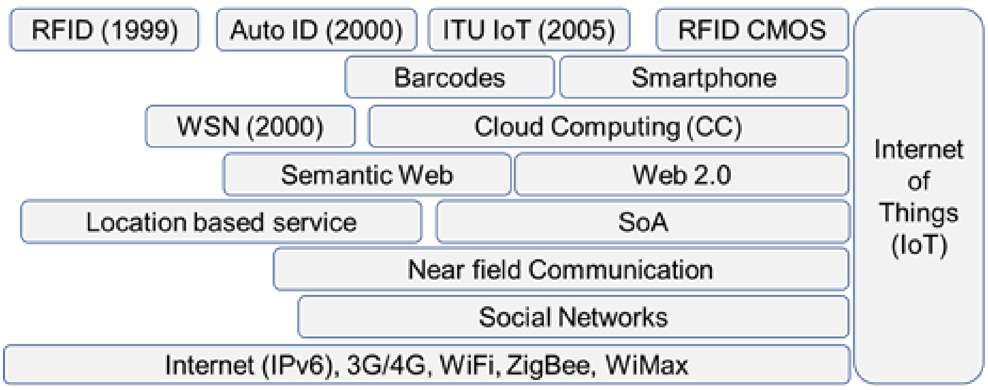


Figure 2.2- Technologies Associated with IoT (Li et al., 2015).

One simple definition of IoT described by Sezer et al. (2018) is: “IoT allows people and things to be connected anytime, anyplace, with anything and anyone, ideally using any path/network and any service". In other words, Bortolini et al. (2017) defined IoT as an ubiquitous presence for a common purpose of various things or objects interacting and cooperating each other, digitalizing all physical systems. For different aims, the digitalized information can be used to adjust production patterns, with the use of a virtual copy of the physical world and using sensor data (Peruzzini et al., 2017). The entire production systems such as machinery and related resources can be the "things" managed and virtualized by I4.0 (Peruzzini et al., 2017; Grieco et al., 2017). In addition, the IoT nature as to be decentralized and heterogeneous (Li et al., 2015). Regarding to IoT design architecture, Trappey et al. (2017) established a logical framework by layers to classify IoT technology and used to characterize and identify CPS. According to several authors (Li et al., 2015; Hammoudi et al., 2018; Ben-Daya et al., 2019), IoT architecture most common layering in a typical network, includes four main layers as represented in the Figure 2.3 as follows:

1) "Sensing Layer" to sense the "things" status with a unique identity and to integrate, e.g., actuators, sensors, RFID tags as several types of "things";
2) "Network Layer" to support the transferred information through wired or wireless network from the "Sensing Layer" to "Service Layer", being the support's infrastructure. This layer determines and maps "things" automatically in the network enabling to connect all "things" for sharing and exchange data;
3) "Service Layer" makes use of a middleware technology supporting services and applications, required by the users or applications. The interoperability among the heterogeneous devices is ensured by this layer, performing useful services, e.g., information search engines and communication, data storage, exchanging and management of data as well as the ontology database;
4) "Interface Layer" to make the interconnection and management of the "things" easier and to display information allowing a clear and comprehensible interaction of the user with the system.

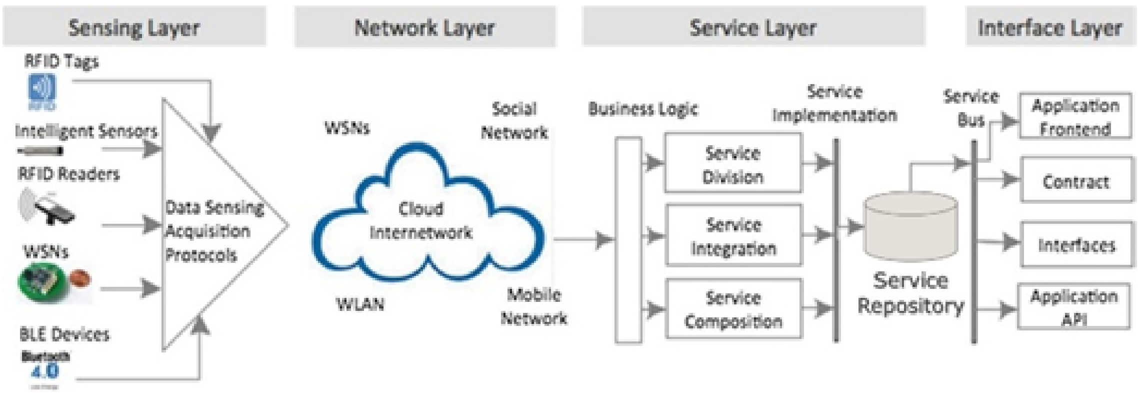


Figure 2.3 - Generic Service-oriented Architecture (SoA) for IoT (Li et al., 2015).

Differing from IoT based users, regarding to industrial environments needing real-time data availability and high reliability (Andulkar et al., 2018), the Industrial Internet of Things (IIoT) is the connection of industrial products such as components and/or machines to the internet. For instance, linking the collected sensing data in a factory with IoT platform, IIoT increases production efficiency with the BD analysis (Choi & Chung, 2017).

A typical IIoT is showed in Figure 2.4, with wire and wireless connections, increasing value with additional monitoring, analysis and optimization.

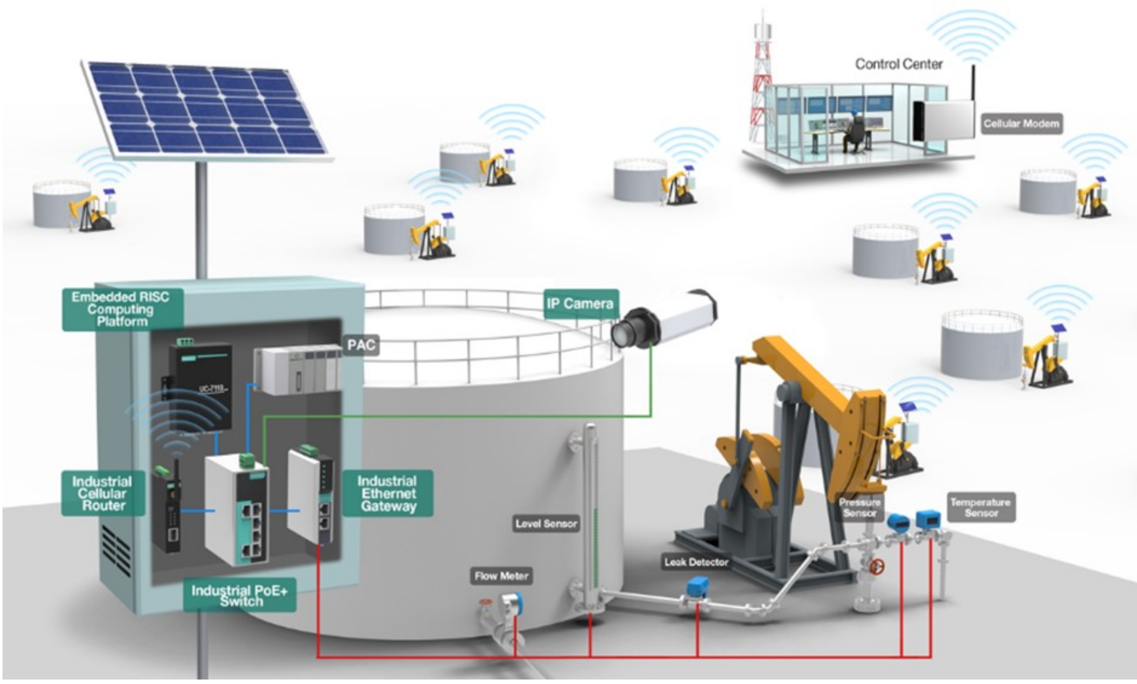


Figure 2.4 - Typical IIoT network (Medium Corporation, n. d.).

As a natural evolution of IoT, the IoS can be seen as the connectivity and interaction of the things creating valuable services and is one of the fundamental bases of the SF. IoS is discussed further in section 2.3.

2.1.3 Cloud Computing

Cloud Computing (CC) is an alternative technology for companies who intent to invest in IT outsourcing resources (Branco et al., 2017). Assante et al. (2016) characterized CC for Small and Medium Enterprises (SMEs) as a resource pooling with rapid elasticity and measured service, on-demand self-service and broad network access. The adoption of CC has several advantages related to cost reduction, e.g., the direct and indirect costs on the removal of IT infrastructure in the organization, the resource rationalization service by the dynamically scalable users consuming only the computing resources they actually use or portability when using any type of device connected to the internet such as mobile phones or tablets accessing from any world location (Branco et al., 2017). By this, the cloud can have any of the four types of access: public (usually on a data center location, managed by vendors and available for all public (Alqaryouti & Siyam, 2018)), private (same organization location and offering special benefits (Alqaryouti & Siyam, 2018)), hybrid (combination of public and private clouds (Alqaryouti & Siyam, 2018)) and community (shared by multi organizations and supported by a specific sharing of interests and concerns community (Xu, 2012)). Everything is treated as a service in CC. These services define a layered system or types of service models structured for CC as in Figure 2.5 and the management overview is shown in Figure 2.6, as follows (Assante et al., 2016; Xu, 2012; Senyo et al., 2018):

- Infrastructure as a Service (IaaS) is where cloud service providers supply users with fundamental computing resources, with virtual infrastructures, e.g., virtual servers, networks or storage and where users into the cloud can deploy and run arbitrary software, which can include, for instance, operating systems applications;
- Platform as a Service (PaaS) is where users develop and run applications using programming languages on the cloud infrastructures. Therefore, it can be achieved scalability, high speed server and storage. Users can build, run and deploy their own applications with the use of remote IT platforms. On this layer, there is no concern on the resource's availability and maintenance (Ooi et al., 2018);
- Software as a Service (SaaS) is where applications reside and runs in a cloud infrastructure (Senyo et al., 2018). Accessible from various client devices through an interface such as a web browser and programs. The focus is to eliminate the service applications on local devices of individual user, achieving an high efficiency and performance for

the users. This category enables software applications such as Computer-Aided-Design (CAD) software and Enterprise Resource Planning (ERP) software, with a lower total cost of ownership (Ooi et al., 2018).

All underlying Everything as a Service (XaaS) layers allows direct interactions with the user interface layer at the top.

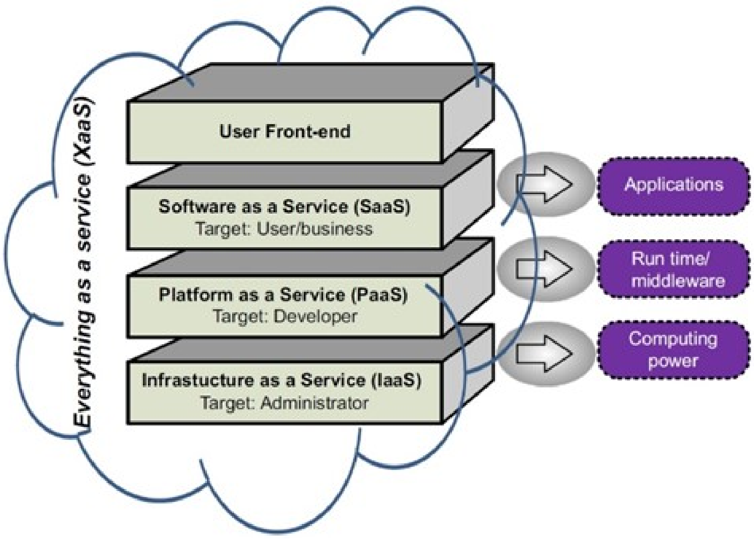


Figure 2.5- Everything as a Service on CC (Xu, 2012).

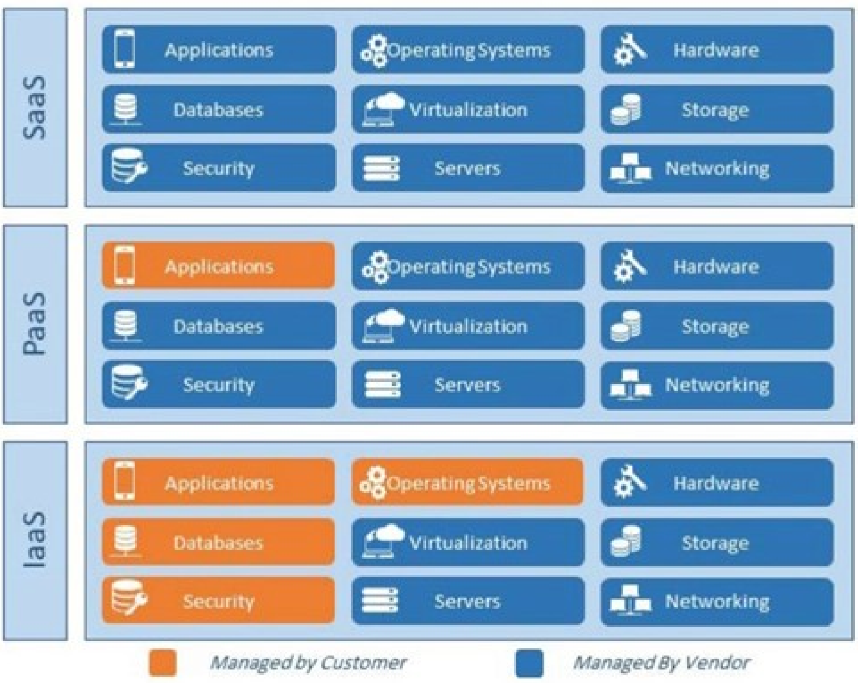


Figure 2.6 - Management overview in CC models (Alqaryouti & Siyam, 2018).

2.1.4 Big Data

Huge amount of generated data from different types, can come from interconnected heterogeneous objects (Bortolini et al., 2017). This huge amount of structured, semi-structured and unstructured data can describe Big Data (BD). In order to obtain the correspondent value, these data would need too much time and money to be store and to be analyzed (Qi &Tao, 2018). Bringing value opportunities to industries in the era of Internet of Everything can be achieving with the connection of more physical devices to the internet and with the use of a generation of novel technologies.

Data collection or storage characterize BD, but the core characteristic of BD is the data analysis and without it, BD has no much value (Babiceanu & Seker, 2016). Systematic guidance can be provided by BD for related production activities within entire product lifecycle (Tao et al., 2018b), achieving cost-efficient running of the process and fault-free (Yin & Kaynak, 2015), and help managers on decision-making and/or to solve problems related to operation (Tao et al., 2018b). The use of BD provides a business advantage through the opportunity of generated of value-added (Cheng at al., 2018).

Cemernek et al. (2017) presented BD definition of the TechAmerica Foundation, as ''a ''term" describing large volumes of high velocity, complex and variable data requiring advanced techniques and techniques to enable the capture, storage, distribution, management and analysis of the information". BD demands a cost-effective, innovative forms of information processing for enhanced insights. According to the researched definitions of BD, differing from the traditional data processing (Sezer et al., 2018), the first suggestion to characterize BD was related in terms of Volume, Variety, and Velocity, also named as the Three V's. These was the three dimensions that emerged as a common framework of challenges in data management (Gandomi & Haider, 2015). To process continuously large amounts of unstructured heterogeneous data collected in formats such as video, audio, text, or others (Babiceanu & Seker, 2016), additionally, other dimensions have also been attempted to assign for a better characterization such as: Veracity, Vision, Volatility, Verification, Validation, Variability and Value (Gandomi & Haider, 2015). According to several authors (Sezer et al., 2018; Babiceanu & Seker, 2016; Gandomi & Haider, 2015; Sen et al., 2016), the description of the dimensions as follows:

- Volume – great data volume size consuming large storage or consist of enormous number of collections. BD sizes are mentioned in multiple terabytes and petabytes;
- Variety – various types of data, generated from a large sources and formats variety, and multi-dimensional data fields contents. It refers to the structural heterogeneity in a dataset;

- Velocity – rapid production. Generation, analysis, delivery, and data creation measured by its frequency. It refers to the data generation rate and the speed for analyzing and acting upon;
- Veracity – represents the unreliability in some data sources. Some data requires BD analysis to gain reliable prediction;
- Vision – only a purposeful process should send data generation. The likelihood of data generation process is addressed in this dimension;
- Volatility – a limited useful life can characterize data generated. The data lifecycle concept is addressed by this dimension. It ensures the replenishment of the outdated data with new data;
- Verification – conformity of the data generated by a specification set. It ensures the conformity of the engineering measurements;
- Validation – the vision conformity of the data generated. Behind the process, the transparency of assumptions and connections are ensured;
- Variability – data flow rates measured by its variation. Variability and Complexity was added as two additional dimensions of BD;
- Value – through extraction and transformation, defines how far BD generates economically worthy insights and benefits. Value as a defining BD attribute.

On manufacturing domain and at the BD process comprehension, it is the engineering aspects that give value to the BD analysis using its dimensions (Babiceanu & Seker, 2016). These dimensions are dependent from each other, related with the relativity of BD volumes applied to all dimensions (Gandomi & Haider, 2015).

To explore data, advanced data analysis is required. Using CC through the advanced analytics, methods and tools, off-line and real-time data are analyzed and mined, e.g., machine learning, forecasting models, among others. Knowledge is extracted from the huge data number enabling manufacturers on understanding the product lifecycle various stages (Qi &Tao, 2018). Moreover, the advanced analytics of BD can be used as a facilitator, identifying and overcoming bottlenecks created by IoT generated data (Mourtzis et al., 2016).

The mutation opportunity from today's manufacturing paradigm to smart manufacturing is offered by BD (Tao et al., 2018c). Therefore, BD can help manufacturers on more rational, informed and responsive decision-making way. Manufacturing competitiveness in the global market is enhanced by these BD characteristics. Various stages in data lifecycle where manufacturing data is exploited are depicted in Figure 2.7 consisting on the complete manufacturing data journey.

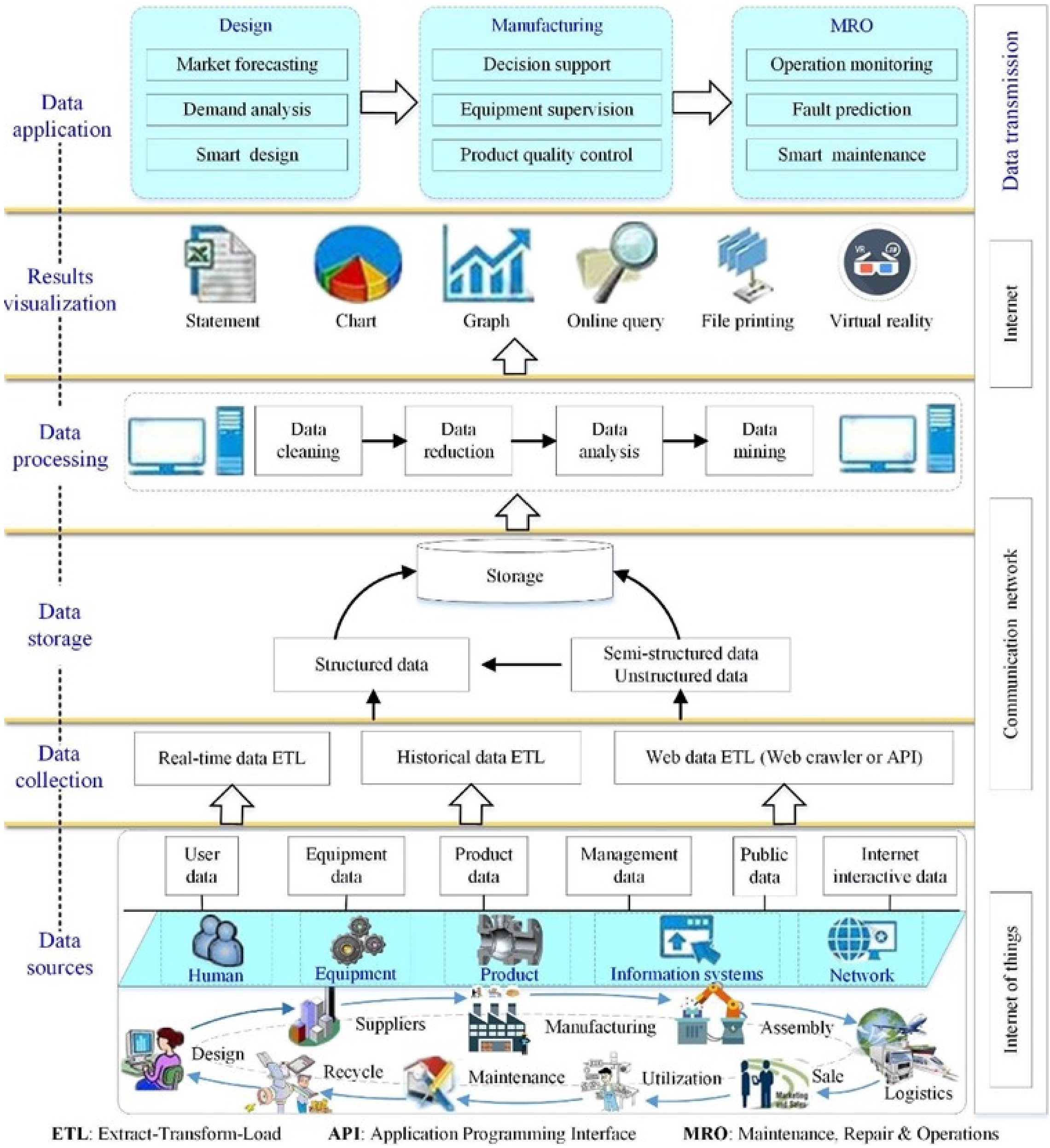


Figure 2.7 - Manufacturing data lifecycle (Tao et al., 2018c).

According to Mourtzis et al. (2016), in a framework structured by levels of a manufacturing enterprise, the lower level generates data directly from machine tools and operators. For an enterprise, this data is very important, providing precious information when used and analyzed enabling adaptivity and flexibility on the higher levels of the enterprise.

BD analytics is an essential key to digital manufacturing, playing as an enabler for technologies. Moreover, the scope of mass customization focusing on the needs of individualized markets, use BD analytics as foundation (Mourtzis et al., 2016).

As mentioned above, IoT data converges to BD in order to analyze it and take conclusions from collected datasets. In other words, IoT data will be a part of BD (Sezer et al., 2018) and BD cannot be explored further without the IoT (Sen et al., 2016). Furthermore, CC and BD are considered as a coin with its two faces: BD is seen as the absorbent application of CC, while CC provides the IT infrastructure of BD (Sen et al., 2016).

2.1.5 Simulation

For the successful implementation of the digital manufacturing (Mourtzis et al., 2014), an indispensable and powerful tool, the computer simulation, is becoming a technology to better understand the dynamics of business systems (Rodič, 2017). Manufacturing industry current challenges can be approached by this technology (Zúñiga et al., 2017), dealing with the complexity of the systems, with elements of uncertain problems that cannot be resolved with usual mathematical models (Lachenmaier et al., 2017). On a customized product manufacturing environment, the value of simulation is remarkable and evident. Simulation allows experiments for the validation of products, processes or systems design and configuration (Mourtzis et al., 2014). Simulation modeling helps on cost reduction, decrease development cycles and increase product quality (Rodič, 2017). In order to analyze their operations and support decision-making, manufacturers have been using modeling and simulation (Shao et al., 2014). Simulation technologies already proved its effectiveness in the approach of several practical real-world problems in manufacturing sector (Negahban & Smith, 2014). Mourtzis et al. (2014) presented on their research, the domain areas of simulation as shown in Figure 2.8 with the focus on simulation methods and tools. Simulation is defined as an operation imitation, over time, of a system or a real-world process. It uses a system´s artificial history and its observation, drawing inferences over the operational features of the representation of the real system.

Figure 2.8 - Domains on simulation research of contemporary manufacturing (Mourtzis et al., 2014).

Simulation modeling is the method that makes use of a real models or imagined system models or imagined process models. It helps on a better estimating and understanding the modeled systems or process through its behavioral analysis (Rodič, 2017). A model is an entity (generally a simplified abstraction) used for representing other entity with a particular defined purpose (White & Ingalls, 2015). Simulation modeling allows to gain insights into complex systems by the development of complex and versatile products and make possible to test new concepts or systems, resource policies and new operating before its real implementation, allowing to gather information and knowledge with no interference on the actual running system (Mourtzis et al., 2014). The Figure 2.9 shows types of simulation models discussed by Mourtzis et al. (2014) regarding to the classification, dimensions, and differences.

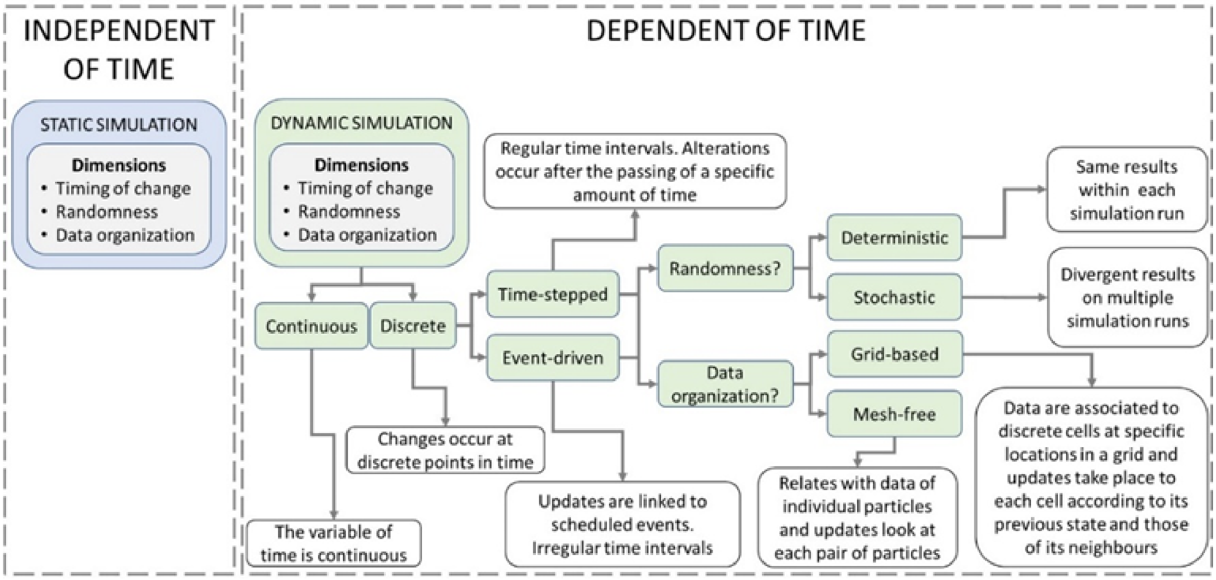


Figure 2.9 - Types of simulation. Based on (Mourtzis et al., 2014).

Choose and develop the best suitable type of simulation model to represent the real system is a multiparameter decision, e.g., static models for modelling a structure without activity and dynamic models for investigating the behavior of a system evolving through time (Mourtzis et al., 2015). Simulation have been playing a spotlight role in design evaluation (referred to as off-line) and operational process performance (referred to as on-line) during a manufacturing system (Negahban & Smith, 2014; Mourtzis et al., 2015).

Its usual the existence of making long-term decisions on the design process (Mourtzis et al., 2015) in, e.g., facility layouts, system capacity configurations, material handling systems, flexible manufacturing systems and cellular manufacturing systems (Negahban & Smith, 2014). Simulation runtime in off-line is not significant on the simulation process, offering the advantaged to study and analyze the what-if scenarios (Mourtzis et al., 2015).

On the operational process of the manufacturing system, e.g., manufacturing operations planning and scheduling, real-time control, operation policies and maintenance operations (Negahban & Smith, 2014), the decision-making is short-term, making the simulation runtime a very important aspect. On-line simulation relates the number of entities belonging to the production system, the number of its generated events, the activities complexity and simulation time horizon. If the IT system is integrated with the on-line simulation, for instance, it's possible to own the capacity to estimate the future shop floor behavior and to emulate and/or determinate the manufacturing system logic control (Mourtzis et al., 2015).

Optimal or near-optimal system design is the goal for decision makers. This optimization is possible due a systematically search on a wide decision space without restrictions or pre-specified requirements. This simulation optimization tool will search for the optimal design within a given system, according to the computer simulation model. On dynamic and uncertain environments, this tool has the potential on optimizing control decisions and on supporting real-time decision-making. This can be possible when the required computational efficiency is reached (Xu et al., 2016). Compared to conventional simulation, real-time simulation, on-line, can analyze the behavior of user and system in milliseconds, allowing the user to develop and produce "virtually" a prototype for the product or service (Cedeño et al., 2018). According Cedeño et al. (2018), a real-time simulation is when a computer runs at the same rate as the physical system, so the simulation model needs to be feed with real-time data that can be reached using IoT.

A high-fidelity simulation of a manufacturing factory is defined as Virtual Factory (VF). An industrial collaboration environment focusing on Virtual Reality (VR) representation of a factory (Jain, & Shao, 2014) or an emulation facility (Jain et al., 2017) can be considered a VF. The VF vision considers validated real factories simulation models to generate data and to be worked in formats of real conditions in a real factory (Shao et al., 2014).

The new simulation modeling paradigm is based on the concept of Digital Twin (DT) (Rodič, 2017). An ultra-high-fidelity simulation is provided by the DT concept and it plays an important role in I4.0. It extends simulation to all product lifecycle phases, combining real-life data with simulation models for better performances in productivity and maintenance based on realistic data (Rodič, 2017).

Technologies based on simulation are the core role in the digital factory approach, allowing experiments and validation upon different manufacturing system patterns, processes and products (Caggiano & Teti, 2018).

2.1.6 Augment Reality

New challenges are coming with Augmented Reality (AR) usage in everyday (Hořejší, 2015). Increase human performances is the aim of AR, supplying the needed information to a given specific task (Palmarini et al., 2017). This novel technology provides powerful tools, acting as an HMI (Fraga-Lamas et al., 2018). AR technology can be found on a wide range of sectors, e.g., entertainments, marketing, tourism, surgery, logistics, manufacturing, maintenance, etc. (Palmarini et al., 2018). As a growing evolving technology, recently, AR usage is spreading to different manufacturing fields (Mourtzis et al., 2017). The use of AR on manufacturing processes regarding to simulation, assistance and guidance has been proven to be an efficient technology helping on problems (Rentzos et al., 2013). AR technology increase reality operator's perception by making use of artificial information about the environment, where the real world is fulfilled by its objects (Syberfeldt et al., 2015; Syberfeldt et al., 2016). As long as it interacts with human senses, AR can make use of any kind of hardware (Palmarini et al., 2017). Using AR can help on closing some gaps, e.g., between product development and manufacturing operation, due to the ability to reproduce and reuse digital information and knowledge at the same time that supports assembly operations (Rentzos et al., 2013). Figure 2.10 shows the most relevant tasks related to industrial environments and manufacturing fields where the AR brings value.

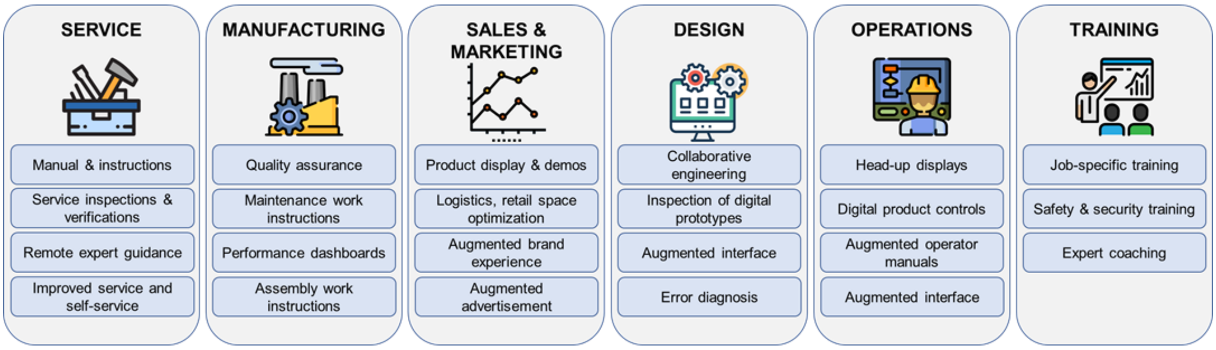


Figure 2.10 - Value of industrial AR across I4.0. Based on (Fraga-Lamas et al., 2018) (Mourtzis et al., 2017).

The principle of AR is the combination of two scenarios: 1) digitally processed reality with 2) digitally added artificial objects that could be 2D flat objects, or by other definitions that only considers 3D objects within the scene (Hořejší, 2015). The authors (Syberfeldt et al., 2015; Syberfeldt et al., 2016) defined AR system features as: 1) the ability on combining real and virtual objects on a real environment, 2) the ability on align each other the real and the virtual objects, and 3) the ability on running interactively, in 3D, and on real-time.

Making use of conventional hardware, the use of AR has a big advantage that can be minimal or even zero purchase expense. Some cases, the see-through glasses component can be more expensive (Hořejší, 2015). On industrial environment, other key advantage was pointed by Blanco-Novoa et al. (2018) about the assets: AR provides dynamic real-time information, so it can suppress most of the paperwork.

The AR system software might be selected based on environment's considerations, which obviosity differ among them, e.g., on the military environment the proper use is zero-connectivity to ensure CS, differing from commercial environment that requires providing remote assistance's connectivity (Palmarini et al., 2017).

The essential parts of an AR system make use of electronic devices to view a real-world combination directly or indirectly with virtual elements. According Fraga-Lamas et al. ((2018), these elements can be:

- Image capture element – web camera is sufficient (Hořejší, 2015);
- Display – for projection of the virtual information on the images acquired by the image capture element. Basically, three device types with optical options can be used (Syberfeldt et al., 2016; Syberfeldt et al., 2017): 1) hand-held (video and optical), 2) head-worn (video, optical, and retinal), and 3) spatial (projector and hologram);
- Processing unit – to generate virtual information to be projected;
- Activating elements – to trigger the display of virtual information, e.g., sensors, QR markers, GPS positions, images, etc.

In order the user to visualize information, these AR devices use types of optics as follows (Syberfeldt et al., 2017):

- Video – merged worlds (real and virtual) into the same digital view;
- Optical – real world with virtual objects overlaid directly on the view;
- Retinal – direct projection of virtual objects onto the retina with the use of low-power laser light;
- Hologram – real world mix with virtual objects using a photometric emulsion;
- Projection – projection of virtual objects directly on real-world objects with the use of a digital projector.

Related to the quality of products, Segovia et al. (2015) proposed an AR system solution to production monitoring, based on Statistical Process Control (SPC) and Six Sigma methodology. It uses AR in real time reports to assist quality data reporting by monitoring Cpk indexes to support the decision-making process. The AR system was linked to a Computer-Aided-Quality (CAQ) to receive data. The CAQ used was Quality Data Analysis (QDA) software that allows the user to verify quality goals. The used measurement device was wireless connected to QDA software. The QDA software generated reports and exported them automatically in a file to the AR application. The mobile device used to run the AR application was a tablet. Figure 2.11 shows the AR technology with the inside of the facilities and the displayed Key Performance Indicators (KPI) of each workstation. According to Segovia et al. (2015), one of the biggest benefits of this tool is the reduction on audit times.

Figure 2.11 - Conceptualization of using the AR-QDA application on a full productive line (Segovia et al., 2015).

Maintenance is one of the most promising fields of AR. It enhances human performances in technical maintenance tasks execution as also supports on maintenance decision-making (Palmarini et al., 2018). One example of AR in maintenance is shown in Figure 2.12 on a step-by-step assembly procedure of a consumer device, using Hand-Held Display (HHD) to carry out maintenance tasks. The AR application has text description of the task on the bottom, right and left arrows to go forward and backward on the procedure.

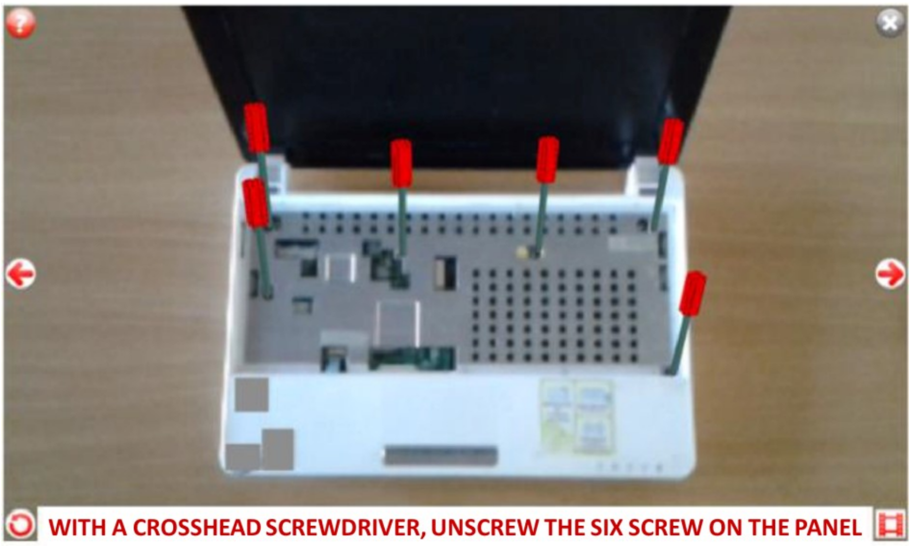


Figure 2.12 - Step-by-step assembly procedure (Palmarini et al., 2018).

Other example in the use of AR technology is on the diagnostics field. A meaningful example is shown in Figure 2.13, also with the use of an HHD. The defects inspection and mapping on the pipe was made with a 3D image. The defects position is indicated on the pipe and it can be seen a clearer image of the nature and scale of defects. At the end, the operator can detect, locate and mark defects using a tablet and a marker (Dini & Mura, 2015).

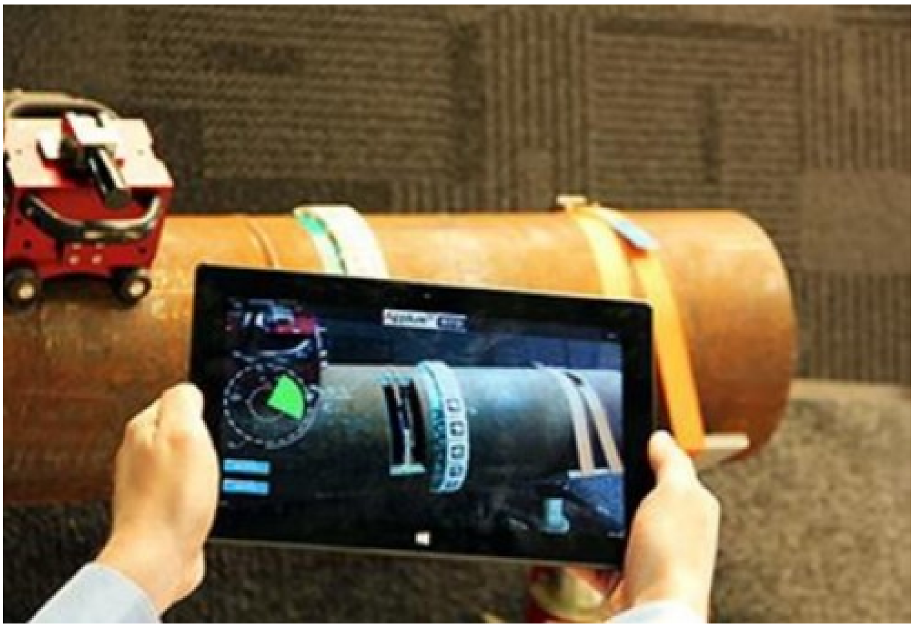


Figure 2.13 - AR in non-destructive testing on pipelines (Dini & Mura, 2015).

2.1.7 Additive Manufacturing

Products and services innovations needs hard and long research work and development that I4.0 with the enabling technologies such as simulation via virtual reality are enabling it. However, on the next step, there is a manufacturing process with its related costs that can be a barrier to competitiveness. Additionally, at the end, there is a dilation of product or service lead time for markets.

The Additive Manufacturing (AM) paradigm is being increasingly developed and it brings into real industry, high feasible applications (Kim & Tseng, 2018). Jian et al. (2017) discussed the potential of AM on the replacement of many conventional manufacturing processes. AM is an enabling technology helping on new products, new business models and new supply chains. A set of technologies that enables "3D printing" of physical objects form the collective term AM (Hannibal & Knight, 2018). Products such as one-of-a-kind, can be manufactured without the conventional surpluses, so it is a big advantage. AM technologies can be referred also with other synonyms such as rapid prototyping, solid freeform manufacturing, layer manufacturing,

digital manufacturing or 3D printing (Chong et al., 2018). With AM it's possible to create prototypes to allow value chain elements dependence, and therefore, achieving time reduction on design and manufacturing process.
As follows in Figure 2.14, AM processes are classified into seven categories according to the standard of the International Organization for Standardization (ISO)/American Society for Testing and Materials (ASTM) 52900:2015 (ASTM standard F2792).

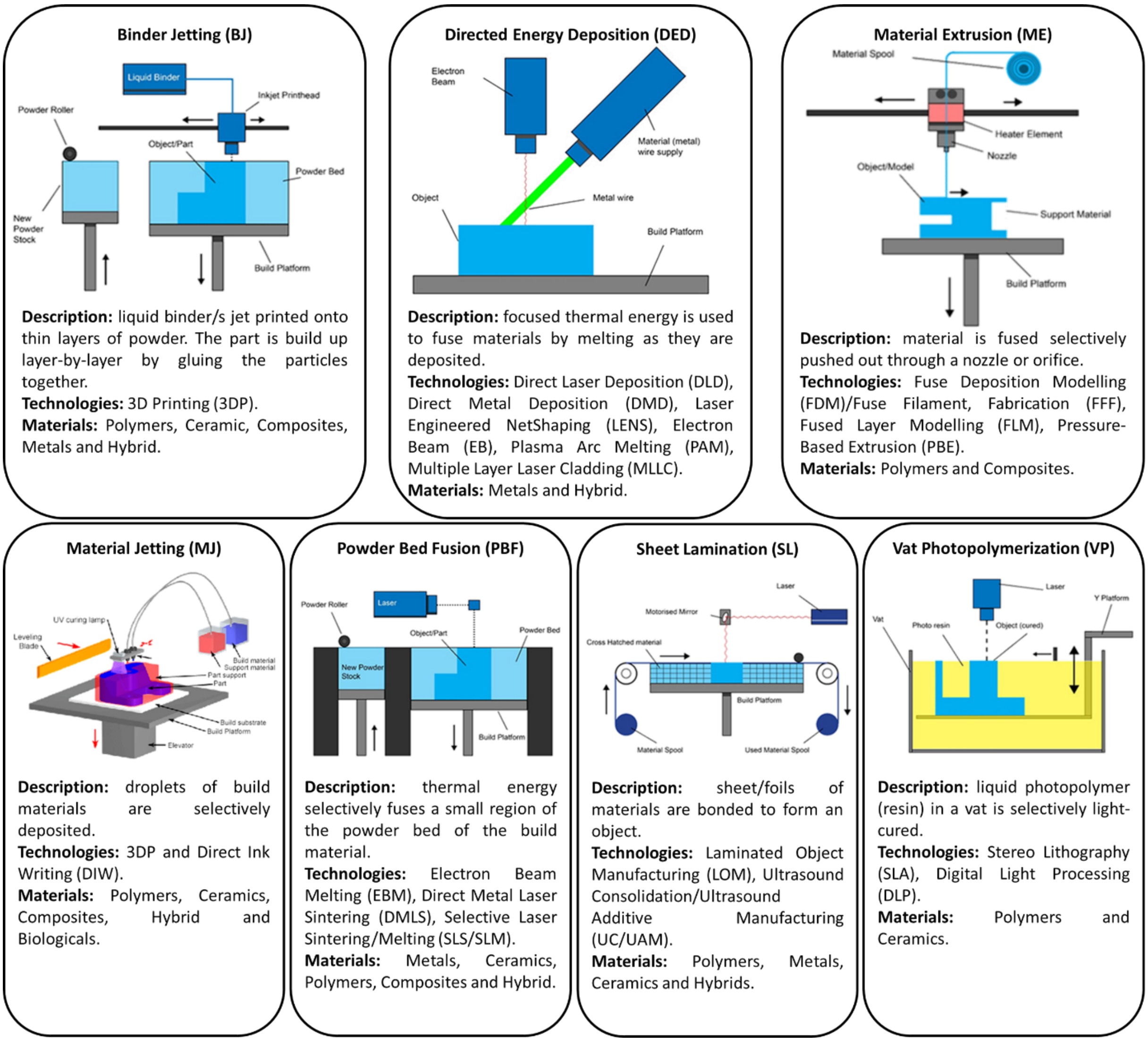


Figure 2.14 - Categorized AM processes. Based on (Chong et al., 2018; Tofail et al., 2018; Pinkerton, 2016; Loughborough University. (n.d.)).

AM technology are defined by Kim & Tseng (2018) as a process of creating a 3D object-based on the deposition of materials on layer-by-layer or drop-by-drop under a computer-controlled system. Some potential benefits of AM can be summarized as follows (Tofail et al., 2018):

- Manufactured parts directly from CAD data files (final or near final parts with minimal to no additional processing);
- Greater customization without extra tooling or manufacturing cost;
- Manufacturing of complex geometries (some geometries cannot be achieved on conventional processes, otherwise, it is achieved by splitting it into several parts);
- Manufacturing of hollow parts (achieving less weight) or lattice structures;
- Maximization of the material utilization for the ”zero waste” approach;
- Smaller operational footprint towards manufacturing a large variety of parts;
- On-demand manufacturing and excellent scalability.

According to Shin & University (2016), AM workflow includes the geometry design, computational tools and interfaces development, material design, process modeling and control tools, and it was also discussed the AM applications fields such as nano-scale (bio-fabrication), micro-scale (electronics), macro-scale (personal products, automotive), and large-scale (architecture and construction, aerospace and defense).

For the next generation of AM processes, Chang et al. (2018) discussed novel processes such as micro/nano scale 3D printing, bioprinting (AM of biomaterials), and 4D printing (combination of AM with smart materials (stimulus-responsive that change their shape or functional properties)) to fabricate within high resolution a complex 3D features, in multi-materials, or multi-functionalities.

On a near future, AM technology will expand eventually to super-advanced technology areas and substitute current technologies (Kim & Tseng, 2018).

2.1.8 Autonomous Robots

Manufacturing paradigm is shifting rapidly production from mass towards customized production, requiring robots, for instance, as a reconfigurable automation technology. The impact on the production systems of the manufacturing companies is that this trend leads to the production adaptation for a wider product variation, focusing ideally on batch size one. Nowadays, to reach the flexibility demanded level, robots are essential on production systems (Pedersen et al, 2016). Towards that, abilities on computing, communication, control, autonomy and sociality are achieved terms when combining microprocessors and Artificial Intelligence (AI) with products, services, and machines to make them become smarter. Robots with AI, adaptive and flexible, can facilitate different products manufacturing and consequently providing decreasing production costs (Salkin et al., 2018). In addition, a robot also can be seen as one of the forms of AI (Wu et al., 2018).

Processes such as product development, manufacturing and assembling phases, are processes that adaptive robots are very useful on manufacturing systems (Salkin et al., 2018). It is important to refer that fully autonomous robots make their own decisions to perform tacks on a constantly changeable environments without operator's interaction (Ben-Ari & Mondada, 2018). Figure 2.15 shows an overview, not strict, on the autonomous robot characterizations, considering industrial and non-industrial environments.

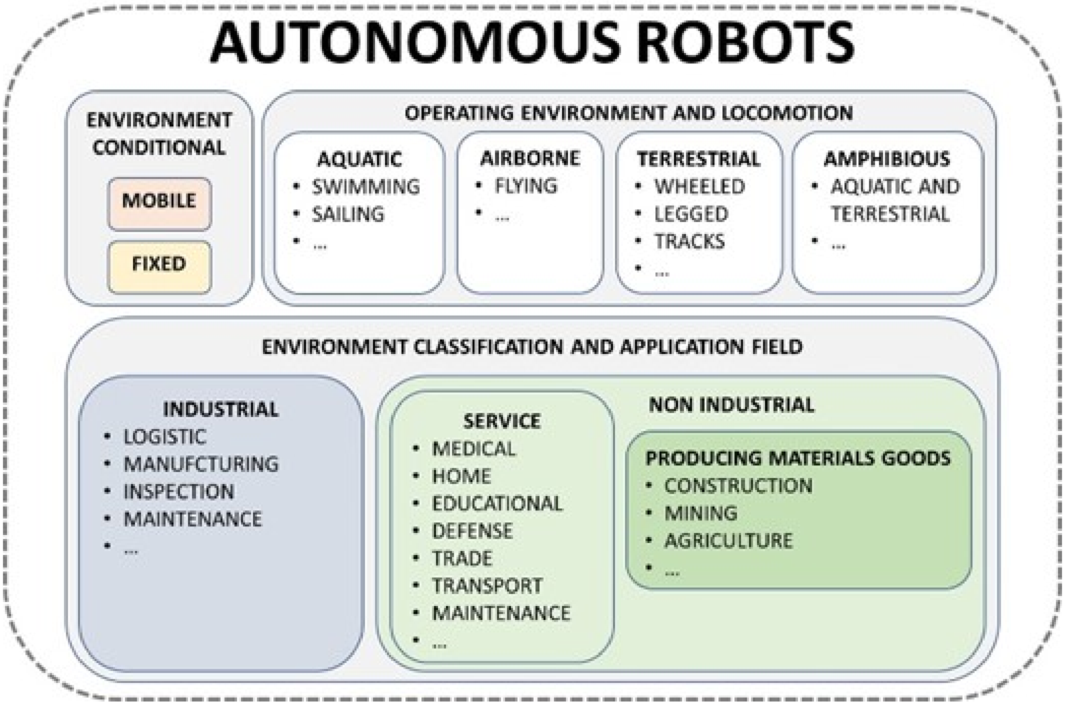


Figure 2.15 - Characterization scheme for autonomous robots. Based on (Ben-Ari & Mondada, 2018; Dobra, 2014).

Dirty or hazardous industrial applications on unstructured environments can be improved by an Autonomous Industrial Robot (AIR) or multiple in a close collaboration. Hassan et al. Hassan & Liu (2017) presented a multiple autonomous robot's collaboration approach in Figure 2.16, consisting on robots with different capabilities performing grit-blasting and spray painting.

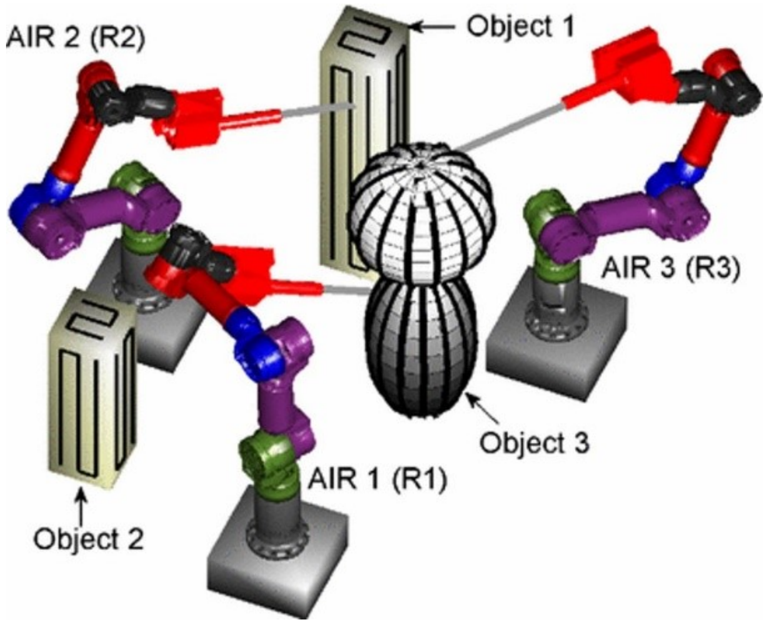


Figure 2.16 - Autonomous industrial robots performing grit-blasting or spray painting (Hassan & Liu, 2017).

According to Hassan & Liu (2017), with the deployment of multiple autonomous industrial robots working as a team, it's possible to have a larger range of manufacturing applications. Other approach in multi-robot systems can be seen in Figure 2.17 during a sequence of collaborative assembly operations, dealing with robot configurations to grasp assembly parts and build complex structures such as a chair (Dogar et al., 2019).

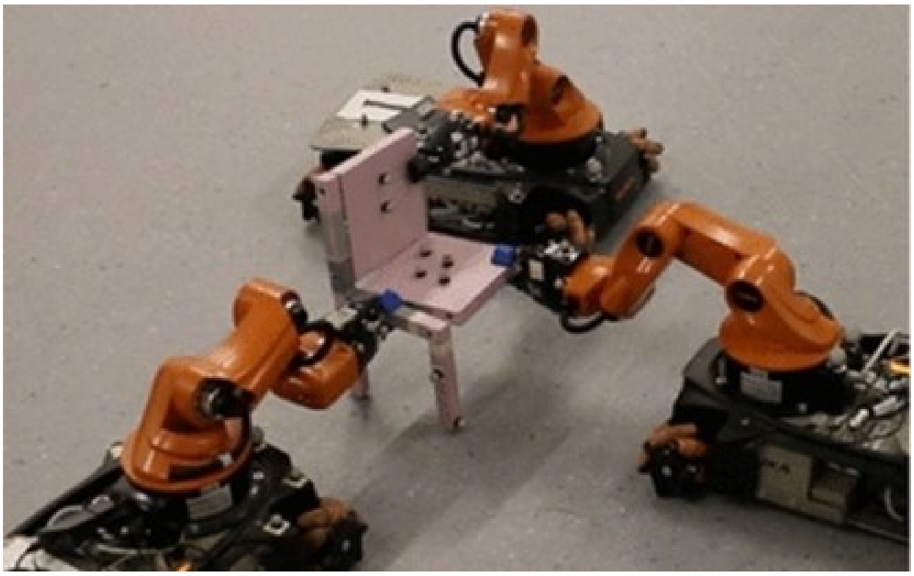


Figure 2.17 - Assembly configuration robots (Dogar et al., 2019).

Collaborative robots concept also introduces the proximity of robots with humans (Koch et al., 2017). On the vision of SF, collaborative robots (cobots) and humans will work closely together. Cobots are a category of robots specially designed to interact directly and physically with humans, in a close cooperation (Weiss & Huber, 2016; El Makrini et al., 2018). This is possible due to the safety existing limits on speed and forces that automatically restarts the cobot allowing to guide the cobot by hand (Weiss & Huber, 2016). By this, for manufacturing companies, human-robot barrier is break down offering bigger affordability and flexibility on solutions (El Makrini et al., 2018).

2.1.9 Cybersecurity

Every year, increasingly, devices are connected to the global network: the internet. In a close future, the main source of data will be inanimate objects (Sergey et al., 2017). By this, IoT, virtual environments, remote access, stored data on cloud systems, etc., are many open opportunities that represents increasing new vulnerabilities leading to a compromised information for people and enterprises. The risk scenario becomes reality because the enterprise boundaries are unclear and are vanishing (He et al., 2016). Kannus & Ilvonen (2018) defined Cybersecurity (CS) as a new term on a high level of information security, and through the word "cyber" it spreads to apply also on industrial environments and IoT. CS is a technology laying on protecting, detecting and responding to attacks (Murillo-Piedrahita et al., 2018).

IoT has to be built based on safety communications on each point of the manufacturing process and safety interoperability has to be assured between facilities as basic elements of the supply chain value. I4.0 technologies must allow the creation of a safety cyber environment, benefiting on CS.

Direct attacks from evil persons and/or software can be hard jeopardies to Industrial Control Systems (ICS). These ICS of the industrial sectors are basically control such as Supervisory Control and Data Acquisition (SCADA), process control systems, distributed control systems, CPS or Programmable Logic Controllers (PLC) (Ani et al., 2017). The increasing of connected devices means more possibilities of cyber-attacks. Benias and Markopoulos (2017) discussed why industrial devices get hacked, the main reasons as follows:

- Devices running for too much time (weeks or months) without updating security or anti-virus tools;
- Considerable number of old controllers used in ICS networks, designed when CS was not a concern;

- CS threats can enter bypassing CS measures due to the existence of multiple pathways from several ICS networks;
- Quick spread of malware due to several ICS networks that still remains implemented as a flat network without physical or virtual isolation among other unrelated networks.

I4.0 creates valuable information that needs to be protected. Information and data security are critical for the industry success. It is important that data is available just for authorized persons. Integrity and information sources must be ascertained. I4.0 has raised two demands for CS in order to secure smart manufacturing systems: Security Architecture and Security by Design. Hence, attacks, threats and malware must be automatically detected with zero-installation by the systems (He et al., 2016). Manufacturing operations can be shut down by a cyber-attack, therefore, companies have money losses, but the main issue are cyber-attacks targeting systems requiring safety operations and representing a serious risk for the safety of the operators (Tsuchiya et al., 2018). Elhabashy et al. (2019) discussed other approach on manufacturing environments regarding to some potential attacks such as modifying product designs (related to CAD files, tolerances), modifying manufacturing processes (Computer-Aided-Manufacturing (CAM) files, machine parameters, used tools, tool paths) or manipulating process/product data (inspection results, indicators of machine maintenance). These attacks can delay a product's launch, cause the production of modified products, can ruin customer trust or increase warranty costs.

The cyber-attack could be internal and/or external source. According to Khalid et al. (2018), in Figure 2.18, a cyber-attack can come from an internal source such as an operator that physically access to a data port or an external source such as an outside communication channel or also a wireless transmission.

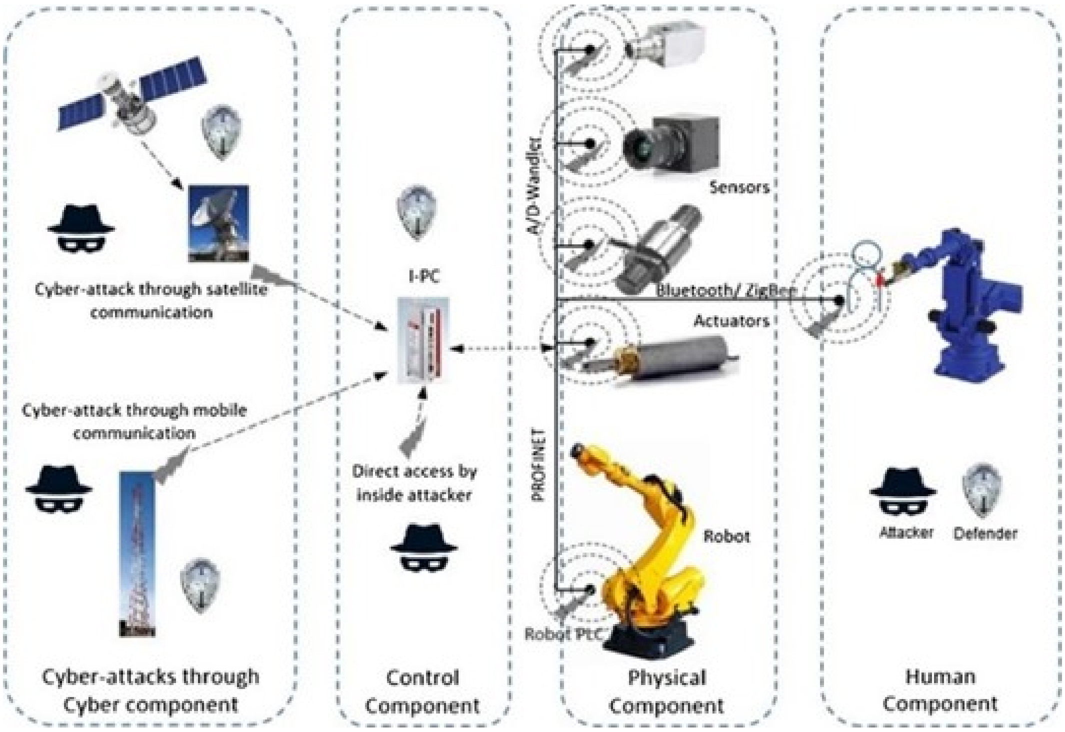


Figure 2.18 - Cyber-attack routes in an industrial connected manufacturing and logical effect diagram for human-robot collaboration (Khalid et al., 2018).

The ICS safety is time-sensitive so an automatic incident response is need it. For a variety of industrial attacks, Software-Defined Networks (SDN) and Network-Function Virtualization (NFV) can facilitate automatic incident response. The incident response in ICS can be achieved using a private-cloud architecture (cost-effective investment). SDN and NFV makes automatic incident response possible to rapidly detect and temporarily replace the failing systems with virtual implementations of those systems. SDN and NFV are technologies to improve the following aspects: 1) network visibility, 2) network capabilities (enables network traffic flows with better management), and 3) network functions deployment and control using software, instead of specific hardware middleboxes (Murillo-Piedrahita et al., 2018). However, the combination of SDN with NFV shows a capable approach in new defense solutions in depth for ICS (Piedrahita et al., 2017).

The concept of defense-in-depth, as showed in Figure 2.19, was discussed by Jansen & Jeschke (2018), according to the international standard IEC/ISA-62433 with the incorporation of three measures as technological, organizational, and human-centered, as multilayer approach for security ICS. Security controls at system level, network and plant must exist on this concept.

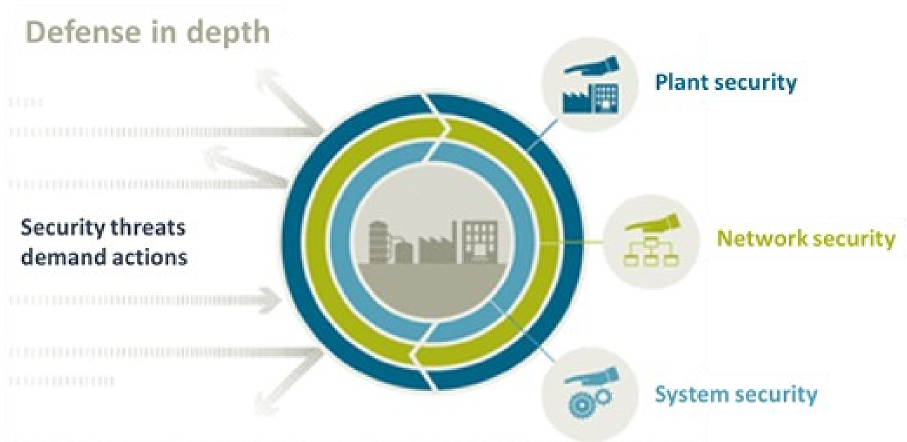


Figure 2.19 - Defense-in-depth (Jansen & Jeschke, 2018).

Updating the implemented security controls continuously is obligatory, keeping the protection up to date (Jansen & Jeschke, 2018), such as follows on:

- Device level - with the installation of new security patches;
- Network level - with the firewall signatures of new threats updated;
- Plant/factory level - with the analysis and monitoring of the actual log sources.

2.3 The Smart Factory of the Industry 4.0

According to several authors (Wagner et al., 2017; Grieco et al, 2017; Motyl et al., 2017; Weyer et al., 2015; Peruzzini et al., 2017; Leyh et al., 2017; Jiang, 2017), the framework of the I4.0 is the development of the Smart Factory (SF). In conceptual terms, the SF is the heart of I4.0 (Gilchrist, 2016b). CPS, IoT and IoS were assumed as the main components of I4.0 (Hofmann & Rüsch, 2017).

These components have very closely linked each other, enabling the SF and built on the concept of decentralized production system with a social network connecting persons, machines and resources (Hofmann & Rüsch, 2017). Using cloud-based manufacturing in SF, both IoT and CPS technologies converges to IoS to create, publish and share the manufacturing processes, represented in services that could be supply by virtual enterprises (Pérez et al., 2015).

Compared to humans living in two worlds such as the physical and the cyber world, SF will work on the physical and on the DT, in the cyberspace. The DT will collect generated data from manual inputs and sensor networks, will process data on cyberspace and take the corrective actions on real-time to handle the physical world (Andulkar et al., 2018).

Based on the manufacturing process digitalization, I4.0 is the development of a new generation of SF's (Bortolini et al., 2017). According to several authors (Wagner et al, 2017; Grieco et al, 2017; Leyh et al., 2017; Tupa et al., 2017), in this new generation of SF, the main key technology is CPS. SF is the key feature of I4.0 and the core concept component, where vertical integration occurs, the horizontal integration occurs in the SF value network and across different SF's, enabling end-to-end engineering integration across the entire value chain (Liu & Xu, 2016). Figure 2.20 identifies the transformation technologies of the current industrial production in a SF framework.

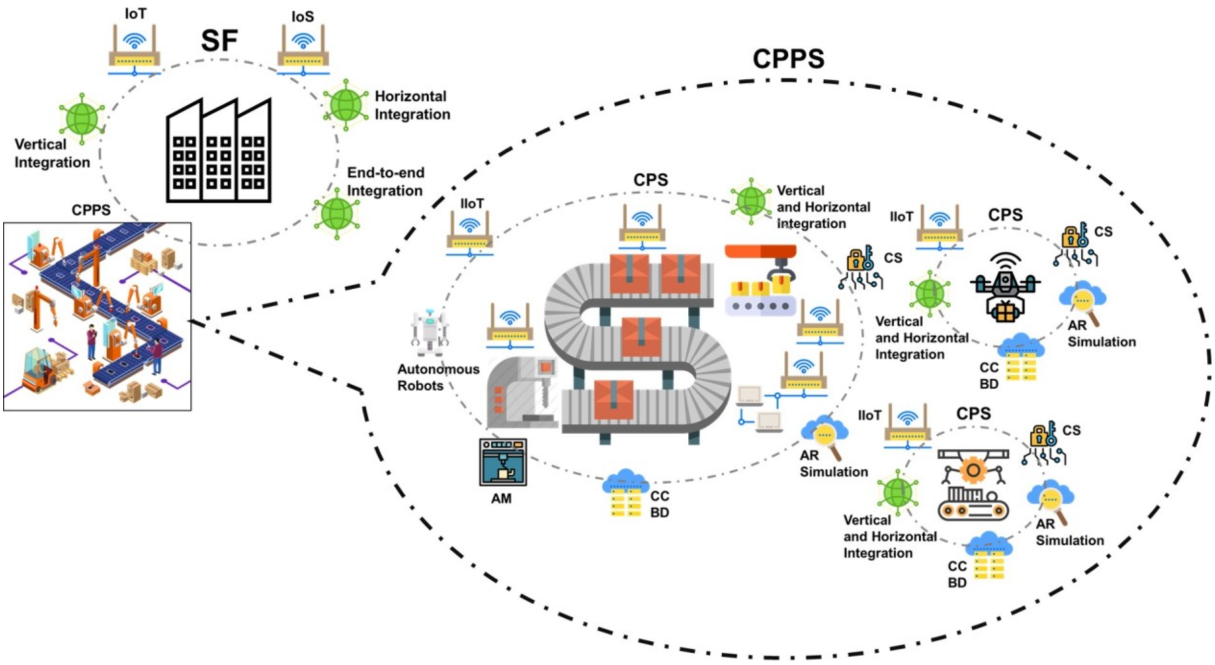


Figure 2.20 - Development of the SF for the I4.0 implementation.

2.3.1 Cyber-Physical Systems

Cyber-Physical Systems (CPS) has the potential to change our life with concepts that already emerged, e.g., robotic surgery, autonomous cars, intelligent buildings, smart manufacturing, smart electric grid, and implanted medical devices (Monostori et al., 2016) (e.g., a pacemaker in a smaller scale (Wang et al., 2015)). CPS represents the latest and significative developments of Information and Communication Technologies (ICT) and computer science (Monostori et al., 2016).

CPS is the merger of ''cyber'' as electric and electronic systems with ''physical'' things. The ''cyber component'' allows the ''physical component'' (such as mechanical systems) to interact with the physical world by creating a virtual copy of it. This virtual copy will include the ''physical component" of the CPS (i.e., a cyber-representation) through the digitalization of data and information. By this, CPS can be assumed as a range of transformative technologies to manage interconnected computational and physical capabilities (Trappey et al., 2016). CPS embraces smart elements or machines who has the augmented intelligence and ability to communicate each other to make part of planning, unique or non-repetitive tasks. These smart elements, for instance, can control the needs of workpieces, alter the manufacturing strategies for the optimal production, choose (if already exists) or find a new strategy all by themselves. These elements will build their own network (Wittenberg, 2016). In other words, the CPS core is the embedded system to process information about the physical environment. This embedded system will perform tasks that were processed by dedicated computers. CPS model can be described as a control unit with one or more microcontrollers, controlling sensors and actuators that interacts with the real world and processes the collected data (Bocciarelli et al., 2017) (Jazdi, 2014). A communication interface will enable this embedded system to exchange data with the cloud or with other embedded systems. CPS is associated with the IoT concept (Harrison et al., 2016). According to Humayed et al. (2017), CPS mainly consists of three components such as: 1) communication; 2) computation and control and; 3) handling and monitoring. The CPS communication can be both wired or wireless and connects CPS to a higher level such as control systems, or lower levels such as physical world components. The intelligence is embedded on the computation and control component with the exchange of control commands and received measures. CPS is connected to the physical world by the handling and monitoring component, using actuators to handle physical components and using sensors to monitor them (Humayed et al., 2017).

Referring a manufacturing system and according to Keil (2017), Figure 2.21 shows a schematic representation of a CPS, an embedded system integrated in physical systems such as production lots or machines. The sensors collect physical data and the electronic hardware and software will save and analyze it. The interaction between data processing and other physical or digital systems are the CPS bases. it's also possible to identify an HMI in this CPS schematics for supervision and exchange information. Several CPS linked within digital networks form a CPPS (Keil, 2017), based on sub-systems and autonomous and cooperative elements linked across all levels of production (Monostori et al., 2016). According to Rojas et al. (2017), CPS are the building blocks for the SF, structured as CPPS. The collected data will be sent to BD and become accessible via CC. The CPPS interaction with the virtual world enables IoT in manufacturing (Pauker et al., 2016; Pérez et al., 2015). As the system are getting intelligence regarding to the so-called smart objects, the IoT creates the connect environment with smart objects to the global internet. Several authors (Lu, 2017; Weyer et al., 2015; Tupa et al., 2017; Gilchrist, 2106a; Mourtzis et al., 2016; Posada et al., 2015; Khalid et al., 2018; Wang et al., 2015; Bocciarelli et al., 2017; Liu & Xu, 2017) discuss the level of cooperation and communication of CPPS in manufacturing.

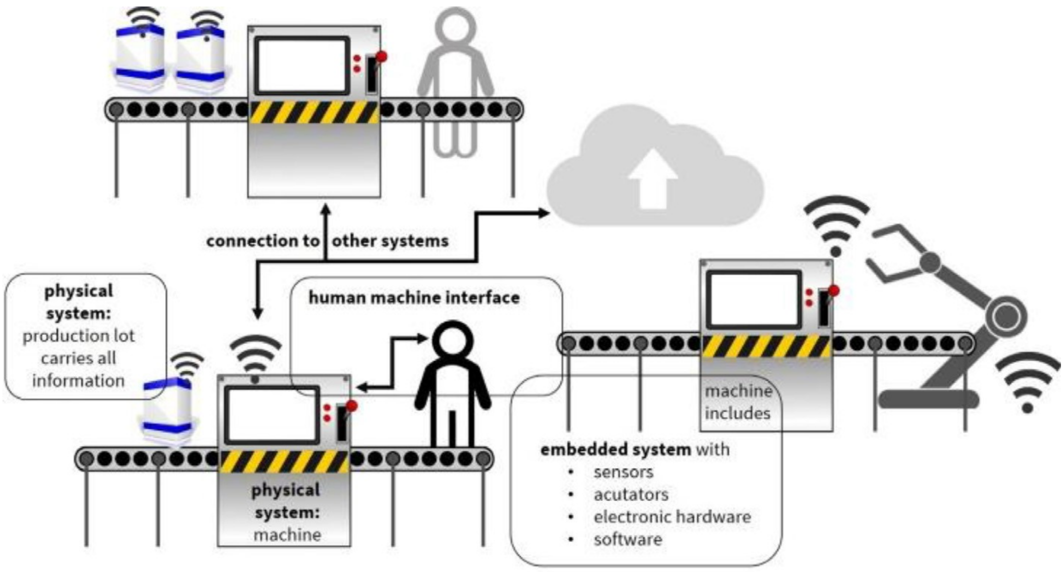


Figure 2.21 - Structure of a manufacturing CPS (Keil, 2017).

The implementation of CPPS in the SF leads to a fundamental design principle as the real-time management in industrial production scenarios. CPPS will make the automation pyramid approach on a different manner. The traditional automation pyramid, as shows the Figure 2.22, is partly break at the PLC's level. The field level and control remain including closest PLC's of the technical processes to improve critical control loops, and the highest levels of the hierarchy will be decentralized (Hozdić, 2015).

In the CPS-based Automation of the Figure 2.22, the squares represent inputs/outputs devices, the lines represent service interactions and the blue, yellow, grey and black points represent the corresponding functionalities of the five-layer architecture of the traditional automation pyramid (Harrison et al., 2016).

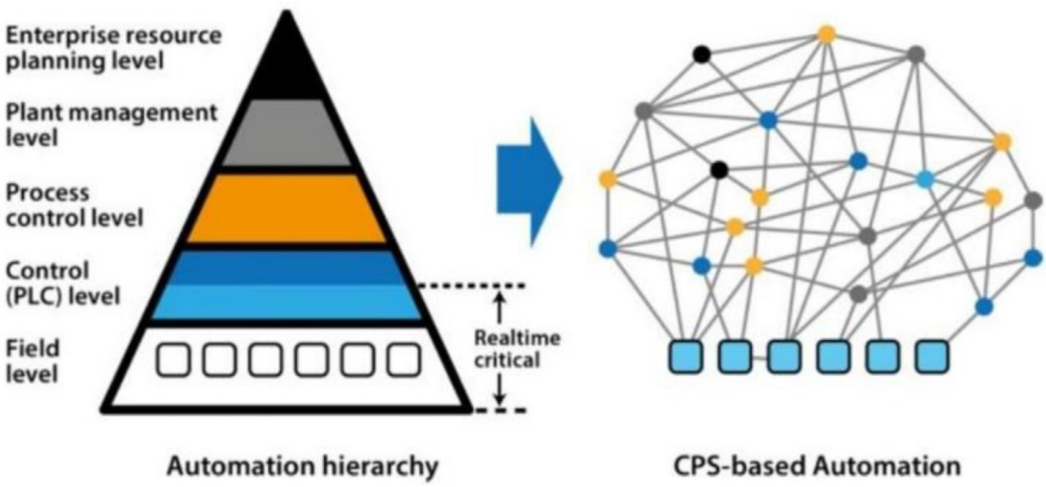


Figure 2.22 - Hierarchy decomposition of the traditional automation pyramid and the CPS approach (Hozdić, 2015).

Some researchers are developing a five C's structure for better analyzing I4.0. This five C's architecture can guide the development of I4.0 and it is dependent of CPS attributes. These five levels are: Connection Level (main attribute is self-configurable), Conversion Level (main attribute is early-aware), Cyber Level (main attribute is controllable), Cognition Level (main attribute is informational) and Configuration Level (main attribute is communicable) (Jiang, 2017; Qin et al., 2016; Lee et al., 2015).

2.3.2 Internet of Services

Replacing physical things by services, the Internet of Services (IoS) is based on the concept that services are available through the internet so that private users and/or companies can create, combine and offer new kind of value-added services (Hofmann & Rüsch, 2017). IoS can enable service vendors to offer their services on the internet. Thus, the manufacturing industry of product-oriented trend is rapidly shifting for service-oriented to enable gaining revenue through all lifecycle of a product service system. By this, high quality on products can be enable by SoA, and side-by-side, gives a strong competitive position for companies through the value-added services. IoS enables collecting product information, e.g., during its operation, for updates and for the development of new services, increasing the perceived product quality (Andulkar et al., 2018). IoS is consider by Andulkar et al. (2018) as the technology to monitor the product lifecycle.

2.4 Conclusions and Outlooks

As aforementioned, the foundations of the I4.0 are the advanced technologies of automation, and the ICT present across this review. Key challenge of I4.0 is to make the production systems more flexible and collaborative. For this purpose, the use of enabling technologies is the strategy that is behind of I4.0 paradigm. On an industrial context, each implemented technology in an individual manner will present a lower impact. On the other hand, when implemented together, it offers new possibilities to embrace the future. For instance, one of the I4.0 impact will be the elimination of monotonous work as well as physically demanding jobs. IoT is an infinite world of possibilities on innovation and optimization, due to the combination of many advanced systems and technologies such as BD and analytics, AI, networks, clouds, intelligent objects, robotics, middleware, people, among others.

The development of a CMfg service integration platform is proposed by Mai et al. (2016) as a promising concept. It is an online tool consisting of build a process with several sub-tasks with a series of modules sequentially connected each sub-task. This concept allows consumers to have customized products or even make products in the cloud. Even more, through CMfg, producers can create smart solutions to save costs and improve profits. A crucial note is the improvement of the safety and security regarding to online services that was mentioned at all examples. The development of CS technology deserves maximum efforts from all actors, since individual, professional users, and organizations that need to be safe and secured to face these rapid technological advances.

The Systems integration of I4.0 has two major characteristics relying on vertical and horizontal integration. The vertical integration of the manufacturing processes, breaks the traditional automation pyramid, focusing on distributed and collaborative architectures. The horizontal integration allows the creation of a new kind of value-added (Rojas et al., 2017). By this, there is an unavoidable surrounding of customers and suppliers that are involved just from the beginning of the product life cycle.

A challenging scenario with the deployment of I4.0 will be the extinction of the centralized applications used in common manufacturing environments, that leads to decentralized systems as one of the main I4.0 goals. By this meaning, distributed computing systems also plays a key role on I4.0 paradigm. It allows to save time on computing runtimes, allows working with more accurate details on smaller systems and for the overall system, and decreases the fail reaction time, e.g., if one computing system fails the others can continuing on computing.

Interoperability is one of the I4.0 design principles and can be found between BD and simulation as discussed by Shao et al. (2014); BD on its analytics supports simulation by estimating the unknown input parameters and performing data calibration for simulation and its validation results. The return is the support of simulation for BD analytics on various roles. Data analytics application can summarize and report production trends (e.g., product variation cycle time or throughput average). Diagnostic data analysis can respond to what has happened and what is happening, identifying causes. Diagnostic analysis can take advantage using of manufacturing system' simulation model that emulates the current operation. Predictive analytics estimates performance based on planned inputs, e. g., product cycle time and throughput estimation for several products based on current policies. It will take advantage from simulation models to execute the what-if scenarios. Prescriptive analytics can respond to how can we make it happen and what will be the consequences. It uses simulation models to improve the production performance in future periods by emulating operations under paralleled realities and these plans can be improved with the arrangement of simulation and optimization models. In the VF level, simulation can be seen as data generator allowing VF to generate for instance, streams of production data and resource utilization, and feed data to analytics applications. Can be seen also as supporting evaluation and validation giving an advantage to the real factory.

Simulation technology on I4.0, using VR, is an integral process to simulate all industrial processes, from planning, design, manufacturing, providing services, maintenance, try-outs or even quality controls. All processes can be simulated as modular (Qin et al., 2016). It's possible to simulate and virtual verify a factory manufacturing process before being realized. After approved, all physicals can be done. For instance, if it is considering the combination within simulation and AM, after product simulation, the production of prototypes allows the time reduction on design and production process, by reducing the value-added dependencies. These time reductions are particularly relevant on customized markets.

Grieco et al. (2017) presented an interesting case study in fashion manufacturing where a decision support system as a software is developed under the I4.0 concept, aiming the minimization of: 1) orders delivered later than due date, and 2) resource overload cases.

Many researchers discuss that the data is the raw material of the XXI century and the real world will be a huge information system. According to this, Lu (2017) discussed one of the major challenges in I4.0 that will be the development of algorithms for dealing with data.

According to Salkin et al. (2018), there is no specific I4.0 definition, and therefore, there is no definitive utilization of the enabling technologies to initiate the I4.0 transformation.

But the fact that this fourth revolution has been announced before it takes place, opens several opportunities for co-working environments between academic researchers and industrial practitioners, shaping on the manufacturing future (Hermann et al., 2016).

2.4.1 Looking Forward

As mentioned by Rojas et al. (2017), I4.0 is on its infancy and to make it a reality, several challenges and gaps must be addressed. By this, the roadmap for the I4.0 fulfillment is still not clear to date in both academia and industry (Qin et al., 2016). Considering five fundamental manufacturing systems to conceive I4.0, Figure 2.23 can represent the research gaps between the current manufacturing and the I4.0 requirements (Qin et al., 2016). These five manufacturing systems are systems where is hard to achieve intelligent concepts, that are the goal of I4.0 development, neither I4.0 lower or upper levels. The closest to I4.0 is the Reconfigurable Manufacturing System.

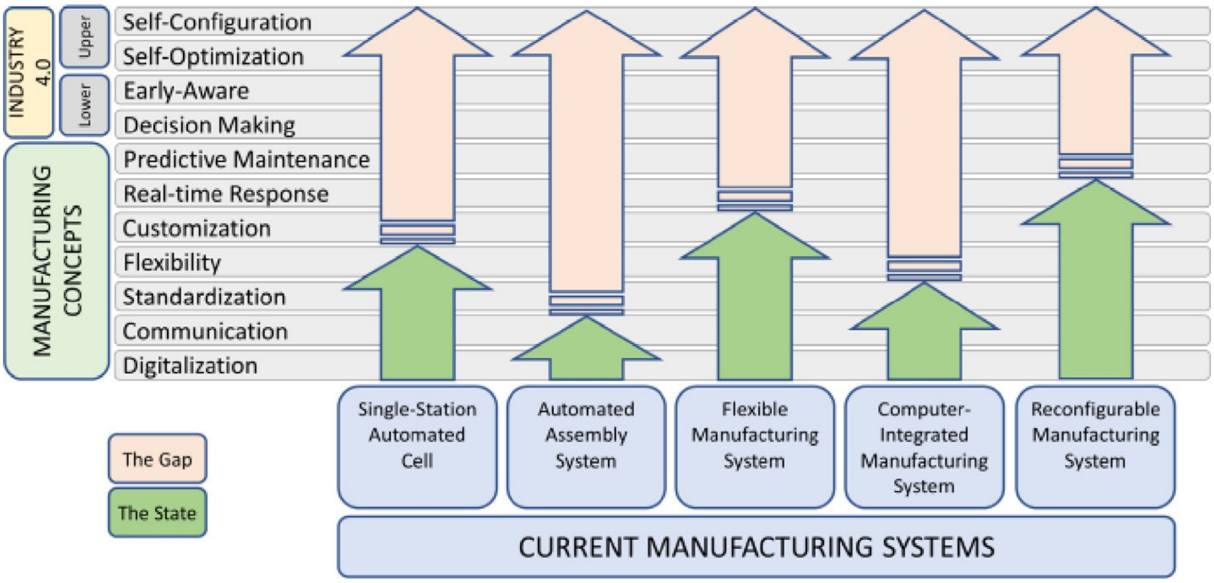


Figure 2.23 - Research gap between current manufacturing systems and I4.0. Adapted from (Qin et al., 2016).

2.4.2 Executing Industry 4.0 in SMEs

Looking at European Union, SMEs represents the backbone of the economy and the key to competitivity. Inside this enterprise dimension, special approaches must be developed to introduce and apply I4.0 enabling technologies (Rojas et al., 2017). The enabling technologies of I4.0 are the foundation for the integration of intelligent machines, humans, physical objects, production lines and processes to form a new kind of value chain across organizational

boundaries, featuring intelligent, networked, and agile. By this, due to the increase level of complexity, manufacturing SMEs has doubts on the required financial effort for the transformation technologies and its impact on their business model (Schumacher et al., 2016).
The implementation of I4.0 in SMEs can be facilitated, for instance, on a SaaS approach, enabling technology acquisition for digital services with appealing investments. A clear example can be an SME integration on the supply chain of a product, allowing collaborative of project development, collaborative working on product's launch and time to market reduction, shared innovation, and consequently, minimizing the related risks.

2.4.3 Creating the Industry 4.0 Environment

RQ1 was answered in this chapter with the vision of the SF, its components and its enabling technologies. The vertical integration will connect all interpreters of the internal value chain, all with only one language, from the sensor until the human being. The ICT will decentralize production systems and transform the importance of the services into the manufacturing systems. This ecosystem is be composed by physical and cyber systems sharing the same space and integrated horizontally on the supply chain and clients and will ease the end-to-end engineering integration along all product and service value chain.
As I4.0 concept was first appeared in 2011 and called the fourth stage of industrialization and was appear again in 2013 to be the German national strategy. Thus, in this thesis alignment, it was important to identify and analyze how I4.0 maturity is so far.

3

TRACKING THE MATURITY OF INDUSTRY 4.0

This chapter is built with the use of a shorter version of the peer-review manuscript version published as: Alcácer, V., Rodrigues, C., Carvalho, H., Cruz-Machado, V. (2021). Tracking the Maturity of Industry 4.0: The Perspective of a Real Scenario. International Journal of Advance Manufacturing Technology 116, 2161–2181. https://doi.org/10.1007/s00170-021-07550-0; (Q1; H-Index = 134; Impact Factor = 3.563 (2021); Citations = 7, Captures = 2861).

Summary: To track industry 4.0 status, maturity and readiness models are used to analyze the state of industry 4.0 technologies' implementation, allowing the quantification and qualification of its maturity level considering different dimensions. Not all companies are adopting these new technologies with the same ease and with the same pace. There are companies unable to blend the industry 4.0 with their business models, leading to a lack of a correct self-assessment on understanding the reached readiness level. Into this purpose, it is important to understand how companies are facing the digital transformation challenges, what is their perception about the enabling technologies towards the industry 4.0, assess the industry 4.0' readiness so far, and what are their perception of the barriers to the adoption of these technologies. This chapter aims to assess the industry 4.0' readiness level of companies and discuss the perception of companies about the barriers on the adoption of industry 4.0 with the reached readiness level of companies. New barriers are also brought for discussion on academic community. To this end, empirical data was collected on a sample of fifteen companies belonging to an important industrial regional sector located in Portugal.

3.1 The Industry 4.0 Implementation

Not all industries are adopting these enabling technologies with the same ease and it is necessary to understand what the reasons behind these differences are. On the one hand, companies are unable to relate I4.0 with their business models and, on the other hand, companies are not able to self-assess in order to understand the reached maturity level. For companies to overcome uncertainty and discontent, it is necessary to use new tools to guide and support them (Schumacher et al., 2016). Thus, to analyze the I4.0 different states, maturity and readiness models can be used.

According to Schumacher et al. (2016), a maturity model measures the maturation process and the readiness model measures how company is ready to the development process. The IMPULS model is an example of how to measure the I4.0 readiness with six dimensions (strategy and organization, smart factory, smart operations, smart products, data-driven services, and employees). These dimensions form the foundations to measure the I4.0 readiness having appropriate indicators.

As the implementation of I4.0 takes place at different pace around the world, it will be very important to understand what the barriers on I4.0 enabling technologies adoption are. The literature provides some studies not only regarding the maturity or readiness levels of I4.0 in companies (Schumacher et al., 2016; Lichtblau et al., 2015; Schuh et al., 2017; Rockwell Automation, 2014; Jung et al., 2016), but also about the perception of the barriers associated with the implementation process (World Economic Forum, 2015; Müller et al., 2018; Stentoft et al., 2019; Müller et al., 2017; Li et al., 2015; El Beqqal & Azizi, 2017; Yang et al., 2017).

I4.0 is considered by some authors the fourth industrial revolution (Alcácer & Cruz-Machado, 2019) and differs from previous because it was declared before it happened, and we are currently experiencing its evolution. In this way, the academic and industrial community have a great opportunity to be part of this revolution. This chapter presents a study carried out on a region of great industrial importance in Portugal allowing the possibility to compare it with other studies in other regions and/or countries.

The surveyed companies bring to this chapter the understanding on how they are facing the digital transformation and which are the main barriers to the technologies' adoption. Empirical data was collected using a survey to operationalize the IMPULS model and assess the companies' readiness level, in addition to semi-structured interviews with managers bring what are the companies' perceptions of the barriers' importance on the adoption of these enabling technologies. Through this study, it is also intended to bring to the scientific community new barriers on I4.0 enabling technologies adoption that, to the best of our knowledge, have not yet been identified in previous studies.

3.2 Measuring the Industry 4.0 with Models

I4.0 and its related concepts are a complex topic for researcher and practitioners. The I4.0 implementation process is context dependent, and it will be different for each company. Therefore, it is necessary to analyze each case to better define the company objectives. The need to measure the progress and success, as well as the need of comparisons with competitors, is part of the industrial environments. Thus, there is a need to use proper methodologies, models, and tools to evaluate the I4.0 adoption. Assessment tools have been developed by academia and practitioners aiming the self-assessment within analytical frameworks to evaluate conditions or analyze it on an interactive form with the framework developers (Canetta et al., 2018). Several authors proposed models to address guidance and support on strategies and operations regarding the I4.0 implementation. A model can be an assessment tool outcoming a formal description of a given system, e.g., a manufacturing system, an organization, a manufacturing process, or a machine. Depending on the representation definition and application purpose, models can be descriptive (reproduction of some reality aspects), explanatory (casual connection relations are investigated to better understand the reality), or predictive (efficient solution suggestions to face the future reality). At the end, all model approaches depict the current state of a given system (Mettler, 2009). Models also can be used as a comparative purpose, enabling maturity benchmarking across companies by similar practices within different industries (De Carolis et al., 2017). Maturity models are a subcategory of models, arising on the software development field, used on an enterprise' assess the quality of implemented processes. The Capability Maturity Model Integration (CMMI) or Software Process Improvement and Capability dEtermination (SPICE) are examples of these models (Stefan et al., 2018). The maturity of a company is seen by Schumacher et al. (2016) as the state of progression of internal and external conditions under the concepts of horizontal, vertical, and end-to-end engineering integration of I4.0 on manufacturing systems. Commonly, maturity models are used to measure the maturity of a given system regarding to a specific target state. Maturity models capture the "as-it-is state" (Schumacher et al., 2016).

Reaching a given maturity level is the foundation for the evolution to the next higher maturity level that can be planned and further implemented. Thus, the maturity models quantify activities and make them mature along time. To assess the maturity of a system using levels, maturity

models are based on the idea of "state of being complete, prefect, or ready" and it can be addressed as qualitative or quantitative, in a discrete or continuous manner. As a close approach to maturity models, to assess readiness systems through levels, readiness models are based on the idea of "this is the starting point for," allowing the preparation for the development process of the measured given system. The "readiness" term induces a tendency for change in the given system. Readiness models intend to assess the state of the system before the engagement into the maturity transformation process (Schumacher et al., 2016). Readiness models to assess I4.0 on companies are based on self-assessment mostly on the collection of information via internet surveys or via phone interviews (Rajnai & Kocsis, 2018).
Maturity and readiness models are mostly feeding by dimensions that represents thematic groups, constructed with numerical indicators, and extracted from the collected information from the given system (Rajnai & Kocsis, 2018). Table 3.1 shows some I4.0 maturity and readiness models identified in the literature.

Table 3.1 - Maturity and readiness models and respective dimensions.

Model	Dimensions	
IMPULS Industrie 4.0 Readiness (Lichtblau et al., 2015)	• Strategy and Organization • Smart Factory • Smart Operations	• Smart Products • Data-Driven Services • Employees
Industrie 4.0 Maturity Index (Schuh et al., 2017)	• Computerization • Connectivity • Visibility	• Transparency • Predictability • Adaptability
Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises (Schumacher et al., 2016)	• Strategy • Leadership • Customers • Products • Operations	• Culture • People • Governance • Technology
The Connected Enterprise Maturity Model (Rockwell Automation, 2014)	• Information Infrastructure • Controls and Devices	• Networks • Security policies
Smart Manufacturing System Readiness Level (SMSRL) (Jung et al., 2016)	• Organizational Maturity • Information Technology Maturity	• Performance Maturity • Information Connectivity Maturity

Both “Industrie 4.0 Maturity Index” (Schuh et al., 2017) and “Maturity Model for Assessing Industry 4.0 Readiness and Maturity of Manufacturing Enterprises” (Schumacher et al., 2016) analyze more than six dimensions which makes them quite complete and may be a negative aspect as respondents need to have extensive knowledge about I4.0 technologies. “The Connected Enterprise Maturity Model” (Rockwell Automation, 2014) and “Smart Manufacturing System Readiness Level (SMSRL)” (Jung et al., 2016) model have four dimensions that includes technical aspects of I4.0 implementing, such as IT, but it does not consider aspects related to human resources and the strategy adopted by the company. After analyzing different maturity and readiness models in Table 3.1, the chosen model to be used on this research is the IMPULS (Lichtblau et al., 2015) because it is based on well-defined dimensions, sub-dimensions, and their details, which greatly facilitates its application. Another reason for this choice was the existence of an online questionnaire of this model (Gernandt & Röger, n.d.). The questions from the IMPULS model can be adapted regarding to a particular country reality.

This model was funded by the IMPULS Foundation of the German Engineering Federation (VDMA) and developed by the IW Consult and the Institute for Industrial Management at RWTH Aachen University. Other studies used this model, from dissertations (Lopes, 2017; Rodrigues, 2020; Agostinho, 2019) to scientific articles (Silva & Rocha, 2020; Hamidi et al., 2018; Maasz & Darwish, 2018).

The IMPULS model consists of six dimensions, as well as the respective sub-dimensions (Table 3.2). The readiness score is calculated using a weighted arithmetic mean applying the weights proposed by (Schumacher et al., 2016) for each dimension. The readiness level on each dimension is attributed considering the minimum score of the respective sub-dimensions (evaluated on a scale from 1 to 5). For example, considering the “smart products” dimension, if a company reaches a score of 5 on “ICT add-on functionalities” sub-dimension, and a score of 1 on “use of data” sub-dimension, then readiness level of “smart products” dimension is 1 (minimum value among 1 and 5).

Table 3.2 - Relative Dimension and Sub-dimension Weight. Adapted from (Schumacher et al., 2016).

Dimension	Weight (%)	Analyzed Sub-dimensions	
Strategy and Organization	25	•Degree of Strategy Implementation •Definition of Indicators	•Investments •Innovation Management
Smart Factory	14	•Equipment Infrastructure (current) •Equipment Infrastructure (target) •Digital Modeling	•Data Collection •Data Usage •IT Systems
Smart Operations	10	•System-integrated Information Sharing •Autonomously Guided Workpieces •Self-reacting Processes	•IT Security •Cloud Usage
Smart products	19	•ICT Add-on Functionalities	•Use of Data
Data-driven Services	14	•Data-driven Services •Share of Revenue	•Level of data Usage
Employees	18	•Employee Skills	

The company's readiness score can be measured using a scale from 0 to 5, as shown in Table 3.3. These six levels can be grouped into three categories as follows: (i) "newcomers" that describes companies that have adopted little or no I4.0 enabling technologies; (ii) "learners" that characterizes the companies that have already taken the first actions to implement I4.0; and (iii) "leaders" that represents companies that have made various efforts to implement I4.0.

Table 3.3 - Readiness levels and their description. Adapted from (Schumacher et al., 2016).

	Level	Description
Newcomers	0 (Outsider)	Companies that do not meet the necessary requirements and have done little to no planning for implementing I4.0.
	1 (Beginner)	Companies that have pilot initiatives related to I4.0 in some departments and investments in one of them. Just a few of the production processes are supported through IT systems, and the existing equipment infrastructure only partially fulfills the requirements for future integration and communications. IT security solutions are still in early planning or starting to be implemented.
Learners	2 (Intermediate)	Companies that integrate I4.0 in their strategic orientation and already has a developed method with the appropriate indicators to measure the implementation status. Some data is already being collected automatically and being used to a limited extent. Information sharing is integrated within the company and the first steps to integrate information sharing with business partners are being taken. Companies are already producing some items with initial IT-based add-on functionalities.
Leaders	3 (Experienced)	Companies that already have a I4.0 strategy developed with investments made in several departments. Data is being collected automatically in key areas and the IT systems in production are connected using interfaces to support the production processes. Information sharing is partially integrated to the system within the company and their business partners. The needed IT security solutions are already enabled, and cloud computing solutions are outlined to adapt to future expansion. Companies already provide items with IT-based add-on functionalities which are the basis for data-driven services that not yet integrated with their customers.
	4 (Expert)	Companies that are already using an I4.0 strategy and using the pertinent indicators to monitor its status. IT systems support most of the production processes and the data collected from them is used for optimization. Companies that are starting to adopt autonomously guided workpieces and self-reacting processes. The items provided by these companies have IT-based add-on functionalities that combine data collection and targeted analysis during the usage phase, which allows for data-driven services that feature direct integration between the customer and producer.
	5 (Top Performer)	Companies that have a well-defined I4.0 strategy and regularly monitor its implementation status. The requirements for integration and system-integrated communications are already satisfied. Information sharing systems are already fully integrated within the company and with its business partners. Exhaustive IT system support is implemented in production and automatically collects all the important data and autonomously guided workpieces, and self-reacting processes are already in use. Companies provide products with IT-based add-on functionalities that supplies data for data-driven services such as product development, remote maintenance, and sales support.

The I4.0 implementation is very important from a strategic point because it allows companies to develop entirely new business models. In the IMPULS model, the “smart factory” dimension describes an intelligent, interconnected factory that can communicate directly with the IT systems. This can be achieved through the placement of sensors across the factory, including machinery and systems, on critical data collection points. This process can generate large quantities of data (i.e., BD) which may be a problem if the IT infrastructure is underdeveloped. Another possible barrier related to this dimension is the high investment cost. The dimension “smart operations” focuses on the integration of systems as a key element for horizontal and vertical integration of the value chain, which provides the potential to improve productivity, flexibility, and quality. This dimension is highly dependent on the collection, analysis, and usage of data of the highest resolution possible which is why IT security is so important. Adding new features to “smart products” provides the data required for the data-driven services such as a predictive maintenance plan based on the usage level of the equipment. This dimension includes the Information and Communication Technologies (ICT) add-on functionalities that allow the data collection and whether the data is used or analyzed. The dimension “data-driven services” represents the shifting from selling products to providing solutions. This change grants companies the opportunity to upgrade their business models and direct their attention to enhance the benefit to their customers. Nowadays, manufacturers are moving past selling machinery and are creating a new business with the maintenance of said machinery. The combination of products and services increases the added value to the final customer. All the above dimensions are focused on the technicalities of I4.0 but employees are the ones affected by the implementation of the I4.0 enabling technologies in their digital workplace. The dimension “employees” focuses on the skills and qualifications that companies require their employees to have.

3.3 Barriers to Industry 4.0 Implementation

Despite the advantages associated with the I4.0 implementation, companies may not use the appropriate technologies for their business; in addition, there are some barriers that hinder its implementation. A 2014 study carried out by the (World Economic Forum (2015) on the implementation of IoT concluded that, of all the identified barriers, the most important ones are the “lack of standards (difficult interoperability)” and “data security.” (Müller et al. (2018) conducted a study on emerging technologies and their impact on business models. This study was carried out on Germany, in 2015, and focused on Small and Medium Enterprises (SMEs). About two-thirds of participants consider that one of the most important barriers is the “high effort for coordination” to implement the enabling technologies. Some participants affirmed that the I4.0 implementation implies high costs that their customers are not willing to pay. Despite these barriers, some participants mentioned that they consider the I4.0 enabling technologies implementation for fear of losing customers to more technologically advanced competing companies.

Müller et al. (2017) interviewed 68 German managers between May and June 2016. The study concluded that the most mentioned barriers were “lack of trust between business partners” due to the "lack of data security” and the “high effort for coordination.”

Stentoft et al. (2019) conducted a study on I4.0 barriers and drivers on Denmark in 2018. The study focused on SMEs and identified three groups of barriers on a literature review: “economic/financial,” “skills/resources,” and “high effort for coordination.”

Li et al. (2015), El Beqqal & Azizi (2017), and Yang et al. (2017) focused on barriers associated with the implementation of certain technologies associated with I4.0. Li et al. (2015) identified barriers related to the implementation of IoT, focusing mainly on more technical aspects such as the “lack of standards” or the “concern with the reliability of systems.” Some barriers related to the implementation process were mentioned such as the “lack of an implementation methodology” and the “need to create new business models.” El Beqqal & Azizi (2017) referred barriers related to technical aspects, as well as the legal aspect of data security in relation to radio frequency identification (RFID) technology. Yang et al. (2017) confirm the results from (El Beqqal & Azizi, 2017), regarding BD and CC, and they add the "need for large investments" as a relevant barrier.

Türkes et al. (2019) conducted a study, in 2018, in Romania to understand the perspective of SMEs about I4.0 barriers and drivers, using a survey where respondents expressed whether they agreed or disagreed with a set of the barriers that companies could encounter when implementing the technologies associated with I4.0. The 176 companies that have participated were from areas such as automotive, pharmaceutical, chemical, insurance, or health. Six barriers were considered important by the respondents: “lack of clarification of economic benefits,” “lack of technical knowledge,” “insufficient workforce,” “need for continuous formation,” “lack of regulations and procedures,” and “high effort for coordination.”

Orzes et al. (2018) propose 6 categories for I4.0 implementation barriers. Table 3.4 provides an overview of the studies available in the literature using the categories proposed by Orzes et al. (2018). Most studies focus on SMEs and do not target a specific technology. The column “total” provides a counter that helps to identify the barriers most cited in the literature.

Table 3.4 - Main barriers to I4.0 implementation. Based on (Orzes et al., 2018).

	Authors	(Stentoft et al., 2019)	Türkes et al. (2019)	(World Economic Forum, 2015)	(Müller et al., 2018)	(Müller et al., 2017)	(Li et al., 2015)	(Beqqal & Azizi, 2017)	(Yang et al., 2017)	
	Analyzed Technology	N/A	N/A	IoT	N/A	N/A	IoT	RFID	BD+CC	
Barriers	*Focus*	SME	SME	SME	SME	SME	N/A	N/A	N/A	**Total**
Economic / Financial	Need for large investments	T		E	E	E			T	**5**
	Lack of clarification of economic benefits	T	T	E						**3**
Cultural	Lack of support from top management			E						**1**
	Worker's demotivation					E				**1**
Skills / Resources	Lack of employees' skills	T		E	E					**3**
	Lack of technical knowledge	T	T	E	E	E				**5**
	Insufficient workforce	T	T							**2**
	Need for continuous formation	T	T							**2**
Legal	Lack of regulation and procedures	T	T	E	E		T		T	**6**
	Concern about data security	T		E	E	E	T	T	T	**7**
Technical	Lack of standards (interoperability and compatibility)			E			T	T	T	**4**
	Concern with the reliability of systems						T		T	**2**
	Underdeveloped IT infrastructure			E			T	T	T	**4**
	Data Storage							T	T	**2**
	Underdeveloped technologies			E						**1**
Implementation Process	Need to create new business models			E		E	T			**3**
	Lack of an implementation methodology						T			**1**
	High effort for coordination	T	T		E	E				**4**

Note: T – Theoretical; E – Empirical; N/A – Not Applicable

3.4 Research Methodology

This study adopts a two-phase methodology:

- First phase — It was carried on a survey to measure the I4.0 readiness levels on an industrial regional sector. The survey was elaborated according to the IMPULS model. The companies' responses were analyzed using an Excel document, coded to automatize the attribution of the readiness level for each dimension and respective sub-dimensions;
- Second phase—Semi-structured interviews were conducted to assess the perception that companies have about the barriers on the adoption of I4.0 enabling technologies. Based on the literature review, it was formulated an interview protocol (including a questionnaire) to better understand what the company's perception is regarding to each barrier.

For the first phase, a survey was conducted. A survey is described as "a systematic method for gathering information from (a sample of) entities for the purposes of constructing quantitative descriptors of the attributes of the larger population of which the entities are members" (Groves et al., 2011). The steps followed on this phase are as shown in Figure 3.1.

Figure 3.1 - Survey methodology steps.

The first step was the identification of the objectives and definition of the sample. This study is focused on companies located in a Portuguese industrial regional sector, more specifically on Setubal peninsula, which has an area of 1421 km2 and covers nine counties, where 782,044 people live. There are 27,788 companies registered across the 9 counties on the Setubal peninsula.

According to *Diretório Empresas Portugal* (INFORMA, n.d.), companies on Setubal peninsula mainly have an activity area of "wholesale and retail trade, repair of motor vehicles and motorcycles." A company can have more than one activity area, one being the primary and the other the secondary; Table 3.5 does not make this distinction, since both are accounted for.

Table 3.5 - Activity area of companies on Setubal peninsula. Adapted from (INFORMA, n.d.).

Activity Area	%
Wholesale and retail trade, repair of motor vehicles and motorcycles	31,0
Construction	15,6
Accommodation, catering and similar	9,5
Manufacturing industries	8,4
Other service activities	5,2
Consulting, scientific, technical, and similar activities	4,9
Real estate activities	4,2
Agriculture, animal production, hunting, forestry, and fishing	4,1
Administrative and support service activities	4,0
Transport and storage	3,0
Human health and social support activities	2,8
Artistic, show, sports and recreational activities	2,1
Information and communication activities	1,7
Financial and insurance activities	1,7
Education	1,2
Water collection, treatment, and distribution; sanitation, waste management and remediation	0,20
Public administration and defense; social security	0,14
Extractive industries	0,11
Electricity, gas, steam, hot and cold water and cold air	0,055
Activities of international organizations and other extraterritorial institutions	0,0024
Activities of households employing domestic staff and production activities of households for own use	0,0012

The target population considered on this study were companies associated to an industry association located in Setubal peninsula named as AISET — *Associação da Indústria da Península de Setúbal* (AISET, n.d.(a)). Currently, AISET is considered a national reference and an active voice not only on the region, but also in Portugal. Since December 2014, this association aims to combat the lack of representativeness of industrial companies on Setubal peninsula (AISET, n.d.(a)). The choice to partnership with AISET was based on the fact that some associated companies operate together and form value chains, leading to the creation of synergies among themselves which leads to the development of the ecosystem itself. The partnership with AISET on this study also enhances the possibility of comparing the readiness levels between the companies involved on the same value chain.

AISET is an association with 55 very diverse members, from large companies (with more than 3500 employees) to micro-companies (with only two employees) (AISET, n.d.(a)). The distribution of members, according to their activity area, is shown in Table 3.6.

Table 3.6 - Activity area of AISET member companies (AISET, n.d.(a)).

Activity Area	%
Manufacturing industries	43,6
Education	10,9
Water collection, treatment, and distribution; sanitation, waste management and remediation	9,1
Wholesale and retail trade, repair of motor vehicles and motorcycles	9,1
Consulting, scientific, technical, and similar activities	9,1
Transport and storage	7,3
Real estate activities	3,6
Administrative and support service activities	1,8
Information communication activities	1,8
Construction	1,8
Other service activities	1,8

The activity area of most companies is the manufacturing industry, followed by education area. These two activities represent more than half of AISET members.

This study makes use of a sample and therefore, there are associated errors present. One of them is the sampling error. This type of error is statistically well understood and is related to the sample size (Leeuw et al., 2008). A sampling error can be summarized as the fact that the chosen sample is not representative of the population. To decrease this error, it is necessary to randomly choose a sample as large as possible (Ponto, 2015). The measurement error occurs when the answers are imprecise and differ from the "true" value (Leeuw et al., 2008). Finally, the nonresponse error, which, as the name implies, refers to the lack of response from some respondents (Leeuw et al., 2008). To reduce this error, follow-up procedures can be scheduled or elaborate an intuitive questionnaire with a simple design (Ponto, 2015).

On the second step, the "Mapping the Adoption of Industry 4.0 Technologies in the Setubal Peninsula" survey was elaborated, as a part of the "Driving Industry 4.0" project (UNIDEMI, n.d.). The survey was operationalized using the LIMESURVEY software, with the questions from the IMPULS model.

The next step was collecting survey data. The survey was launched on the beginning of July 2020. Under the General Data Protection Regulation (GDPR), AISET contacted its associates to identify which ones would be interested on participating on this study. As companies are protected by GDPR, it is not possible to identify them, having been assigned a number to each one. After this collection, 17 companies accepted to participate in the study, representing 30.9% of the associates.

Due to the COVID-19 pandemic, the first contact was made by email and only two companies have responded to entire survey. Since the response rate was insufficient, it was necessary to send the survey a second time. This second contact was made on the first half of September 2020. Some companies were contacted by email, but the phone contact was more efficient in order to request the survey conclusion. On this phase, 13 responses were collected, adding to a total of 15 and, thus obtaining a response rate of 88.2%. After compiling all the answers, it was necessary to organize and analyze them. For this purpose, an Excel document was coded to carry out a statistical analysis. Based on this document, conclusions were drawn on the final step.

To understand what the perception of the barriers' importance is to implement I4.0, it was used a methodology similar to Türkes et al. (2019). To generalize the obtained conclusions, it was necessary to choose more than one company to interview. The selection of cases represents an opportunity, allowing a better understanding of the cases and provides a holistic view of them (Al-Qurtas & Zairi, 2003). It is necessary to consider the available resources to expand the investigation and cover as many cases as possible. The choice of a small number of case studies may impact the quality of the results obtained and the ability to generalize them, as an unrepresentative sample of case studies can result in unreliable conclusions (Al-Qurtas & Zairi, 2003). In this study, the criteria for the company's selection were the polar type method, where companies that were on extreme and opposite situations are selected. Companies that obtained a maximum and minimum readiness level on the first research step were selected, i.e., two companies were selected from each extreme. This approach makes possible to identify contrasting patterns (Eisenhardt & Graebner, 2007). This selection method was used due to the limited number of responses to better represent the population (Eisenhardt, 1989).

An interview protocol was elaborated including a questionnaire with the most cited barriers in Table 3.4. Before the interview took place, the resulting questionnaire was sent to the four companies by email, on the 23rd of October 2020. Due to the COVID-19 pandemic situation, it was not possible to schedule in-person meetings, the semi-structured interviews were done by phone. The mentioned barriers on the questionnaire were discussed during these interviews to understand which ones were considered most important and whether there were any other relevant barriers beyond those already listed. Each interview lasted approximately 30 minutes.

3.5 Results

All readiness levels mentioned in this section are between 0 and 5, using the criteria defined in Table 3.3. The best readiness level for a company is readiness level 5, which represents a "top performer" company and belongs to "leaders" category, which also includes readiness level 3 as "experienced" and readiness level 4 as "expert" companies. A company classified as readiness level 2 is called "intermediate" and belongs to "learners" category. Finally, companies that reach readiness level 0 as "outsider" or readiness level 1 as "beginner" belong to the "newcomers" category.

The last part of this section is focused on the impacts of the current pandemic scenario. Some companies took it as a chance for implementing new technologies in order to ease remote working and others viewed it as a barrier to new investments due to the decrease of its turnover.

3.5.1 Survey Answers

The online survey was sent and analyzed according to the IMPULS model methodology proposed by Lichtblau et al. (2015). The survey was completed autonomously by the respondents; therefore, the answers translated a company's self-assessment. Assistance was offered to the respondents to decrease the possibility of answers that deviated from the companies' reality. Despite this, there is still a possibility that the answers do not depict their reality due to lack of knowledge of the I4.0 thematic. To assure data confidentiality and anonymous, each company participating into the survey was numbered from 1 to 17. Companies 3 and 14 did not answer to this survey; therefore, they will not be referred on this analysis.

3.5.2 Characterization of Companies

The fifteen surveyed companies can be classified according to the number of employees and business volume, and then classified as micro, small, medium, or large companies. The companies' characterization regarding their business volume is represented in Figure 3.2.

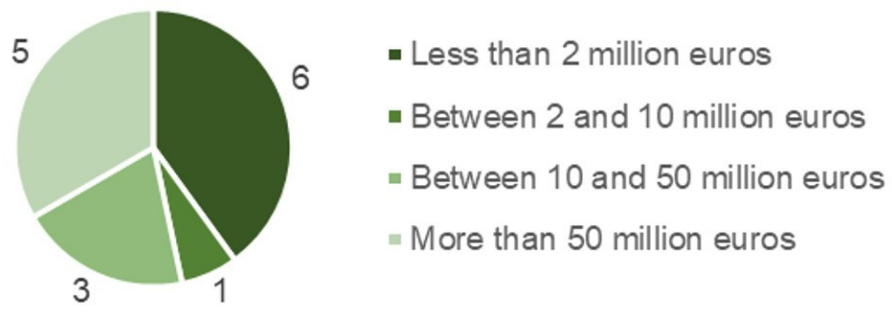


Figure 3.2 - Characterization of companies according to their business volume.

According to the established parameters in Table 3.7, only one company is defined as micro, four companies as medium and large, and small companies are in equal number, five of each. This distribution can be seen in Figure 3.3.

Table 3.7 - Criteria to characterize the dimension of companies.

Number of Employees	Business Volume	Classification
Up to 9 employees	Less than 2 million euros	Micro
Between 10 and 49 employees	Between 2 and 10 million euros	Small
Between 10 and 49 employees	Between 2 and 10 million euros	Small
Between 50 and 249 employees	Between 10 and 50 million euros	Medium
Between 50 and 249 employees	Between 2 and 10 million euros	Medium
Between 50 and 249 employees	More than 50 million euros	Large
250 employees or more	More than 50 million euros	Large

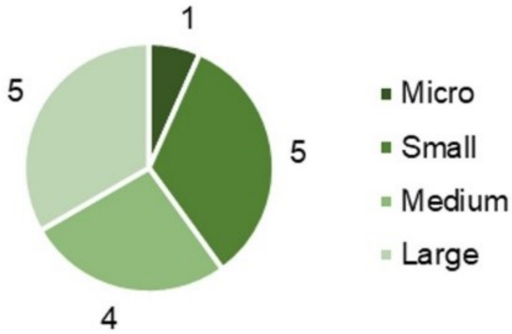


Figure 3.3 - Characterization of companies according to the number of employees.

The companies in sample were also classified according with the principal economic activity. The bigger activity area of respondents belongs to the manufacturing industry, as can be seen in Figure 3.4.

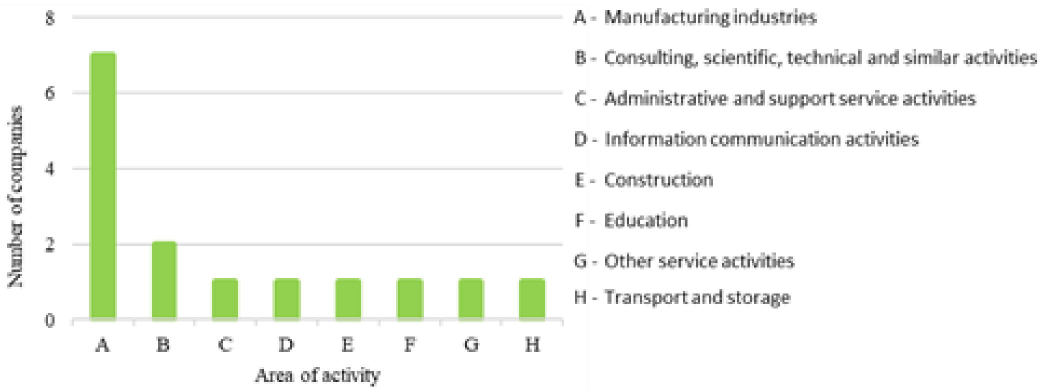


Figure 3.4 - Characterization of companies according to their activity area.

3.5.3 Overall Sample Results

The answers obtained through the survey can be grouped according to the readiness level for each dimension, as shown in Table 3.8. Figure 3.5 provides another data visualization, allowing to quickly identify the readiness level for the IMPULS six dimensions.

Table 3.8 - Number of companies in each readiness level according to the dimensions.

Readiness level		Strategy and organization	Smart factory	Smart operations	Smart products	Data-driven services	Employees
0	Outsider	7	8	1	9	11	0
1	Beginner	2	5	2	3	1	0
2	Intermediate	1	2	4	1	3	2
3	Experienced	2	0	6	0	0	4
4	Expert	3	0	2	0	0	8
5	Top performer	0	0	0	2	0	1

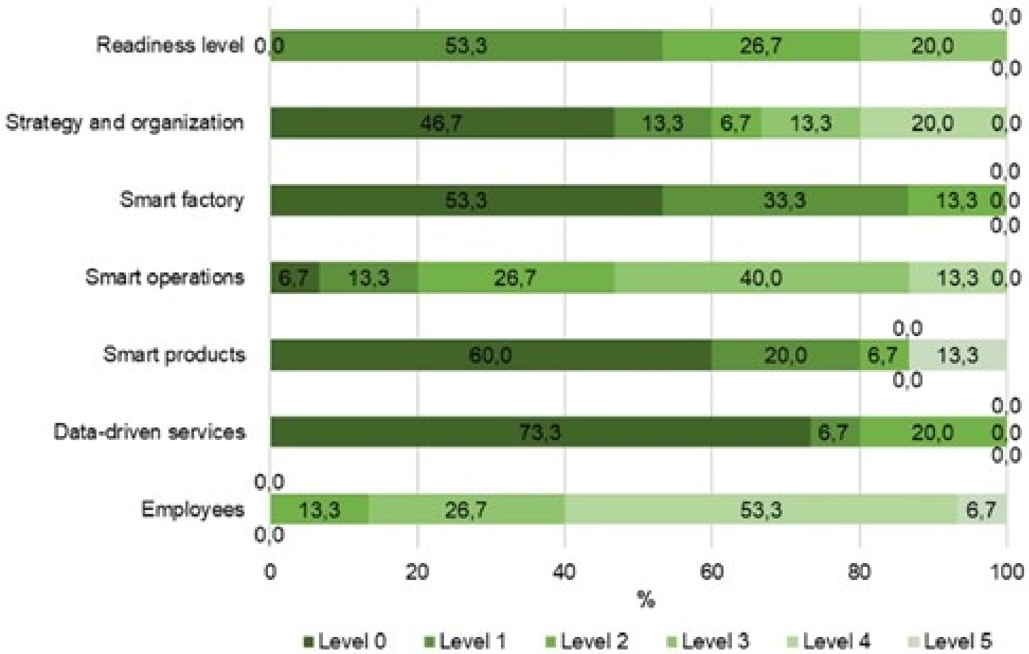


Figure 3.5 - Readiness level distribution on different dimensions.

The “employees” dimension is the only one in which the surveyed companies presented a readiness equal or higher than 2 “intermediate.” Only two dimensions, “smart products” and “employees,” have companies with the maximum readiness level 5 “top performer.” Table 3.8 shows that on four out of six analyzed dimensions, there are no companies reaching the highest readiness level: “strategy and organization", “smart factory", “smart operations,” and “data-driven services.”

Table 3.9 shows the average readiness level obtained on each sub-dimension. The lowest average readiness level was 0.6; it was obtained on “level of data usage” sub-dimension on “data-driven services.” The highest average readiness level was 4.2; it was obtained on “cloud usage” sub-dimension which belongs to “smart operations”. Each dimension will be analyzed in more detailed on next subsections.

Table 3.9 - Average readiness level on each sub-dimension.

Dimension	Sub-dimension	Average Level
Strategy and Organization	Degree of Strategy Implementation	1,7
	Definition of Indicators	2,8
	Investment	2,8
	Innovation Management	3,4
Smart Factory	Equipment Infrastructure (current)	2,1
	Equipment Infrastructure (target)	1,4
	Digital Modeling	2,2
	Data Collection	2,3
	Data Usage	1,8
	IT Systems	1,7
Smart Operations	System-integrated Information Sharing	3,3
	Autonomously Guided Workpieces	3,4
	Self-reacting Processes	3,9
	IT Security	4,1
	Cloud Usage	4,2
Smart Products	ICT add-on Functionalities	1,7
	Use of Data	2,1
Data-driven Services	Data-driven Services	0,9
	Level of Data Usage	0,6
Employees	Employee Skills	3,5

Through the analysis of Figure 3.6, it is possible to conclude that only less than 20% of companies do not use any technology from those mentioned on the survey and more than 70% already use sensors, which is the most used technology.

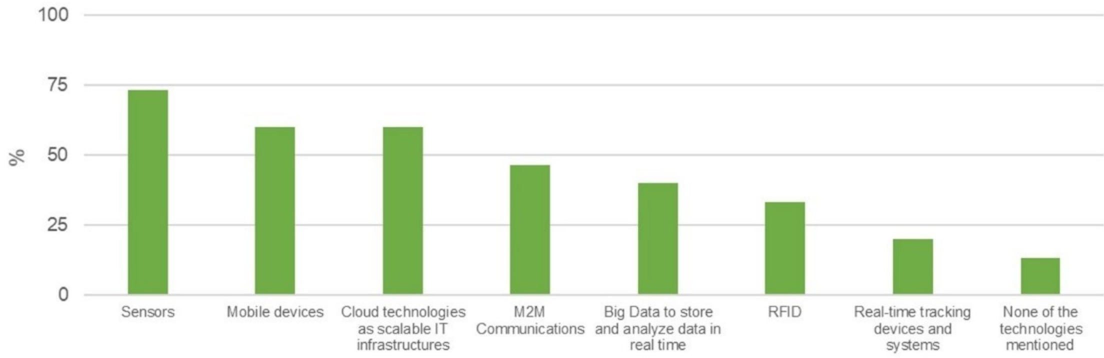


Figure 3.6 - Used technologies by surveyed companies.

Depending on the product or service type offered by each company, it may be difficult to introduce certain I4.0 enabling technologies, which may negatively impact their readiness score. For illustration purposed, considering the "smart factory" dimension, there are companies who obtained the minimum level on a particular sub-dimension because of their context. For example, a company that manufactures electronic-based products and equipment will find it easier to use digital modeling than a company dedicated to transportation and storage. According to Lichtblau et al. (2015), the "smart factory" dimension has a weight of 14% on the final readiness score. If a company reaches the maximum readiness level on all other five dimensions and the minimum readiness level on "smart factory" (readiness level 1), then the company overall readiness score will be given by of 4.44, which translates to a final readiness score of 4. According to Table 3.2, the IMPULS model readiness overall score has the criteria of the weighted six dimensions as follows: strategy and organization (25%), smart factory (14%), smart operations (10%), smart products (19%), data-driven services (14%), and employees (18%).

As described previously, companies can be grouped according to their readiness score into three categories. Companies categorized as "newcomers" (readiness score 0 and 1) represent 53.3% of the sample. About 26.7% of the sample belongs to "learners" category (readiness score 2) and the remaining 20% belong to "leaders" group (readiness score 3, 4, and 5). On "leaders" group, there are no companies with readiness level 4 (expert) or readiness score 5 (top performer), with the maximum readiness score being seen by companies as a long-term objective. By looking at Figure 3.7, it can be seen that more than half of the companies (60%) obtained a readiness score below the average. There is a discrepancy of 2.71 between the readiness score of the company with the highest and lowest rating, with no apparent relationship between the rating and the size or activity area of the companies.

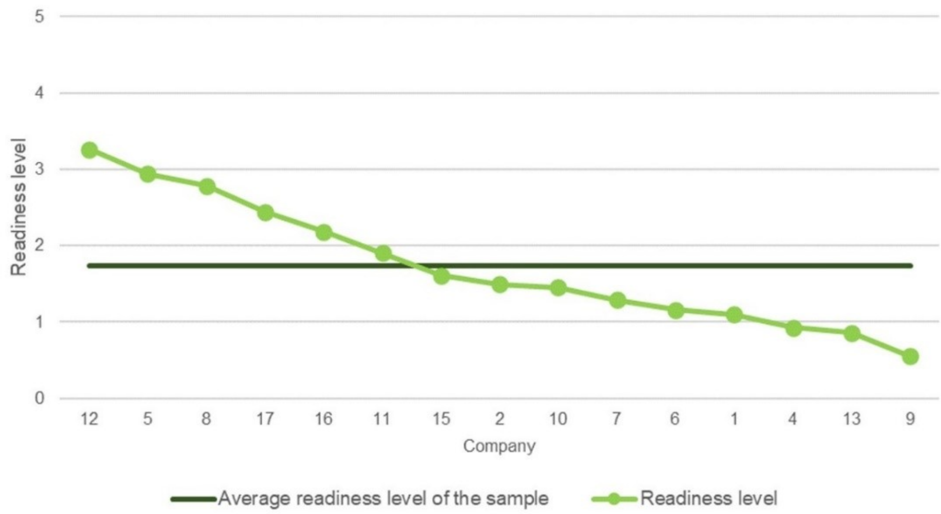


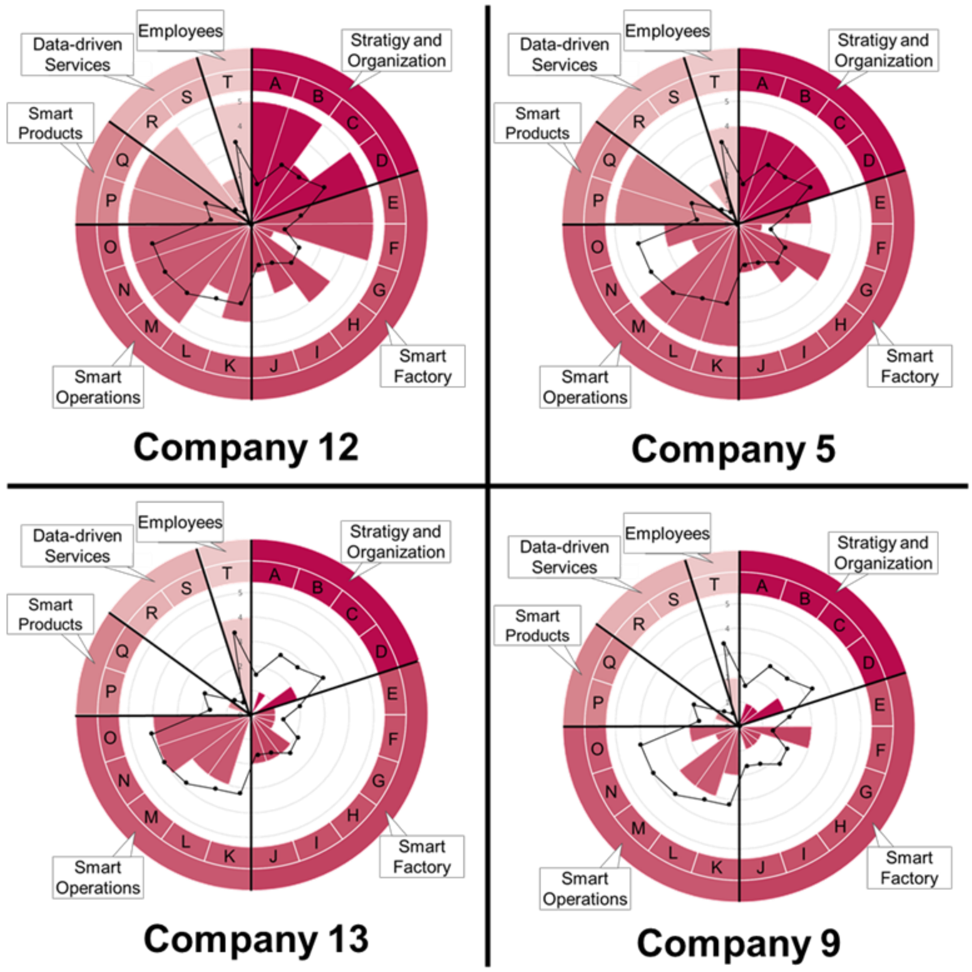
Figure 3.7 - Distribution of companies' readiness score and comparison with sample's average readiness score.

On average, companies reached a readiness score of 1.74, which is a relatively low readiness score, despite being higher when compared with the readiness score obtained by Lichtblau et al. (2015). This difference can be explained by the characterization of the chosen sample of companies. Lichtblau et al. (2015) conducted the study exclusively with companies with more than twenty employees located across Germany, focusing on manufacturing companies. The chosen sample on this study includes companies of different sizes and does not include exclusively companies on manufacturing sector.

Table 3.10 provides the details of the two companies with highest and lowest readiness levels. Figure 3.8 shows for this set of companies, the readiness level achieved in the different sub-dimensions and its comparison with sample' average level.

Table 3.10 - Companies with highest and lowest readiness levels.

Company	Activity Area	Employees	Business volume	Dimension	Readiness Level	Final Readiness Level
12	Information and communication activities	10 to 49	Less than 2 million euros	Small	3,26	3
5	Manufacturing industries	More than 250	More than 50 million euros	Large	2,94	3
13	Manufacturing industries	50 to 249	More than 50 million euros	Large	0,86	1
9	Manufacturing industries	10 to 49	Less than 2 million euros	Small	0,55	1



Subtitle:

A – Degree of Strategy Implementation
B – Definition of Indicators
C – Investments
D – Innovation Management
E – Equipment Infrastructure (current)
F – Equipment Infrastructure (target)
G – Digital Modelling
I – Data Collection
J – Data Usage
K – System-integrated Information Sharing
L – Autonomously Guided Workpieces
M – Self-reacting Processes
N – IT Security
O – Cloud Usage
P – ICT add-on Functionalities
Q – Use of Data
R – Data-driven Services
S – Level of Data Usage
T – Employee Skills
–•– – Average Readiness Level

Figure 3.8 - Comparison of obtained readiness levels on dimensions and its sub-dimensions for best and worst performers.

3.5.4 Analysis of "strategy and organization" dimension

The average readiness level for "strategy and organization" dimension was 1.5. Thus, 46.7% of companies obtained a readiness level 0, which means that they are considered "outsiders"

because they do not reach the necessary requirements. On this dimension, no company reached readiness level 5.
One aspect that may contribute to such a low average readiness level is the fact that almost half of the respondents (46.7%) have no I4.0 strategy implemented or under development. As shown in Table 3.9, the sub-dimension that has the lowest average level is "degree of strategy implementation," and the sub-dimension with the highest average level was "innovation management," on which the readiness level most often obtained by companies was readiness level 3, which means that there is only innovation management in one company area.
The three companies that obtained the highest readiness level on this dimension are companies 5, 8, and 17. Companies 5 and 8 have a similar characterization, both belong to the manufacturing sector and large companies, with a business volume of more than € 50 million and more than 250 employees. Company 17 is a small company in the construction sector, a business volume of less than € 2 million and a number of employees between 10 and 49.

3.5.5 Analysis of "smart factory" dimension

On this dimension, companies obtained an average readiness level of 0.6, with the most common value of readiness level 0 (53.3% of respondents), as can be seen in Table 3.8. A company that has a readiness level 0 on this dimension means that it has not met the necessary requirements.
Table 3.9 shows that sub-dimension with the lowest average readiness level is "equipment infrastructures (target)," in which seven respondents obtained readiness level 0, that is, 46.7% of the companies report their systems and machines cannot be updated. The sub-dimension with the highest average readiness level is "data collection," in which 40.0% of companies answered that they do not collect data from machines and processes.
The two companies that obtained the readiness level 2 on this dimension were companies 8 and 11. Company 8 is a large company and has an activity area of manufacturing industries. Company 11 is considered medium size and belongs to the activity area of consultancy, scientific, technical, and similar activities.

3.5.6 Analysis of "smart operations" dimension

On the "smart operations" dimension, companies in sample obtained an average readiness level 2 on the corresponded scale from level 0 to 5. Only one company obtained readiness level 0, most companies (40%) obtaining readiness level 3 and none achieving readiness level 5, as shown in Table 3.8. A company at readiness level 3 is considered experienced and it can be said that there are initial solutions for CC, data storage, and data analysis, it already has IT security solutions partially implemented, and there are some information sharing systems.

As it can be seen in Table 3.9, the sub-dimension where companies obtained, on average, a lower readiness level was "system-integrated information sharing," which means that these companies have integrated sharing information systems between departments on all areas and between customers and suppliers in more than five areas. The sub-dimension on which most companies obtained a higher average readiness level was "cloud usage," where only two companies do not use CC, one of which is planning on starting to use it. On this sub-dimension, most respondents reached readiness level 4, stating that there is some use of CC services on the company.

Most companies (80%) do not use autonomously guided workpieces, 53.3% do not have self-reacting processes, and 53.3% of the companies have implemented all IT security solutions mentioned on the survey.

Companies that obtained readiness level 4 on this dimension were the same ones that obtained the highest readiness level on the "smart factory" dimension (companies 8 and 11).

3.5.7 Analysis of "smart products" dimension

On the "smart products" dimension, companies obtained an average readiness level 1 on the corresponded scale from level 0 to 5. As it can be seen in Table 3.8, most companies (60%) obtained a readiness level 0, being placed on "outsider" category because they do not meet the necessary requirements.

As shown in Table 3.9, the sub-dimension on which companies reached the highest readiness level on average was "use of data." Despite having a higher level than the other subdimension (ICT add-on functionalities), it is still a low value due to the lack of data analyzed during the usage phase, being that ten companies (66.7%) do not collect or analyze them, which represents a readiness level 1 on this sub-dimension.

The two companies that have reached the maximum readiness level on this dimension, companies 5 and 12, have different activity areas and sizes. Company 5 has already been described in section 4.1.3. Company 12 is considered small because it has between 10 and 49 employees and its business volume does not exceed € 2 million. This company belongs to the information and communication activity area.

3.5.8 Analysis of "data-driven services" dimension

On the "data-driven services" dimension, companies obtained an average readiness level of 0.5 on the corresponded scale from level 0 to 5. As it can be seen in Table 3.8, the most frequently readiness level assigned was readiness level 0, which means that the companies under study do not meet the necessary requirements.

The most frequently assigned value on "data-driven services" sub-dimension was readiness level 0, as shown in Table 3.9, which leads to a low average value. A company on readiness level 0 does not provide data-driven services, which may be due to their activity area. Some companies may integrate data-driven services in an easier way because of the product or service type they offer. For instance, a company that offers electronic-based products and equipment will find it easier to introduce a data-driven service than an ink manufacturing company. Through the surveyed questions, it was not possible to obtain the readiness level of "share of revenues" subdimension; thus, this sub-dimension was not considered. On this study, it was not possible to apply directly the methodology proposed by the IMPULS model. According to the suppression of "share of revenues" sub-dimension, the "level of data usage" sub-dimension reached a maximum of readiness level 2. This limitation affects four companies that have a higher level on the other sub-dimension, as it can be seen in Table 3.11.

Table 3.11 - Companies affected by the limitation imposed on "level of data usage" sub-dimension.

Company	Data-driven Services	Level of Data Usage
2	3	1
8	3	2
12	5	2
17	3	2

The maximum level reached on this dimension was readiness level 2 and only three companies (8, 12, and 17) reached it, all of which were affected by the limitation described above. Throughout section 4.1, these companies were characterized. The only common factor is the size of companies 12 and 17, both considered small.

3.5.9 Analysis of "employees" dimension

On the "employees" dimension, companies obtained an average readiness level of 3.5 on the corresponded scale from level 0 to 5. This was the dimension that obtained the highest average readiness level which is justified by the fact that no company obtained a readiness level 1 or lower and the most frequent value was readiness level 4, as Table 3.8 shows. The eight companies (53.3%) on readiness level 4 fall into "expert" category which means that they consider that their employees have the adequate qualifications on most of relevant areas. Only company 12 reached the maximum of readiness level 5 on this dimension.

3.6 Results of identifying the barriers to I4.0 implementation

Based on the surveyed companies' readiness level, the four companies represented in Figure 3.8 were selected to carry out the second phase of this study.
Based on the barriers to I4.0 implementation presented in Table 3.4 and using the criteria described in section 3.3, it was elaborated a questionnaire to serve as guide during the semi-structured interviews. This questionnaire contained the barriers displayed in Table 3.12 and the respondents had to evaluate their importance by attributing a number between 1 and 5, meaning 1 being not important and 5 being extremely important. The overall perception of each barrier's importance was obtained by adding the importance values that each company attributed. The sum of the importance values is represented on the "total" column of Table 3.12.

Table 3.12 - Perception of the barrier's importance on I4.0 implementation.

	Company				
Barrier	**12**	**5**	**13**	**9**	**Total**
Need for large investments	4	3	4	3	14
Lack of clarification of economic benefits	4	5	2	5	16
Lack of support from top management	2	2	5	5	14
Demotivation of workers	3	2	2	5	12
Lack of employees' skills	4	2	4	5	15
Lack of technical knowledge	4	2	4	4	14
Lack of regulation and procedures	4	2	1	3	10
Concern about data security	5	2	1	4	12
Lack of standards (interoperability and compatibility)	4	5	2	5	16
Concern with the reliability of systems	3	4	4	4	15
Underdeveloped IT infrastructure	5	3	4	4	16
Need to create new business models	2	2	4	3	11

Both companies with a lower readiness level considered that one of the most important barriers is “lack of support from top management.” This barrier is not related to the size of these companies as one is large and the other small. Company 9 (small) also states that “lack of employees’ skills” is a very important barrier, which is on agreement with the readiness level obtained on the dimension “employees” being lower than the average of the AISET associate members. Company 13 considers “lack of employees’ skills” an important barrier, despite having a higher readiness level than average readiness level on this dimension.

Regarding the “lack of support from top management” barrier, there is a clear distinction between companies with a higher and lower readiness level. The same is not true on any other category. Barriers that companies perceive to be the most important are “lack of clarification of economic benefits,” “lack of standards (interoperability and compatibility),” and “underdeveloped IT infrastructures.” During the interviews, other barriers that companies consider to be important were mentioned.

Company 12 is a business solutions provider through software development, which allows them to have both the company’s point of view as well as the customers’ point of view. The respondent from company 12 affirmed that it is necessary to invest on the implementation of I4.0 enabling technologies, but that this will not be the biggest barrier. Also believes that the biggest barrier to I4.0 implementation on companies is “underdeveloped IT infrastructures.” The respondent of company 12 also adds that the vision of companies is short term and, therefore, there is no well-defined long-term strategy.

Unlike company 12, the respondent of company 5 does not consider that “underdeveloped IT infrastructures” is a very important barrier. It was mentioned that Return of Investment (RoI) analysis is used to understand the economic benefits. The RoI analysis makes it possible to analyze “need for large investments” and “lack of clarification of economic benefits” barriers together. Despite emphasizing the importance of “concern about data security” barrier, the respondent of company 5 does not consider it to be a very important barrier. This concern implies that employees of company 5 are not allowed to use clouds, although there is already data that is collected into a private cloud, but it is only on experimental stage. It was also mentioned by the respondent of company 5 that another barrier not specified on the questionnaire is “delay on allocation of public funds,” which are a great help on I4.0 implementation regarding its enabling technologies.

The respondent of company 13 considers “lack of support from top management” barrier the most important, adding that this barrier would be equally important on any area because if there is no support from top management, it is quite difficult to introduce new concepts. Also considers “concern about data security” and “lack of regulations and procedures” as minor barriers. The respondent of company 13 affirms that there is no effective dissemination of the theme of I4.0 among potential users (companies).

The respondent of company 9 states that the concept of I4.0 is not clear and, therefore, there should be a certified entity that could perform a diagnosis helping companies on their digital transformation. This company has a clear perception of the need for innovation and the importance of constant evolution on a competitive market. The respondent of company 9 owns two other companies, one of which is being created incorporating some I4.0 enabling technologies.

3.7 Impact of the COVID-19 pandemic

The impact of the COVID-19 pandemic is evident around the world. Many nations are or had on lockdowns affecting all industrial tissue among other activities. All these imposed changes forced all industrial stakeholders to quickly adapt to new working conditions.

The organizations’ response to COVID-19 pandemic had to be quick to its unprecedented demands, changing work practices in a short time period to train or to prepare the organizations to these new normal, new work practices where the IT technologies are the central role regarding to aspects such as behavioral, temporal, societal, and organizational (Carroll & Conboy, 2020). According to the impact of the COVID-19 pandemic on several business sectors, Herath & Herath (2020) pointed out three scenarios: some organizations had to rethink their business models, some had to reduce their operations, and many were forced to close down.

On the last group of this survey was included a question to understand how the current pandemic scenario has influenced companies, what is its impact on the use of I4.0 enabling technologies and how will they be used on the future.

Due to the decrease on turnover, four companies under study mention that they had to freeze or postpone planned investments. The uncertainty associated with the pandemic scenario is also a factor that led to the cancelation or postponement of new projects.

Eight companies affirmed that this pandemic has had little to no impact. The tools that allow collaborative work already existed and it was only necessary to learn how to get the best out of what was already implemented.

Company 2, in addition to intensifying the use of communication and online meeting software, also began to develop products to support the fight against COVID-19 pandemic. The development of these products will be continuing on in accordance with the market's necessity, and company 2 is contemplating the possibility of continuing developing other products. The respondent of company 16 also claims that the pandemic had created an opportunity to develop some technologies. This company accelerated the use of analysis and remote assistance to its customers.

An interesting point is the respondent of company 17 mentioning the COVID-19 pandemic impact so far has been none. Company 17 has not stopped activity and even developed the following actions that they consider to be of a very significant relevance, as follows:

1) Fully implementation of an IT structure integrated among all resources (hybrid solution);
2) Implementation of an entirely new installation based on an integration perspective;
3) And a full-time contract of five hired new employees.

The influence and the impact of the COVID-19 pandemic on this sample is aligned with the first two scenarios pointed by Herath & Herath (2020). To date of this study, no company under sample was forced to close down. On the other way, it is evident that the positive impact of COVID-19 pandemic regarding to the usage of ICT is higher than the negative impact which is described as the freezing or postpone planned investments.

3.8 Discussion

Even that some companies and its stakeholders are leading the adoption of the I4.0 enabling technologies in a certain way, the perception of the world in general related to the digital environment scenario is that this reality its very far away.

As presented in section 3.5, there are companies unable to relate the I4.0 with their business models, and there are companies who do not have a clear vision of I4.0 and how they can take advantages of this digital environment. This leads to a lack of I4.0 strategy with clear goals to short term, without measures to get benefits to companies. Nevertheless, there are companies with I4.0 pilot projects trying to understand the benefits and to extract the best of the I4.0 enabling technologies for their business models. Although, it is missing the needed skills to perform the correct capacity' assessment related to the adoption of the I4.0 enabling technologies as a whole and the needed strength to stimulate collaborators to embrace this new digital environment.

The usage of data, its collection, and its sharing to further analyze and use on decision-making on product and process improvement and also on connections with all the value chain is poor.

It is clear that most of companies are taking a defensive stance with fear of investments and waiting for the evolution of its competitors and its business partners.
The literature brings some qualitative studies using IMPULS model. Silva & Rocha (2020) used IMPULS model to study a Brazilian strategic defense company. Hamidi et al. (2018) studied Malaysian SMEs from various industries showing IMPULS dimensions average levels. (Maasz & Darwish (2018) studied one South African company in the mining industry.
Lichtblau et al. (2015) present a full study, both qualitative and quantitative in two German activity areas such as mechanical and pant engineering (sample of 234 respondents) and manufacturing (sample of 602 respondents), having 0.9 and 0.6 average readiness scores, respectively. This study presents a wider sample regarding the activity area with an average readiness score of 1.74. It is higher from readiness scores of Lichtblau et al. (2015) but the characteristics of the samples are different.
Looking forward on the understanding of the poor readiness level of this sample, the perception of the I4.0 enabling technologies adoption barriers that were extracted from the semi-structured questionnaire retrieves useful insights. The most important perceptions of the highlighted barriers were "lack of clarification of economic benefits", "lack of standards (interoperability and compatibility)", and "underdeveloped IT infrastructure".
The "lack of clarification of economic benefits" barrier can show that companies do not have a clear vision on I4.0 environments and this lack of vision and company strategy to face the near future starts on the top management.
The "lack of standards (interoperability and compatibility)" barrier can show that companies do not have the needed working skills on their working groups to prepare the digital environment.
The "underdeveloped IT infrastructure" barrier can show that companies are not as proactive and do not have a long-term vision. Most companies depend on public funds to innovate in products, processes, or even on their facilities. This dependence is harmful and, as company 5 respondent mentions, the delay on public funds leads to the cancelation of innovation initiatives. Using relevant studies regarding the I4.0 barriers (World Economic Forum, 2015; Müller et al., 2018; Stentoft et al., 2019; Müller et al., 2017; Li et al., 2015; El Beqqal& Azizi, 2017; Yang et al., 2017), on the interviews regarding the perception of the importance of the barriers, brought to discussion new barriers as "delay on allocation of public funds" and "lack of a certified entity to perform a I4.0 diagnosis."

3.9 Concluding Remarks

Some experts estimate that the progress of I4.0 will boost the industry allowing to meet the increasingly demanding requirements of its customers and thus preserve its competitive advantage (Oztemel, & Gursev, 2020). Despite the advantages associated with its implementation, companies may not use as many technologies as there are some barriers that hinder their implementation.

The answer of the RQ2 was obtained through "Mapping the Adoption of Technologies for Industry 4.0 on Setúbal Peninsula" survey. It was possible to conclude that the responding companies have an average readiness level of 1.74, with the most frequently attributed readiness level 1. A company inserted on this readiness level is part of "newcomers" category and it is considered that it is involved on I4.0 through pilot initiatives on several departments, has investments on a single area, and IT security solutions are still on the planning or implementation phase.

With the assessment of what is the perception of the barriers' importance to implement I4.0 with semi-structured interviews, it was possible to understand what the most important barriers from the companies' perspective are. It was concluded that the barriers considered most important were as follows: "lack of clarification of economic benefits", "lack of standards (interoperability and compatibility)", and "underdeveloped IT infrastructure". The linkage of these barriers to the surveyed readiness levels leads to the understanding of companies without a vision and a strategy to face the near future starting on the top management. These perceptions on the barriers' importance also leads to lack of proactive and long-term vision. It was also perceived that most companies depend on public funds to innovation initiatives.

The surveyed question related to the impact of the COVID-19 pandemic shows that more than half of the companies in the sample (53.3%) affirm that the necessary tools for working remotely already existed, being only necessary to learn how to make the best of them. On the opposite direction, four companies reported that the pandemic scenario has negatively affected their turnover, which has led to a freeze on I4.0 investments. Only one company claims that they were not affected, and all previously planned actions were implemented. One of the companies started to use communication software for remote working more often and claims that changed its production in order to develop products to support the fight against COVID-19 pandemic.

As a recommendation for future research, a new assessment of companies' readiness level is suggested to evaluate the impact of the COVID-19 pandemic on I4.0 enabling technologies adoption. On the one hand, companies may have postponed the implementation of some I4.0 enabling technologies due to lack of financial resources, human resources, or even lack of time. On the other hand, companies may have been driven to consider new ways of manufacturing with less human resources due to the increase on remote work. Knowing that the most affected companies by this crisis associated with the COVID-19 pandemic are SMEs (Dimson et al., 2020) and that 66.7% of respondents on this study belong to this category, it would be interesting to study if this trend is verified with these companies and understand its impact.

Some AISET member companies operate together, forming value chains and creating synergies with each other. An opportunity created through the partnership with AISET would be to compare the readiness levels between the companies involved in the same value chain. It was not possible to achieve this goal because AISET member companies that were available to be surveyed unfortunately do not form value chains.

One of the mentioned barriers by the surveyed companies is the "lack of clarification of economic benefits" and some add that they would be interested in being assessed in this area by an accredited entity. On this way, it would be beneficial to conduct a study on the added value, not only economic but also competitive, of I4.0 enabling technologies adoption.

Reaching the answer to the RQ2, it was important to study a company regarding the I4.0 implementation to understand in deep what was made and what can be made to reach better I4.0 maturity levels.

4

INDUSTRY 4.0 MATURITY FOLLOW-UP

This chapter is built with the use of a shorter version of the peer-review manuscript version published as: Alcácer, V., Rodrigues, J., Carvalho, H., Cruz-Machado, V. (2021). Industry 4.0 maturity follow-up inside an internal value chain: a case study. International Journal of Advance Manufacturing Technology 119, 5035–5046. https://doi.org/10.1007/s00170-021-08476-3; (Q1; H-Index = 134; Impact Factor = 3.563 (2021); Citations = 1, Captures = 674).

Summary: Social, economic, and technological developments are leading companies to face new production challenges. The use of information and communication technologies offers to companies physical and virtual structures, allowing cooperation and quick adaptation along all value chain. However, companies are using those technologies without a proper integration with business partners and even with internal departments. This is the research gap under analysis on this study. Using a readiness model to measure the status of the industry 4.0 enabling technologies adoption inside a company, it is possible to transmit knowledge, and pathing initiatives to help on progress and monitorization. This study presents the industry 4.0 enabling technologies readiness level of three departments of one manufacturing company internal value chain and discusses the limitations to reach better levels. It also presents the potential results if the benefits of industry 4.0 enabling technologies were reached on a company that assumes to be aligned with the industry 4.0 strategy.

4.1 The Internal Value Chain

Recent environmental, social, economic, and technological developments have led production and manufacturing companies to face new challenges. Companies will need resources to manage their entire value chain in an agile and efficient way. Also, companies will need physical and virtual structures to ease cooperation and rapid adaptation throughout entire product life cycle, from product innovation to production and distribution (Schumacher et al., 2016).

The academia shows some recent and relevant studies on the automotive industry. Sanz et al., (2021) shows a framework of an industrial CPS integrating computing, communication, and control, combining artificial intelligence and IIoT through the I4.0 ecosystem and predictive maintenance. Neal et al. (2021) demonstrated the implementation of a CPS to monitor and control the returnable transit items to improve quality assurance and also process compliance. However, most current IT systems are not fully integrated. Supplier companies and customers rarely establish interpersonal relationships. The same goes for organizations' internal departments, such as engineering, production, or services. With I4.0, these connections are expected to be established and to enable truly automated value chains (Brandherm & Kroner, 2011).

No studies were found regarding the use of a maturity or readiness model analyzing a company's internal value chain considering each department being an element of the value chain. The main objective of this study is to individually assess the level of technological maturity related to the I4.0 concepts, on a quantitative and qualitative matter, on three internal departments (designated by logistics, board preparation, and plastics) of an automotive company that assumes to be aligned with the I4.0 strategy. A secondary objective of this study is to contribute for the identification of I4.0 enabling technologies that are used on each department to check the systems integration of the company.

4.2 Industry 4.0 Enabling Technologies Adoption

Several national governments keep on developing policies and measures to support financially (through funds) and structurally (through institutional actions) the digitalization path of companies, forecasting the relationship between all stakeholders inside each value chain, involving also within this value chain universities, intermediaries and innovative companies, and training programs (Agostini & Nosella, 2019).

Da Silva et al. (2020) state that I4.0 is a reality on countries like German, France, the USA, the UK, China, Japan, and Brazil, among others, although it should be admitted that I4.0 enabling technologies' implementation and adequacy could be a challenge for all stakeholders.

Systems integration is the first step to achieve I4.0 vision. Considering all productive flow, the systems are analyzed as a whole (Pérez et al., 2020).

The systems integration, as shown in Figure 2.1, can be understood as the linkage of system components (components like software, hardware, or other systems and subsystems), called vertical integration, two or more systems, called horizontal integration, and the system to provide interfaces linking physical and virtual objects of a system is called end-to-end engineering integration. These components interoperate and provide solutions according to collective or individual objectives. Technologies, like IoT, are integrated with these systems, enabling the interoperability between the "things" (data, people, and/or services) (Sanchez et al., 2020).

The vertical integration or intra-company integration (or internal integration mapping) consists of evaluating the system in a different manner to identify crucial areas for their assistance (Stentoft et al., 2019). Corporate planning, manufacturing, production management, control, and actuators are examples of informational systems; subsystems and physical "things" are elements belonging on a typical manufacturing system. This integration on a manufacturing system allows flexibility and reconfigurability and a rapid adaptation to different product types. The vertical integration allows processing the collected massive information in a transparent process manner (Wang et al., 2016).

The horizontal integration or inter-company integration is based on the cooperation or collaboration between two or more companies, achieving common or individual objectives (Sanchez et al., 2020). It allows an efficient ecosystem inside value networks related to information, finance, and material flows between companies (Wang et al., 2016).

The end-to-end engineering integration mixes virtual and real entities using connected devices to a network, sending information to a cloud or people and communicates with the system using human machine interface (Sanchez et al., 2020). It is a process of product-centric value creation, involving costumer requirements, design and development of products, production planning and engineering, associated services, maintenance, and recycle (Wang et al., 2016).

To be able to perform inside I4.0 environment, companies must have socio-technical environments, as well as the virtualization of physical objects with the use of smart systems (Pérez et al., 2020). The adoption of the I4.0 enabling technologies, from a socio-technical perspective, is not supported by itself. The socio-technical component is complemented with dimensions related to the technological aspect on the digitalization process to achieve the I4.0 implementation, as follows (Dalenogare et al., 2018):

- Work organization: Rethink how companies will operate with I4.0 enabling technologies;
- Human factors: New operator's competences and skills are needed to operate with I4.0 enabling technologies;
- External environment: The adoption of I4.0 enabling technologies is maturity dependent on where they are implemented.

4.3 Research Methodology

The present study has a main objective to carry out an evaluation of a company' systems integration that allows to verify the level of technological readiness related to the I4.0 concept, quantitative and qualitative, on three departments of one automotive company. A secondary objective of this study is to contribute to the identification of the used I4.0 enabling technologies on each department, using the IMPULS readiness model questionnaire, which allows a survey of these technologies. Thus, the chosen methodology is a case study since it allows applicability on a real context.

Three department were analyzed: the logistic department and two production lines named as board-preparation and the plastic injection departments. The head of each department answered to the questionnaire, making it possible to assess the level of I4.0 technological readiness of each one, and to do a comparative analysis of the results.

Moreover, shopfloor visits were made to each department, to survey their processes, as well as the technologies under use. During these visits, interviews were carried out with employees who perform tasks on the production lines and on the logistics warehouse (operators, maintenance technicians, and process engineers), because these employees establish connections with the existing technologies.

Each department was assessed autonomously and according to the IMPULS readiness model levels, allowing to understand on which dimensions there is an opportunity for improvement and if the levels of I4.0 implementation differ between departments. The collected data was analyzed and the results with the levels' attribution for each dimension and the overall assessment of the department discussed.

4.3.1 Company Characterization

This anonymous company is a worldwide supplier dedicated to car cockpit electronics and has one of the largest product portfolios on this segment. This company is uniquely positioned to meet the needs of smart digital cockpit manufacturers for electric and automated vehicles. In 2017, this company had sales greater than US $ 3.000 billion and approximately 10 000 employees, on more than forty facilities located in eighteen countries.

This company operates on the industrial installations for the assembly, manufacture, manufacture and processing of electronic, electrical and electro-mechanical devices, namely for the manufacture of radios, graphic equalizers and amplifiers for automobiles. The facilities located in Portugal have several departments, essential for its business model. On this study, three departments were analyzed to assess the level of technological maturity of each one individually, making it possible to draw comparative conclusions from the I4.0 development status.

4.3.2 Data Collection

Processes were monitored for the logistics, board-preparation, and plastic injection departments. It was possible to verify how it is made the reception of materials, components and products for production, as well as, how the production lines establish communication with other departments for assuring on-time line supply. For a better understanding of the production flow, 26 informal interviews were carried out with employees (technicians, operators, and engineers) who operate on each evaluated department: logistics department - 18 employees were interviewed; board-preparation department - 5 employees, 1 maintenance technician, and 2 process engineers plastics' department - 4 employees and 2 process engineers. These interviews allowed to assess, not only the way that which employees establish connections with the enabling technologies, but also to collect information on how production processes work. On the second phase, after 37 direct observations made on the shop floor, the department managers were questioned, according to the IMPULS questionnaire. It was possible to individually evaluate each department and quantify the dimensions presented in the IMPULS model based on the collected data.

The first respondent is responsible for logistics' warehouse, a professional with more than 11 years of experience on the area and also on the company. The second respondent is responsible for the production line on the board-preparation department, graduated with engineering degree with more than 3 years of experience on this company. The last respondent is responsible for the plastics department, with 23 years of professional experience on the area and on this company.

4.5 Results and Discussion

The first part of the assessment aims to know the knowledge level of each of the respondents related to I4.0 concept. Table 4.1 allows visualizing the answers given by each respondent, with no quantitative assessment being made in relation to the answers presented.

Table 4.1 - Characterization of departments and familiarity with the i4.0 concept.

Question	Logistics	Board-preparation	Plastics
What is the approximate number of employees on the department?	250 or more employees	250 or more employees	From 50 to 249 employees
What was the turnover in 2018?	Above € 50 million	Between 10 and € 50 million	Between 2 and € 10 million
What is your knowledge about I4.0 concept?	Superficially and I want to know more to assess I4.0 performance on the company	Enough to already have some pilot projects underway	Enough to already have some pilot projects underway
What motivates the department to embrace I4.0 challenges?	The department has an innovative spirit aligned with new concepts experiments	Market requirements and competitive pressure	Market requirements and competitive pressure
Which objectives do you intend to achieve with the adoption of I4.0 concepts?	Increased efficiency of the manufacturing system	Increased efficiency of the manufacturing system	Increased efficiency of the manufacturing system

The logistics department presents itself as the department with the highest business volume, since it establishes links with other production departments, assuring the on-time supply of all materials necessary for production. It is possible to observe that the responses of the production departments (board-preparation and plastics) are identical, and that there is an adaptation to the concept due to market competition. In relation to the logistics department, due to the lack of proximity of the interviewee with the I4.0 concept, the answers are different from other respondents.

The last question on the first part of this assessment is related to I4.0 planned activities, underway or implemented on each department as Table 4.2 shows.

Table 4.2 - Planed I4.0 activities.

Activities	Logistics	Board-preparation	Plastics
Digitization of processes with the implementation of information systems	Don't know how to answer	Ongoing	Implemented
Integration between systems and / or machines using IoT	Don't know how to answer	Planned	Implemented
Systems implementation that allows efficient control of processes, products and services and performance analysis in real time	Don't know how to answer	Ongoing	Implemented
Hiring essential technicians for digital transformation	Don't know how to answer	Planned	Not relevant
Conversion of technicians to respond to the digital transformation	Don't know how to answer	Ongoing	Ongoing

It was not possible to make a qualitative assessment regarding the I4.0 activities on the logistics department due to the lack of information that the respondent has about the existence of these activities. The higher level of knowledge revealed on the other two departments makes it possible to know that: on the board-preparation department these activities are all ongoing or planned; on the plastics department, most of the activities have already been implemented or are in progress and hiring technicians for digital transformation is not relevant for the plastic injection department.

4.5.1 Global Assessment

According to IMPULS readiness model on Table 4.3, the plastic injection department has a greater I4.0 readiness obtaining a score of 3.14 and clearly distancing itself from the other departments. The logistics and the board-preparation departments scores are very similar, being 1.91 and 1.84, respectively. The scores were rounded according to the IMPLUS readiness model. Figure 4.1 shows the obtained readiness levels for the department under study, considering each IMPULS dimension. Matching the Table 4.3 with the Figure 4.1 allows to conclude that the weight of 25% of Strategy and Organization dimension is determinant for a higher overall evolution score as the readiness levels of the other dimensions are almost similar.

Table 4.3 - Readiness level of each department.

Activities	Logistics	Board-prep	Plastics
Strategy and Organization	0	1	4
Smart Factory	3	2	3
Smart Operations	2	2	0
Smart Products	1	3	4
Data-driven Services	4	0	3
Employees	3	3	3
$N = \sum_{i=1}^{m} Min(D_i) \times f_i$	1.91	1.84	3.14
Overall Evolution	2	2	3

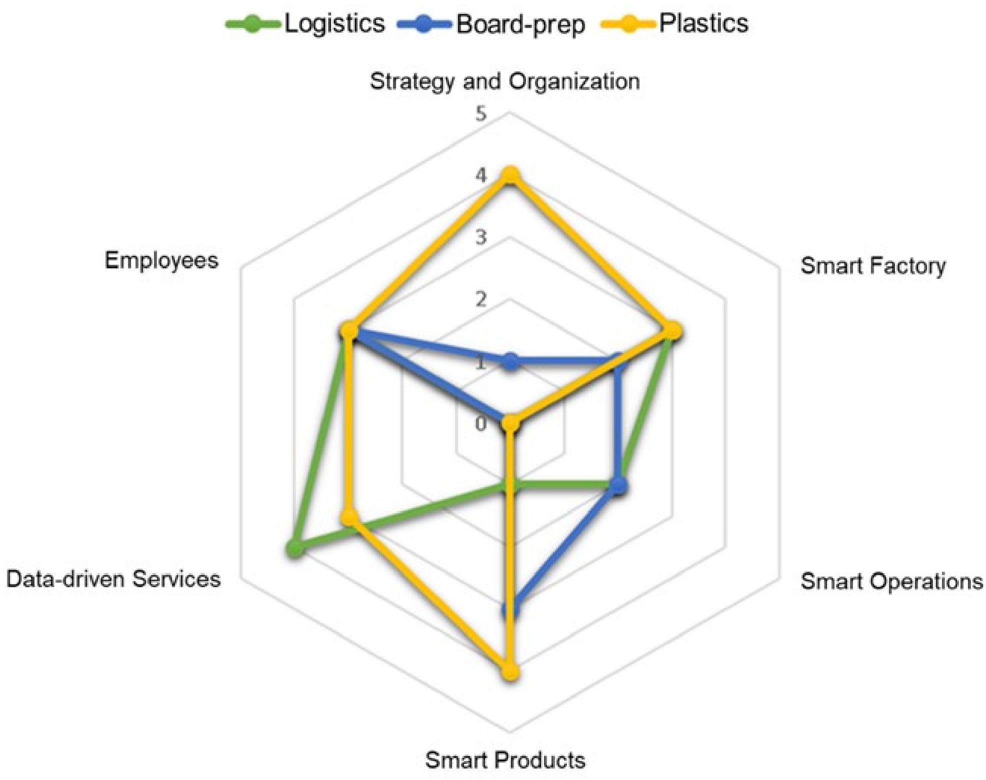


Figure 4.1 - Comparison of all levels.

4.5.2 Improvement Opportunities

The main factors that limit an higher final readiness score on the logistics department are the absence of a defined I4.0 strategy, lack of indicators to monitor the state of implementation, and the lack of I4.0 investment. The lack of more ICT-based functionalities is another relevant factor.

The absence of a defined I4.0 strategy, lack of indicators to monitor the state of implementation, and the lack of I4.0 investment are the main factors that limit a higher final readiness level on the logistics department. Another factor that penalizes the final level on this department, is related to the lack of more ICT-based functionalities. Finally, the least significant factor is related to information sharing with customers and suppliers. The I4.0 implementation strategy, the definition of indicators allowing the monitor of the state of I4.0 strategy development needs to be developed and the start of investment to be carried out at the level of I4.0 are activities related to the same dimension (Strategy and Organization) and were classified as readiness level 0.

On the board-preparation department, the main factor that limits a higher level of readiness is the lack of services based on data collection and the client's integration, since the other departments already implement technologies supporting this functionality. The absence of indicators to monitor the state of I4.0 strategy implementation is another factor with an opportunity to improve increasing the final readiness level. Finally, the fact that the infrastructure features are poorly adaptable and scalable also limits a better final assessment, although it is the field that has the least impact on an opportunity for improvement.

On plastics department, the main factor that does not allow a better final evaluation lies on the fact that the internal information shared between departments is not integrated with the company's central system.

4.6 Concluding Remarks

I4.0 refers on particular to recent technological advances, where its enabling technologies are the foundations for the integration of physical objects, smart machines, production lines, logistics, and processes, thus creating a smart network. Most of the organization's current IT systems are not integrated with its customers and suppliers, nor with its internal departments. I4.0 then expects to establish full integration within an organization and also with its business partners.

With the application of maturity and readiness assessment models, it is possible to measure the current state of a company to guide improvement initiatives and to monitor progress towards a future state. In a case study approach, to answer the RQ3, three department of one company belonging to the Portuguese automotive industry, were analyzed: the logistic, the board-preparation and the plastic injection departments. Data were collected on shop floor to understand the sequence of operations in each analyzed department, as well as, to map the enabling technologies under use. Also, interviews were carried out with managers of three departments to assess each department's readiness level.

On logistics department, the most limiting field for a more positive assessment of technological development level are related in particular to the absence of an I4.0 implementation strategy with its indicators to monitor the development status of a company' future strategy and investments on that direction. Other less significant, but also important factors are the lack of a more varied range of ICT-based functionalities on the products involved on this department and the information sharing with its business partners.

On board-preparation department, the lack of services provision based on data collection presents itself as the field with the most impact as an opportunity for improvement, added to its integration with customers. The lack of indicators to monitor the state of I4.0 strategy development and the low adaptability of functionalities of the current infrastructures are the other fields where there are also opportunities for improvement.

The plastic injection department has the best final evaluation where the real opportunity for improvement is related to the integration of the information shared between the department with the central system of the organization.

The lack of information of the respondents or the relevance (perceived by the respondents) of some questions for the department is an important limitation of this study. This may have led to data bias since some responses given by the respondents may not be representative of the current reality. The IMPULS model was used to study three of the company's departments but in future studies it is possible to use it in all departments. The use of the IMPULS model gives the opportunity to make respondents reflect about how their department technologies and systems are, or should be, integrated and how they can be improved to meet the I4.0 requirements. This fact leads to an important barrier on the adoption of the I4.0 environment placing the human being at the center of this digital transformation, needing to be I4.0 skilled.

5

INDUSTRY 4.0 MATURITY STRATEGIC SCENARIOS FOR 2030

This chapter is built with the use of a version of the peer-review manuscript version submitted as: Alcácer, V., Araújo, F., Tenera, A., Cruz-Machado, V. (2022). Industry 4.0 Strategic Scenarios Development and Risk Mitigation for 2030 in the International Journal of Production Economics.

Summary: Market dynamics have been changing significantly with considerable impacts on business models of industrial companies. To remain competitive, companies are increasingly interested on using Industry 4.0 technologies. However, this transition is especially demanding and costly, so it is essential that companies develop adequate strategic plans. This chapter reviews, analyses and identifies Industry 4.0 implementation major risks, checks companies' risk appetite and develops strategic scenarios, and proposed risk mitigation plans for 2030-time horizon to support companies to adapt their risk management strategies to the most serious identified risks that are arising from the transition to industry 4.0 environment.

5.1 Industry 4.0 Strategic Scenarios

Industry 4.0 (I4.0) makes the interconnection of information, objects and people a reality through the convergence of the physical world and the digital world in the form of cyber-physical systems. These systems enhance the development of vertical, horizontal and end-to-end engineering integration that, as a whole, transform current factories into intelligent environments capable of significantly increasing their productivity and operational efficiencies (Ibarra et al., 2018).

However, the economic value added by implementing I4.0 technologies depends on means and resources that only large companies have access to. Considering that most industrial players are largely small and medium-sized companies, it will be the adaptability and resilience demonstrated by them in the coming decades that will dictate their relevance in national and international markets.

Manufacturing and goods production companies and also stakeholders in Setúbal peninsula region, in Portugal, were surveyed to identify and analyze risks on the implementation of I4.0 technologies on industrial companies' region. These companies are associated to AISET, which the company's participation in this study reveals the interest in the study and results potential add value.

Strategic scenarios play a fundamental role in providing company management with a vision and tools helping on reducing the uncertainty associated with technological development, in order to take full advantage of the opportunities that arise.

The main goal of this study is the elaboration of strategic scenarios and risk mitigation plans as a response to the identification of insufficiencies in the current risk management strategies of companies. In this way, measures are proposed that stakeholders can apply in order to make companies more competitive and create favorable conditions for innovation in the context of I4.0 enabling technologies. Since this study intends to formulate strategic scenarios in relation to the I4.0 enabling technologies adoption, it was relevant to structure the knowledge present in the literature, perform a critical analysis and identify gaps.

5.2 Identifying Strategic Scenarios

The unpredictability that comes from technological development requires, from both companies and public institutions, a high level of flexibility and adaptability. Often, it is these characteristics that dictate the pace of change and evolution of society. So, efforts made to foresee future developments, and consequent implications, to fruitfully plan and performed are considered extremely relevant (Jiang et al., 2017) as success will be greater the sooner, they will be able to identify opportunities and develop appropriate solutions (Gausemeier, et al.,1998).

In the literature, there is no consensus regarding the definition of a scenario. According to Fotr et al. (2015), the diversity of opinions is due to the fact that the authors derive their definitions from different types of scenario types, which will be described later. The researcher carries out an extensive analysis and brings together some of the different perceptions and meanings that the authors share. Schoemaker (1995) interprets a scenario as images of the future developed through the inter-connection of qualitative and quantitative elements. Foster (1993) presents a very similar definition. According to Van der Heijden (2005), scenarios are tools that identify the driving forces of development and their interdependencies, relating them to existing opportunities and risks. An alternative view is presented by Ratcliffe (2000), who describes scenarios as follows:

- Present descriptive reports of different projections in the future;
- Be perceived as auxiliary tools to improve the quality and robustness of strategic decisions;
- Represent vehicles that clarify the quality of current strategies considering a future purpose.

The main objective of forecasting and developing scenarios is the construction of a complete and integrated auxiliary tool that allows understanding the course of future technological events, reducing uncertainty and maximizing the probability of reaching a certain objective (Chen et al., 2020).

The scenario building exercise is, of course, complex and not always rigorous in predicting the future. The development of emerging technology scenarios is accompanied by a high degree of uncertainty that makes traditional forecasting methods less accurate (Jiang et al., 2017; Alizadeh & Soltanisehat, 2020). However, it is the creation of alternative scenarios considering different perspectives, and not the search for the exact forecast, that allows companies to understand and dialogue about all the paths that a technology can follow, stimulating competitiveness and, at the same time, dealing with unpredictability (Gausemeier, et al.,1998).

Börjeson et al. (2006) distinguishes three distinct categories of scenarios: 1) predictive, 2) exploratory and 3) normative, each offering answers to the questions: 1) What will happen? 2) What can happen? and 3) How can a specific objective be achieved?, respectively. In each of the categories, the authors define two types of scenarios, which offer different approaches to the questions raised.

The purpose of predictive scenarios, through probabilities, is to try to predict what events will take place in the future. They are especially useful for decision-makers and managers, as the anticipation of changes in circumstances allows for a more planned line of action. This category includes:

- Forecasts, derive from the events that are most likely to happen. Thus, the scenario resulting from these forecasts will be the one that appears to be the most likely;
- What-if, or conditional scenarios, account for the conditional nature that arises from elements such as external events and internal decisions. Therefore, the conditional scenarios can be described as a set of predictions that presents bifurcations that characterize these same elements.

Exploratory scenarios seek to explore the consequences of events that may take place using a set of scenarios that represent different perspectives and possibilities. They represent an interesting option to analyze the multiple impacts that can arise from alternative events unfolding. Exploratory scenarios include:

- External scenarios focus on factors over which active agents have no control. They allow the creation of resilient strategies, capable of adapting to the development of external factors;
- Strategic scenarios seek to describe the different consequences that can arise from a strategic decision. In contrast to external scenarios, strategic scenarios focus mainly on internal decisions, over which agents have control, always considering the evolution of external factors.

Finally, normative scenarios are used to determine the steps necessary to achieve a future objective, or set of future objectives, while evaluating the probability of occurrence of events (Cho & Daim, 2013). This group of scenarios includes:

- Preserving scenarios are scenarios that objectively seek ways to achieve a certain objective in the most efficient way and used when the defined goal can be achieved with the existing structure;
- Transforming scenarios are constructed when the defined objective does not appear to be attainable given the current development circumstances and present a set of goals that must be achieved for the development trend to change.

The mentioned scenario classification typology - can be synthesized in Figure 5.1. As scenario forecasting and modeling is a challenging exercise, experts believe that some of the available methods can be used complementary to incorporate as many influencing factors as possible (Daim, et al.,2006). Table 5.1 shows a list of techniques used in setting up scenarios.

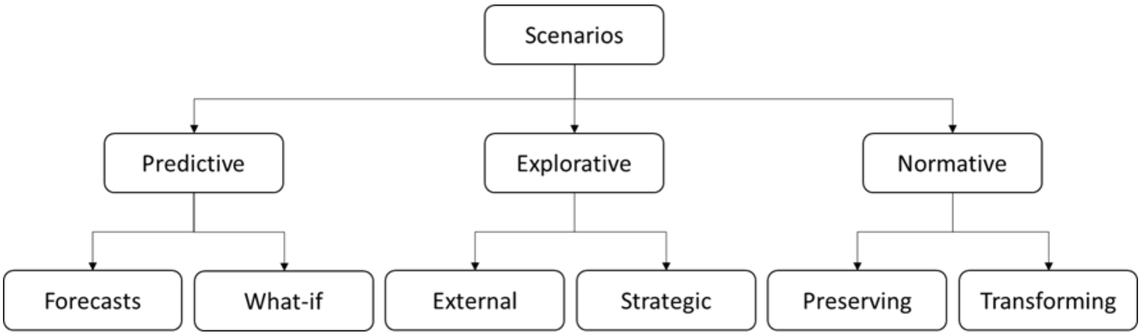


Figure 5.1 - Scenario typology (Börjeson et al., 2006).

Table 5.1 - Tools for scenario forecast (Mishra et al., 2002).

Subjective Methods	Exploratory Methods	Normative Methods
Jury of executive opinion	Scenario Development	OR Models and Simulations
Sales force composite methods	Delphi Analysis	Network Techniques
Formal questionnaires and market analysis	Cross-Impact Matrices	System of Opportunities and Negatives (SOON) charts
Subjective individual probability analyses	Curve fitting	Relevance Tree, Planning Assistance Through Technical Evaluation of Relevance Numbers (PATTERN)
	Comparison methods	Systems dynamics
	Morphological research	Dynamic modelling
	Catastrophe theory	Phenomenological modelling
	Trend extrapolation	
	Simple analytical methods	
	Multi-criteria analysis	
	Game theory	
	Growth models	
	Input-Output Models	
	Contextual mapping	
	Monitoring	
	System for Event Evaluation and Review (SEER)	
	Brainstorming	
	Substitution Analysis	
	Analytic Hierarchy Process	
	Nominal Group Technique	

To assess the existence of strategic scenarios for the adoption of I4.0 enabling technologies, a Systematic Literature Review (SLR) was carried out on available scientific databases were selected. To guarantee the quality of the sample, only "peer reviewed" publications of newspaper or conference articles was selected (Correia et al., 2017). Thus, only "Scopus", "ScienceDirect", "Emerald Insight" and "Web of Science" databases were used. To obtain a relevant sample to follow the study objective, the keywords "strategic scenario", "predicting future scenarios", "predicting scenarios", "industry 4.0", "future scenario" was used with no publication year limit. The search strategy involved counting articles that contained in the title, abstract or keywords, one of the described terms combined with "industry 4.0".

In step 1, conference and newspaper papers, written in English, found through the use of keywords in each defined database were counted as showed in Table 5.2. In a step 2, the results of step 1 were reviewed to check the suitability of the papers to the study objectives in place. According to the keywords and databases used, and articles' complete availability to the researchers very few articles, listed in the articles reference, were found in step 2 that matched the selected search criteria.

To ensure that only relevant articles were analyzed, inclusion and exclusion criteria were applied. Since applying the criteria is a somewhat subjective exercise, Tranfield et al. (2003) suggests that this phase should be performed by more than one researcher. Following this, three researchers performed this phase.

Table 5.2 - Search results for the systematic literature review.

Keywords	*Scopus*	*ScienceDirect*	*Emerald Insight*	*Web of Science*	*Global results*
"*Predicting future scenarios*" *AND* "*Industry 4.0*"	0	5	3	0	8
"*Predicting scenarios*" AND "*Industry 4.0*"	0	3	0	0	3
"*Strategic scenario*" *AND* "*Industry 4.0*"	0	1	2	0	3
"*Future scenario*" AND "*Industry 4.0*"	13	96	29	1	139

Culot et al. (2020) conducted a study in which analyses, from a value chain perspective, and using the Delphi method, the contributions of 76 experts from manufacturing companies and academia to understand their perception of expectations and challenges that the sector may face. In the end, based on the questionnaires' results, 8 scenarios are produced for the state of the manufacturing industry in 2030. For the production of scenarios, 9 dimensions are counted, grouped into 3 sets that allow researchers to build a structured vision of the future. However, the nature of the scenarios created is technological, that is, focused on the operational aspect of the companies, and not on the strategic aspect.

5.3 Proposed Methodology for I4.0 strategic scenarios development

When answering the question "What can happen if we act in a certain way?", strategic scenarios provide a description of the possible range of hypotheticals and conceivable consequences of strategic decisions. More specifically, they describe how the consequences of a decision can vary depending on the course of future events, being quite relevant for decision-makers and for the inspiration and vision of stakeholders. Stakeholders or interested parties are all agents or individuals who are negatively or positively affected by the decisions of a company or organization. They are qualitative and quantitative, usually in the long term and the focus is on internal decisions, over which agents have control, but always considering the influence of external factors (Börjeson et al., 2006).

The lack of consensus in the literature regarding the definition of a scenario was mentioned. Spaniol et al. (2018) shows that the aforementioned disharmony is more extensive when describing the development of scenarios as a "methodological chaos" that, according to Bradfield et al. (2005), is verified due to the abundance of different definitions, sometimes contradictory, of characteristics and methodologies. This fact implies an analysis of the scenario's construction processes present in the literature so that the choice falls on the most appropriate methodology.

A generic scenario construction follows a process, with several steps to be performed, which can be applied at a company or group of companies' level. In Table 5.3, the scenario construction methodologies of five different authors can be consulted, the way in which each one of them defines the scenario concept and the objective of each one of the studies. Thus, Table 5.3 allows to check the existing similarities and common steps in several identified scenario development methodologies, in which it can be noted that only Zahradníčková & Vacík (2014), in 2013, mentions the construction of strategic scenarios as the objective of their investigation. So, given this research study objectives, the proposed study methodology will incorporate steps from Zahradníčková & Vacík (2014), namely: identification of risk factors, selection of key risks and scenario analysis to verify their agreement with the strategic objectives. Nevertheless, this proposed methodology showed in Figure 5.2 leads to the development of strategic scenarios allowing the critical analysis and the development of risk mitigations plans.

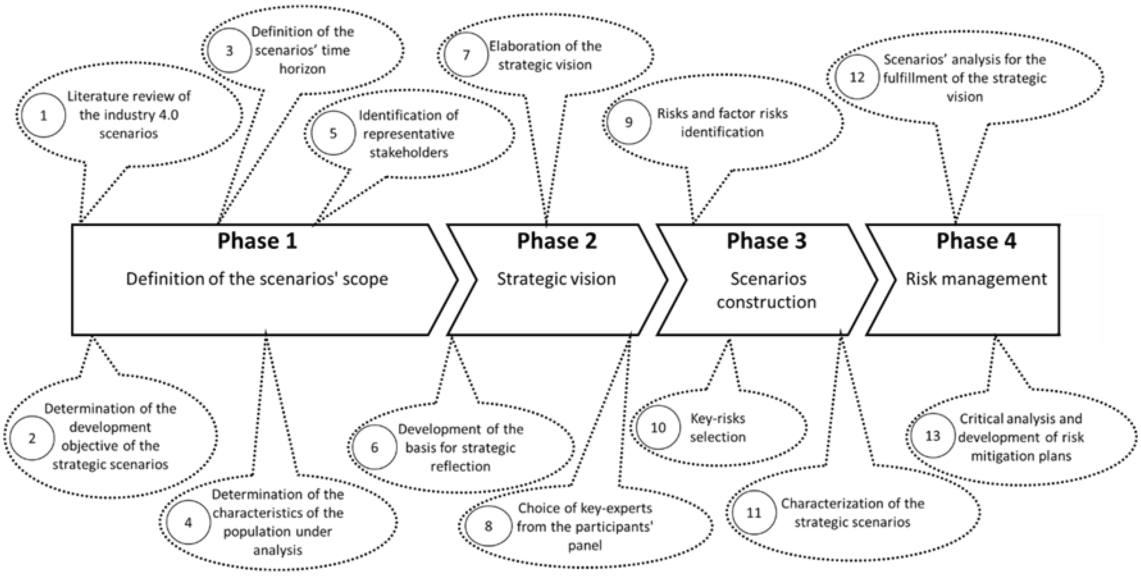


Figure 5.2 - Development process of strategic scenarios.

5.4 Development of Strategic Scenarios

The following strategic scenarios were developed intended to provide an image of the greatest risks and opportunities presented to industrial companies, in structuring adequate and resilient strategic plan, supported by effective and informed risk management plans to mitigate plans, to create favorable conditions for innovation in the context of I4.0 technologies.

5.4.1 Definition of the Scenarios' Scope

The initial phase to strategic scenarios construction is defining their scope. It is necessary to classify the objectives and purpose that motivate the creation of scenarios (Fotr et al., 2015). In this stage, authors often use a set of comprehensive questions that incorporate the relevant elements to be considered when defining the scope (Liu et al., 2008; Alizadeh et al., 2016). Thus, three questions were formulated:

- What is the purpose of developing strategic scenarios?
- What is the time frame of the planning process?
- What is the strategic level of analysis considered?

Table 5.3 - Scenario construction methodologies.

Author	Liu *et al.* (2008) (2008)	Fotr *et al.* (2015) (2008)	Mazzarino (2012) (2012)	(Zahradníčková & Vacík, 2014) (2013)	Jiang *et al.* (2017) (2017)
Objective	Development of scenarios for the study of environmental impacts.	Description of the concept, methodology and application of scenario building as a risk mitigation methodology.	Development of scenarios for evaluating the European logistics sector.	Provide a methodology for building strategic scenarios supported by risk management.	Forecast of social and economic impacts in 2030 resulting from the development of additive manufacturing.
Definition	A coherent and plausible way of describing the future of the world. A scenario does not represent an exact prediction, but an alternative of how the future can develop.	N/A	N/A	It illustrates the development of a certain agent through the collection and structuring of qualitative and quantitative elements.	N/A

Table 5.3 - Scenario construction methodologies (continuation).

Author	Liu *et al.* (2008) (2008)	Fotr *et al.* (2015) (2008)	Mazzarino (2012) (2012)	(Zahradníčková & Vacík, 2014) (2013)	Jiang *et al.* (2017) (2017)
Methodology	1) Setting the scenario; 2) Scenario construction; 3) Scenario analysis; 4) Scenario assessment; 5) Risk management.	1) Choice of participants; 2) Determination of driving; forces and future events; 3) Scenario construction and validation of its consistency.	1) Identification of the key drivers of change; 2) Defining the relationships between the driving forces in order to create a coherent frame of reference; 3) Analysis of the individual impacts of each identified driving force; 4) Conjugation of the different driving forces to produce preliminary scenarios; 5) Definition of scenarios that share the greatest support from experts.	1) Risk factors identification and assessment of their significance; 2) Choice of key risks that influence the achievement of objectives; 3) Formulation of base scenarios and validation of their consistency; 4) Deduction of the probabilities of occurrence of the defined scenarios; 5) Analysis of scenarios to verify their agreement with the strategic objectives; 6) Base scenario construction for the development of a strategic plan.	1) Formulation of projections about the future of the object under study; 2) Selection of the most relevant projections: 3) Construction of scenarios.

In the present phase, representative stakeholders are selected who had collaborated and provide information for the vision elaboration.
The development of the present strategic scenarios is intended to help companies producing goods, manufacturing and metalworking in the Setúbal peninsula region in managing their risk in the transition to the I4.0 paradigm.

5.4.1.1 Development Objective of the Strategic Scenarios

The objectives for the development of strategic scenarios are defined. The definition of a relevant purpose needs to consider issues and results that will produce value for companies in the future (Schoemaker, 1995). The major trends or uncertainties that predict significant impacts on the health of a particular business sector or region are identified. Considering these factors in the definition of objectives for the development of strategic scenarios, the present study focuses on companies producing goods production and manufacturing companies on the region of Setúbal with the purpose of providing assistance on managing the risk of I4.0 transition process.
The main objective is to inform companies about how the impacts arising from the risks and risk factors present in the market may affect their operations and business models, exposing the consequences that may arise from their strategic decisions.

5.4.1.2 Scenarios' Time Horizon

It is necessary to consider the predictability and information about future events that may affect the scenarios. The longer the time horizon chosen, the greater the difficulty in predicting new factors or future events that cannot be adequately evaluated in the present (Kosow & Gaßner, 2008). Considering this long-term unpredictability, the time horizon defined was the year 2030, considering the strategic importance that the financial resources that will be made available by the Portugal 2030 program and the recovery and resilience program (RRP) added to this decade.
The Portuguese incentive system works through an agreement between Portugal and the European Commission for the receipt of funds from the European Union (EU) to achieve the development of the country according to principles that enshrine Portugal's economic, social and territorial development policy (Portugal 2020, n.d.). The Portugal 2030 program is ongoing, which defines the strategy for the application of European funds in the 2030 horizon. This program started in 2021 has a deadline for the execution of the funds until 2029. Additionally, until 2023, the funds still need to be spent of Portugal 2020. Of the eight axes defined for the

application of European funds, there are three that deserve special attention (República Portuguesa (a)):

- Innovation and knowledge, to ensure the conditions of business competitiveness;
- Qualification, training and employment, to ensure the availability of qualified human re-sources;
- Energy and climate change, to reduce energy dependence and adapt territories to climate change.

At the same time, to stimulate recovery and mitigate the serious impacts felt on the economy and society due to the Covid-19 pandemic, it was prepared in a unique and unprecedented process in the History of the European Union, the Resilience Recovery Plan (PRR). This document develops a strategic vision, reforms and structuring investments to be implemented before 2026 in the European Community member states, to ensure an exit from the pandemic crisis and guarantee a resilient future for Portugal. These investments are grouped into three major dimensions (Recuperar Portugal, República Portuguesa (b)):

- Resilience: This dimension considers nine components that include interventions in strategic areas such as health, housing, social responses, culture, innovative business in-vestment, qualifications and skills, infrastructure, forest and water management;
- Climate Transition: Result of the commitment to achieve carbon neutrality goals by 2050. It considers six components: the sea, sustainable mobility, decarbonization of industry, bioeconomy, energy efficiency in buildings and renewable energies;
- Digital Transition: This dimension involves investments and planned reforms in the digitization of companies, the state and the provision of digital skills in education, health, culture and forest management. It is based on five components: empowerment and digital inclusion of people through education, training in digital skills and promotion of digital literacy, digital transformation of the business sector and digitalization of the State.

An analysis of the three axes of Portugal 2030 and the dimensions and components that characterize the PRR shows that Portugal and the EU are making efforts to ensure that the strategic decisions of this decade result in sustainable development, with a focus on strategic sectors and the updating of the industry. In this sense, it is possible to understand that part of the resources is allocated to mitigate the obstacles posed to companies by the barriers to the I4.0 adoption, described in Alcácer et al. (2021). The need for large investments, the lack of workers' skills, the need for training and the lack of human resources stands out. 2030 marks the end of the decade that benefited not only from Portugal 2030 incentives, but also from the PRR. Thus, the year 2030 was defined as the time horizon for the strategic scenarios developed.

5.4.1.3 Characteristics of the Population Under Analysis

The population under analysis was the industrial companies in the region of the Setúbal peninsula that are part of the sectors of production of goods and manufacturing. At this stage of the methodological proposal, the region of the Setúbal peninsula will be characterized in terms of its area, population, the economic activities of companies. This region is considered strategic for the location of industries in Portugal due to accessibility, the existence of faculties and educational institutions related to engineering and management, the available seaports and the proximity to Lisbon and its airport (AISET, n.d.(a)).

With the aim of improving conditions in the region and making it more attractive for companies and for new investments, in 2014, AISET was created, as an active voice that seeks to create representation for the industrial companies of the Setubal peninsula, which incorporates 55 associated companies. Companies of different sizes are present in this association, from micro to large companies (AISET, n.d.(b); SICAE, n.d.).

The main higher education institutions in the region are the Faculty of Sciences and Technologies of Universidade Nova de Lisboa (FCT NOVA) and the Polytechnic Institute of Setúbal (IPS). Both higher education institutions have partnerships and encourage initiatives to foster close contact with companies.

5.4.1.4 Representative Stakeholders

The representative stakeholders were identified who had the role of, together, elaborated a vision of what will be the state of development of the Setúbal peninsula by 2030. These was selected through criteria that seek to include specialists with leadership positions linked to the strategic management of companies in the region and researchers with knowledge in the area. This step was extremely important since the success of the strategic scenario development process depends mainly on the selected representative stakeholder panel since the quality of the results obtained is directly related to the contributions of the chosen specialists.

Considering that it seeks to define a vision of what will be the future trends and developments, in the region of the Setúbal peninsula, in relation to I4.0, it is pertinent to establish criteria that lead to the inclusion of specialists who occupy leadership positions in companies, in business associations, in higher education institutions or of researchers with knowledge in the area. Given this need, criteria were created for professionals in companies or associations and for researchers in higher education. To be eligible, professionals from companies or associations would have the following requirements: 1) to hold top management positions in companies or associations of companies in the region of the Setúbal peninsula and 2) whose businesses are part of the goods production and manufacturing. Regarding researchers, those who: 1) are part of higher education institutions or in partner research institutions located in the region of the Setúbal peninsula or surroundings and 2) whose experience or research demonstrates extensive knowledge of the subject of I4.0 or whose projects have connections to the industries of the Setúbal peninsula. Using researchers' knowledge and contact networks, companies, associations or people who fit the defined criteria were invited via e-mail. The eight invitations made to participate in the panel began to be sent on 06/17/2021 and the last one was sent on 07/09/21. All individual contacts received a positive response. The profile of each stakeholder, showed in Table 5.4 is described as follows:

- The industrial sector (in the case of a professional);
- The area of investigation (in the case of an investigator);
- The position of each specialist in your company or institution;
- The main economic activity of the company in which it operates (in the case of a professional).

Table 5.4 - Panel of representative stakeholders.

Stakeholder	Investigation area / Sector	Role	Principal Economic activity
Respondent 1	Non applicable	AISET executive administrator	Non applicable
Respondent 2	Department of Information Systems and Technologies	Coordinator of Industry 4.0 shop	Non applicable
Respondent 3	Research Unit in Mechanical and Industrial Engineering	Science and Technology Faculty Dean	Non applicable
Respondent 4	Engineering and Telecommunications Industry	Responsible for the Finance and Human Resources Department	Engineering activities and related techniques
Respondent 5	Graphic Arts Industry	Executive director	Printing and reproduction of recorded media: another impression
Respondent 6	Mechanical Technology and Industrial Management	Associate Professor	Non applicable
Respondent 7	Industrial startups	Former Chairman of the Board of Directors	Other associative activities
Respondent 8	Technology information	Commercial director	IT consulting activities

5.4.2 Strategic Vision

The main purpose of this phase is the elaboration of the strategic vision for the considered 2030-time horizon. This vision was built through a tree-step procedure: 1) the development of a base of strategic reflection that aims to provide a basis for discussion with stakeholders, 2) a stage of collecting information that allows gathering data so that, in 3) the strategic vision can be elaborated using a content analysis.

The developed basis for strategic reflection has as central themes the I4.0 enabling technologies and the definition of maturity. Considering the limitations imposed by the covid-19 pandemic, which forced remote interviews to be carried out, the format chosen for carrying out the strategic reflection base was PowerPoint presentation. In this way, a document was prepared in a format that was presented to stakeholders before they gave their opinions in order to provide contextualization on the subject under analysis.

5.4.2.1 Basis for the Strategic Reflection

In Alcácer et al. (2021) is mentioned the main barriers for organizations in the process of I4.0 implementation. This highlights the importance of a step that contextualizes the stakeholders considering the complexity of the I4.0 concept. Therefore, a basis for strategic reflection was created, whose main objective is to provide a framework for the I4.0 topic and establish an objective discussion structure for the collection of the panel's opinions regarding its vision for 2030 of I4.0 in Setubal peninsula.

The basis for proposed strategic reflection addressed: the I4.0 concept, the main enabling technologies and the concept of maturity in the context of I4.0, in line with the needs and structure of the information collection to be retrieved from the stakeholder panel.

Since I4.0 maturity context is a vague concept and something complex to define, it was necessary to establish a more objective structure that allowed focusing the questions on common characteristics that, as a whole, define maturity. Schumacher et al. (2016) describes maturity as the external or internal conditions that condition the development of vertical, horizontal and end-to-end engineering integration. Given this definition, stakeholders were asked about their opinion of the state of each of the integrations (vertical, horizontal and end-to-end engineering) on the Setubal peninsula in the year 2030. This presentation lasted an average of 15 minutes and used for the stakeholder interview.

5.4.2.2 Key-Experts from the Participants' Panel to the Strategic Vision

Once the panel of representative stakeholders has been established and a basis for strategic reflection has been developed, the next step was data collection. For this stage, it was necessary to reflect on the type of data to be collected, quantitative or qualitative, and on the methods that were used.

For the process of elaborating the vision it was considered that the collection of qualitative elements would be more appropriate. This choice is mainly due to the freedom that a qualitative approach offers to participants to share their experiences and develop visions without being influenced or limited by more limited quantitative techniques. However, according to Saunders et al. (2009), the fact that non-numerical elements can have several meanings, as well as unclear concepts, make it necessary to explore and clarify the participants on the study purposes and main concepts. So, to support this qualitative data collection requirement the strategic-based reflection elaborated in the previous subsection was here used.

Considering the collection of qualitative elements, an open question was initially asked to stakeholders that, depending on the participant, will or will not be followed by other questions that allow reaching the panel's vision of the I4.0 maturity in the region of the Setúbal peninsula in 2030. In this way, the interviews were semi-structured.

The iterative nature of the process, the lack of availability of stakeholders and the limitations imposed by the Covid-19 pandemic, remote interviews were carried out via Zoom or Microsoft Teams, between 06/24/2021 and 07/27/2021 and had an average duration of 47 minutes, which includes the presentation of the strategic basis for reflection. Interviews were carried out with each participant of the panel in which two researchers were present. One of the researchers was in charge of presenting the strategic reflection and asking the questions, while the second was in charge of taking the minutes with the objective to understand the vision that different stakeholders have regarding the state of development in 2030 of vertical, horizontal and end-to-end engineering integration.

5.4.2.3 Elaboration of the Strategic vision

The stakeholders' contributions regarding their opinion of the I4.0 maturity in the Setúbal peninsula by 2030 were analyzed and the panel's vision was extracted. This stage was divided into two phases: 1) the opinions of stakeholders were first verified using content critical analysis; and in 2) the retrieved results were analyzed and a vision of maturity for 2030 was drawn up.

Considering the qualitative nature of the data collected from the panel, the use of content analysis was proposed to proceed with its treatment, consisting on the analysis of the available qualitative data in order to highlight similarities, differences or patterns that can be identified in the retrieved responses establishing relations in order to draw identified conclusions (Graneheim et al., 2017).

A critical analysis of the results of the content analysis allowed the extraction and construction of the panel's global vision regarding its vision of what will be the I4.0 maturity in the Setubal peninsula by 2030.

In addition to defining the vision for 2030, a characterization of the current I4.0 maturity in the region under analysis was made. This drawing of the current situation in the industry is essential to understand what state of implementation organizations are in and to measure the progress that needs to be made to achieve the vision shared by the panel.

Table 5.5 shows the extracted aggregate opinion of the stakeholders' regarding the state in 2030 of the three types of integration (horizontal, vertical and end-to-end engineering).

The stakeholders' opinions gathered in the interviews carried out with the stakeholders aware cataloged and grouped according to the levels of conviction that was reflected on the existence of the three types of integration in 2030.

In horizontal integration, the first level of conviction, with three responses (2, 4 and 6), is the most optimistic. These three stakeholders considered that by 2030 "horizontal integration will be implemented between companies in the same value chain". At the second level also three stakeholders (3, 5 and 8) believed that horizontal integration is conditioned by the development of technologies such as 5G, artificial intelligence and cybersecurity. These stakeholders showed confidence that horizontal integration will be achieved with the development of the mentioned technologies. In the third level one stakeholder (7) revealed that horizontal integration will be facilitated, since SMEs will be forced to enter this ecosystem so as not to lose their customers. Finally, one of the stakeholders (1) stated that "companies will not be integrated with each other", expressing his pessimistic position regarding the existence of this type of integration in 2030.

Table 5.5 - Opinions from the stakeholders.

Maturity	Response
Vertical integration	1) "Vertical integration will be under development and will be greater or lesser according to the dictates of competition and the market where each company is inserted."
	2) "Companies will be fully vertically integrated, medium-sized companies will follow the growth of vertical integration and small companies will be in survival mode, in which some, through their renewal, will be able to keep up with the challenges of industry 4.0."
	3) "The companies' production systems will be interconnected with communication systems in which all CPPS will be interoperable."
	4) "Companies will be vertically integrated with data acquisition systems, machines, using the cloud and with production management systems, with ERPs."
	5) "The vertical integration of companies will have digitized processes/RPA, IoT-based sensing and data analytics, connected in the cloud."
	6) "Companies will be developed in terms of internal communication between all elements and interconnected with each other."
	7) "Medium and large companies will be vertically integrated with ERP systems. Small companies may not be vertically integrated and tend to hardly be able to react to the dynamism of demand, however, there may be some companies that may have vertical integration informal organizations that meet the objectives of vertical integration."
	8) "Companies will not yet be vertically integrated in their entirety, so the technologies and their advantages will still be under analysis."
Horizontal integration	1) "Companies will not yet be integrated with each other, that is, horizontal integration will not exist."
	2) "Horizontal integration will be implemented between companies in the same value chain and reinforcing this value with the knowledge that resides in space."
	3) "Integration will be achieved as a result of vertical integration and for ease and speed in reducing and minimizing errors in communications between companies."
	4) "Horizontal integration will be more significant in relationships with companies that have more impact on the company's business."
	5) "Horizontal integration will be facilitated downstream using electronic commerce and upstream with integration of the logistics chain and should be enhanced through artificial intelligence and cybersecurity."
	6) "Companies will be horizontally integrated between all elements of the value chain."
	7) "Horizontal integration will be simpler as customers will push medium and small companies to integrate horizontally with the risk of ceasing to be suppliers of their usual suppliers."
	8) "Horizontal integration will be more advanced due to new 5G technology."
End-to-end engineering integration	1) "Most companies will not yet be linked together through end-to-end engineering integration."
	2) No opinion.
	3) "Companies will be integrated in end-to-end engineering in sharing data due to the needs of technological dependencies and as a result of strategic partnerships."
	4) "The product life cycle, in the traditional sectors of the Setúbal region, will preferably be integrated between partner organizations with a high degree of strategic synergy."
	5) "End-to-end engineering will be leveraged via virtual design and the circular economy, contributing to the sustainability of the value chain."
	6) "End-to-end engineering integration will be integrated across all product lifecycle stakeholders."
	7) "In end-to-end engineering integration, the most expensive equipment (products in which the investment justifies the double investment) for the customer tends to be smart products."
	8) "The product life cycle will be shorter making companies communicate more."

In vertical integration, at the first level, with five responses (2, 3, 4, 5 and 6), stakeholders are optimistic, declaring that “companies will be fully vertically integrated”. In the second level one stakeholder (7) is confident in the existence of vertical integration but distinguishes its nature between different dimensions of the company, that is, in small companies it will be a more informal integration, since, for these, the investments may be too large given the opportunity they present. At the third and last level of conviction, one stakeholder (1) revealed doubts in the existence of vertical integration, not providing a concrete answer on the possible scenario for 2030 and other (8) was pessimistic considering that companies will not be fully vertically integrated and that many of the solutions available for this purpose are still under analysis.
Considering the categorization carried out regarding vertical integration, the following conclusions were reached:

- 62.5% of stakeholders believe that in 2030 there will be vertical integration;
- 12.5% are optimistic, but refer to informal vertical integration for small companies;
- 12.5% are not able to conclude on the existence of vertical integration, choosing to take a neutral position;
- 12.5% do not believe that companies will be vertically integrated in 2030.

The majority of the panel was optimistic about the availability of the vertical integration development in the Setúbal peninsula region by 2030.
The panel showed some confidence in the existence of horizontal integration. Due to the observed frequency of responses in each of the levels of conviction, the global response considered that there will be horizontal integration in the region of the Setubal peninsula in 2030. Regarding the horizontal integration, the analysis results revealed that:

- 37.5% of stakeholders believe that in 2030 there will be horizontal integration;
- 37.5% of respondents condition horizontal integration with the maturity of underlying technologies. They simultaneously show optimism in their development;
- 12.5% believe that companies will be forced to integrate horizontally, but are not sure whether integration will be achieved or not in 2030;
- 12.5% do not believe in the existence of horizontal integration in 2030.

In end-to-end engineering integration, a lower dispersion of responses was revealed and, therefore, a lower number of levels of conviction was here used. At the first level, 6 stakeholders (3, 4, 5, 6, 7 and 8) shown a high level of confidence in the development of this type of integration, referring, for example, that “end-to-end engineering integration will be integrated among all the players in the product life cycle”. One of the stakeholders (2) did not provide an answer regarding their forecast for 2030. Finally, the last stakeholder (1) believed that “most companies will not yet be linked together through end-to-end engineering integration". Regarding end-to-end engineering, the panel's responses revealed that:

- 75% of stakeholders believe that by 2030 there will be end-to-end engineering integration;
- 12.5% do not offer an outlook for the development of end-to-end engineering integration by 2030;
- 12.5% do not believe in the existence of end-to-end engineering integration in 2030.

The dominant opinion within the panel is of trust in end-to-end engineering and the overall response considered that there will be end-to-end integration in the companies of the Setubal peninsula in the year 2030.

So, prom this results the strategic vision retrieved indicates that the three types of integration (vertical, horizontal and end-to-end) can be implemented in 2030 on the Setubal peninsula.

5.4.3 Scenarios' Construction

This phase aimed to formulate scenarios and all the collection, quantification and testing of elements that the process requires. It is pertinent to introduce brief notions about the risk and the used tools. There are different approaches and definitions of risk. Knight (1921) defines risk as events whose probability of occurrence can be calculated as opposed to the uncertainty of events in which their analysis is impossible since their occurrence does not follow an apparent pattern. Frost et al. (2000) defines risks as uncertain future events that influence the achievement of an organization's objectives. Many definitions see risk as a threat to the organization's health, affecting the achievement of their strategic objectives and the satisfaction of stakeholders. Risks can be generally characterized through two attributes as follows (Jallow, et al., 2007):

- Impact – the consequence of the realization of the risk related to the process;
- Probability – the relative chance that the event will happen.

Risk factors, or risk categories, are the causes for the occurrence of risk and can be of external or internal nature to an organization, which means that the identification of events must incorporate these two environments. The identification of these events must be differentiated in terms of negative aspects (risks) and positive aspects (opportunities) (Jallow, et al., 2007). Given this, the SWOT analysis is one of the proposed strategic tools that can be used to support risk identification (Gurl, 2017). So, using the literature review done and associated critical analysis, the risks and risk factors for the adoption of I4.0 technologies were identified and, later, categorized according to a SWOT analysis.

5.4.3.1 Key-Experts from the Participants' Panel to the Risks

After risk identification key companies' experts were used to check, revise and evaluate the list of identified risks and risk factors that positively or negatively could affect the transition to I4.0 and access each potential risk impact on the industry operations, covered by professionals' specialists or researchers with experience or knowledge in the companies' daily operations.

The requirements for choosing professionals were: 1) holders of positions in companies or associations in the region of the Setúbal peninsula and 2) whose businesses fit into the goods' production and manufacturing companies. For the selection of researchers, the requirements were: 1) that the researcher is inserted in higher education institutions on the Setubal peninsula or surroundings and 2) whose experience or research shows in-depth knowledge of operations management or whose research projects have links to the industries on the Setubal peninsula. Invitations to participate in the expert panel were then sent between 01/07/2021 and 22/07/2021. From the 27 collaboration requests sent, 15 have been accepted. Table 5.6 shows key-experts panel profiles.

Table 5.6 - Key-experts panel.

Specialist	Investigation area / Sector	Role	Principal Economic activity
Respondent 1	Metallurgical industry	Operations director	Steel and alloy steel manufacturing
Respondent 2	Engineering and telecommunications industry	Responsible for the finance and human resources department	Engineering activities and related techniques
Respondent 3	Graphic arts industry	Executive director	Printing and reproduction of recorded media: other printing
Respondent 4	Metallic industry	General director	Manufacture of metal construction structures
Respondent 5	Pulp and paper industry	Process improvement specialist	Pulp manufacturing
Respondent 6	Paints and coatings industry	Supply chain Manager	Manufacture of inks (except printing), varnishes, mastics and similar products
Respondent 7	Ceramic industry	Managing partner	Brick manufacture

Table 5.6 - Key-experts panel (continuation).

Specialist	Investigation area / Sector	Role	Principal Economic activity
Respondent 8	Automotive components industry	Plant manager	Manufacture of other components and accessories for motor vehicles
Respondent 9	Digital transformation	Coordinator	Non applicable
Respondent 10	Metallic industry	Product manager	Manufacture of metal construction structures
Respondent 11	Mechanical technology and Industrial Management	Associated professor	Non applicable
Respondent 12	Manufacturing industry	Senior Vice President Operations and Supply Chain	Electronic automotive components
Respondent 13	Mechanical industry	IT manager	Metallic automotive components
Respondent 14	Mechanical industry	Commercial director	Metallic structures
Respondent 15	Manufacturing industry	Maintenance director	Wine manufacturing

5.4.3.2 Risks and Risk Factors

The process of identify risks and risk factors has a considerable influence on the strategic basis since the quality of the scenarios is dependent on the quality of the collected information (Zahradníčková & Vacík, 2014), which was here achieved by the SLR performed and associated content analysis. Two aspects were found: 1) related to the number of articles that effectively discriminate against risks and risk factors in I4.0, and 2) related to the fact that risk and risk factor were distinguished. Although there are plenty of publications that mention the terms "risk" or "risk factors", showing that researchers recognize and are aware of their existence, very few characterized and describe them in detail. From the keyword search string on "risk factors" and "industry 4.0" six articles were found specially relevant.

Moeuf et al. (2020) described the factors that determine the success, the risks and the challenges faced when implementing I4.0, focusing on the industrial performance of SMEs, mentioning the lack of qualified labor, the possibility of perceiving I4.0 as a means of increasing vigilance and short-term strategy and vision. Finally, technological obsolescence was also mentioned as a financial risk factor.

Birkel et al. (2019) drawed an extensive list of risks in the context of I4.0. In addition to those already mentioned by other authors, risks related to the difficulty of understanding new business models, increased competition, internal resistance, organizational culture, its transformation, interoperability and the technical complexity of the industry are mentioned. Regarding the workforce, the researchers reinforce the increase in costs, the change in skills, the lack of qualified personnel, adding the need for new training requirements due to the increasing level of automation. Additionally, risks are raised in the area of sustainability due to the industrial transformation that could lead to the change of machines and the consumption of more resources. Concerning the financial aspect, concerns about the uncertain return on investments and the possibility of false investments are mentioned, due to the difficulty in forecasting the evolution of I4.0. There are concerns regarding data protection, the growing legal complexity, the reliability and existence of network infrastructures and the maturity of technologies.

Sanchez (2019) conducted an exploratory analysis of the main challenges and risks that may arise with the implementation of I4.0 and mentions as main risks the need for more qualified and, consequently, better paid labor and the disappearance of certain positions, a factor that may contribute to a more accentuated social fragmentation. Additionally, mentions the difficulty of companies in adapting to new methods, the fact that some companies are late in the implementation and, on a financial level, the risk of technological obsolescence.

Tupa et al. (2017) seeked to develop a risk management system suited to the new risks arising from I4.0 processes, listening two risks that they consider relevant. The first, related to cybersecurity, addresses the risk of loss of sensitive information, and the second, regarding labor, refers to the lack of qualified workers.

Macurová et al. (2017) used the literature and industrial companies from the Czech Republic in an effort to identify the driving forces, risks and main barriers of I4.0, pointed out: the lack of workers with the necessary qualifications, the unstable demand, the more demanding requirements of product individualization and the increased pressure due to competition.

Niesen et al. (2016) study aimed the conceptualization of a risk management structure for data from I4.0 processes. The risks pointed out were mainly related to cybersecurity, including industrial espionage, using computer attacks to steal vital business information and sabotage, manipulating and/or destroying production systems, and technical failures that can occur due to unforeseen behavior or defects in factory hardware or software.

Table 5.7 shows the Risks (R) identified in the literature and grouped by Risk Factors (RF), which represent the proposed risk categories. After risk identification conditions were met to carry out a SWOT analysis which was performed, within brainstorm sessions (June 18 and 30, 2021) between researchers to reflect on identified risks and associated categorization as well as classify them on the type of influence (external, internal, positive or negative) that risks may have on organizations in the process of I4.0 transition. Moreover, this interview using the panel of key-experts was used with two objectives:

1) In the process of checking and validating the proposed risks and risk factors identification, categorization and the SWOT analysis carried out. The panel of key-experts was interviewed and surveyed with two objectives' analysis validation, risks, risk factors and collection of ideas and suggestions to complement the initial list of risks and risk factors;
2) Assessment of each identified risks according to three parameters: occurrence level, impact level and risk appetite.

The experts, from risk factor to risk factor, were asked about the identified risks, whether they agreed on their existence, their classification in the SWOT and invited to evaluate according to the three risk parameters. Before moving on to the next risk factor, survey respondents could suggest the same risks with other categories of the SWOT analysis, which they considered more appropriate, or new risks not previously identified. These risks were added and also evaluated according to risk metrics. Since the availability of specialists made it impossible to repeat interviews, the risks suggested by a given respondent were only assessed by him/her and by the respondents of the remaining interviews. For the remaining ones who did not respond, a null response was considered, assuming that they do not recognize the suggested risks. In addition to the two typical attributes that defines the risk (occurrence level, impact level), the risk appetite of each was also assessed.

Risk appetite is defined as the level of risk that an organization is willing to accept in the pursuit of its objectives before any action is determined to be necessary to reduce it (Oliveira et al., 2019). This dimension was included due to the information it offers regarding the perception and notion that a particular company has of a risk. A reduced risk appetite leads to greater control by companies, given the low tolerance for a given risk. On the other hand, a higher risk appetite leads to the acceptance of the risk before taking any action to minimize it assuming that companies will have risk capacity to face those risks.

Table 5.7 - Risks and risk factors identified in the literature.

Risk factor	Risks	References
RF1. Cybersecurity	R1. loss of sensitive information	(Sanchez, 2019; Tupa et al., 2017; Niesen et al.,2016; Birkel et al., 2019)
	R2. Industrial espionage	(Niesen et al., 2016)
	R3. Industrial sabotage	(Sanchez, 2019; Niesen et al., 2016)
RF2. Labor	R4. Disappearance of jobs	(Sanchez, 2019; Birkel et al., 2019)
	R5. Lack of skilled labor	(Sanchez, 2019; Tupa et al., 2017; Moeuf et al., 2020; Birkel et al., 2019; Macurová et al., 2017)
	R6. New training requirements	(Birkel et al., 2019)
	R7. Perception of I4.0 as increased surveillance	(Moeuf et al., 2020)
RF3. Competition	R8. Emergence of new competitors	(Birkel et al., 2019; Macurová et al., 2017)
RF4. Organizational structure	R9. Lack of long-term strategy	(Moeuf et al., 2020)
	R10. Resistance and organizational culture	(Sanchez, 2019; Birkel et al., 2019)
	R11. Difficulties in implementing I4.0	(Sanchez, 2019)
RF5. Infrastructure	R12. Infrastructure reliability	(Niesen et al., 2016; Birkel et al., 2019)
	R13. Technological maturity	(Birkel et al., 2019)
	R14. Existence of network infrastructures	(Birkel et al., 2019)
	R15. Interoperability	(Birkel et al., 2019)
RF6. Legal	R16. Data protection	(Birkel et al., 2019)
	R17. Growing legal complexity	(Birkel et al., 2019)
FR7. Sustainability	R18. Waste	(Birkel et al., 2019)
RF8. New business models and market conditions	R19. Demand instability	(Macurová et al., 2017)
	R20. More demanding product individualization requirements	(Macurová et al., 2017)
	R21. Knowledge of data-driven business model	(Birkel et al., 2019)
RF9. Financial	R22. Technological obsolescence	(Sanchez, 2019; Moeuf et al., 2020)
	R23. Inefficient investments	(Birkel et al., 2019)
	R24. Labor cost	(Sanchez, 2019; Birkel et al., 2019)
	R25. Uncertain return on investment	(Sanchez, 2019; Birkel et al., 2019)

To assess the occurrence level and the impact level, a 6-point Likert scale was proposed (1- Very low; 2- Low; 3- Some, something reduced; 4- Some, something elevated; 5- High; 6- Very high) and for risk appetite the same scale was used. In choosing the proposed Likert scale, it was necessary to consider: the size of the scale, whether or not it is odd and the meaning of each level. The most frequently used scale is the 5-point scale. However, as it is unique, it offers respondents the possibility of not taking a position by allowing the choice of an intermediate point (neutral) (Chyung et al., 2017). For this reason, the considered alternatives were the 4 and 6-point scales. Considering that interviewees are specialists with in-depth experience and knowledge in the area, it was closed the scale that offers more detail, the Likert scale from 1 to 6. At this stage, the list of risks and risk factors prepared was adapted according to the suggestions of the experts in the interviews regarding new risks and risk factors. In addition to the list of risks and risk factors, the SWOT analysis carried out by the researchers. The list was also adapted to be able to distinguish the risks identified in the literature from the risks suggested by key-experts. For that, fifteen remote interviews were conducted via Zoom or Microsoft Teams between 06/07/2021 and 27/07/2021 with an average duration of 52 minutes each with two researchers. One of the researchers was in charge of conducting the interview and the other was in charge of recording observations of key-experts. Data was aggregated, processed and analyzed using the Microsoft Office Excel tool.

5.4.3.3 Key Risks

The data processing concerns the selection of key risks to be considered later. This stage is extremely relevant since the usefulness of the study lies in the adequate selection and identification of key risks that provide industrial companies in Setubal peninsula with a basis for the creation of assertive and impactful strategic plans.

To identify the key risks to address on the scenario development it was required to data processing on risk levels and risk appetite obtained from the experts. The average risk levels resulting from key-expert assessments were calculated by multiplying the average level of risk occurrence of each and the associated average impact level. For each risk the associated risk appetite index was also calculated considering the average level perception.

Following the qualitative risk analysis practices, to categorize the risks levels and obtain a clear reading of their relevance, it was used the following probability and impact matrix for risk level assessment (Figure 5.3).

Occurrence / Impact		Likelihood of impact					
		1	2	3	4	5	6
Likelihood of occurrence	1	1	2	3	4	5	6
	2	2	4	6	8	10	12
	3	3	6	9	12	15	18
	4	4	8	12	16	20	24
	5	5	10	15	20	25	30
	6	6	12	18	24	30	36

Figure 5.3 - Risk levels categorization: Probability and Impact risk matrix used study.

Risk appetite index level was homogeneously categorized as 1) high- if between 4 and 6 (inclusive), 2) moderate- if between 2 and 4 (inclusive) and 3) low- until 2 (inclusive).
The key-expert assessments and validation results were added to the analysis including new proposed risk suggestions (record as Suggested Risks (SR)) were added to the risk list complementing the Risks (R) and Risk Factors (RF) identified in the literature. The final list can be found in Table 5.8 which includes average risk appetite index level and the average risk level values as well as the SWOT classifications validated by the different key-experts.
To verify the correlation between the variables the statistical analysis of Pearson (R) and Spearman (Rho) coefficients was made indicating an $R = 0.5405$ showing a moderate positive correlation with a p-value of 0.000073 has a significant result at $p<0.01$ and $Rho = 0.5197$ also showing an association between the two variables considered as statistically significant.
The key risks identification was made using the Figure 5.4, where four strategic scenarios can be developed, considering the turning points of risk level of 18 (related to the risk probability impact matrix in Figure 5.3) and the 4 level in the risk appetite index (related to the risk appetite Likert scale, as the risk level, contains the impact and probability components, measures the perception of severity that key experts have in relation to a given risk and the risk appetite index level characterizes the level of risk that an organization is willing to accept in the pursuit of its objectives before any action is determined to be necessary to reduce it.

Table 5.8 - SWOT analysis with identified risks validated by key-experts.

Strength	Weakness
R15. Interoperability (4.40;19.85) R21. Knowledge of data-driven business models (3.79;16.49)	R6. New training requirements (3.67;19.07) R9. Short-term strategy (3.4;17.6) R10. Resistance and organizational culture (4.07;21.78) R11. Difficulties in implementing I4.0 (3.93;18.76) R13. Technological maturity (3.57;19.43) R14. Existence of network infrastructures (4;19.49) R15. Interoperability (4.31;21.28) R18. Waste (4.12;15.98) R21. Knowledge of data-driven business models (3.67;16.61) R22. Technological obsolescence (3.73;20.84) SR2. Difficulty in finding solutions for infrastructure (3;12.96) SR8. Talent hiring (3.57;15.39) SR10. Agility and flexibility of the organizational structure (3.67;15.75) SR13. Liquidity/Treasury Management (4.4;17.68)
Opportunities	**Threats**
R12. Infrastructure reliability (3.40;17.33) R14. Existence of network infrastructures (4.21;22.55) R15. Interoperability (4.31;21.28) R20. More demanding product individualization requirements (3.87;18.4) R21. Knowledge of data-driven business models (3.87;18.40) SR6. Talent retraining (3.63;16.47) SR12. Online transactions (4.00;22.08)	R1. Loss of sensitive information (4.29;18.12) R2. Industrial espionage (3.85;13.74) R3. Industrial sabotage (3.54;11.50) R4. Disappearance of jobs (4;17.45) R5. Lack of skilled labor (4.14;25.35) R6. New training requirements (4;18.49) R7. Perception of Industry 4.0 as increased surveillance (3.13;13.37) R8. Emergence of new competitors (3.67;16.21) R12. Infrastructure reliability (3.75;19.13) R13. Technological maturity (4.08;19.74) R14. Existence of network infrastructures (3.77;17.50) R15. Interoperability (3.75;16.65) R16. Data protection (3.57;14.83) R17. Growing legal complexity (4.20;18.16) R19. Instability in demand (4.27;17.91) R20. More demanding product individualization requirements (4.50;19.78) R22. Technological obsolescence (4.08;18.06) R23. Inefficient investments (3.64;17.31) R24. Labor cost (4.00;14.91) R25. Uncertain return on investment (3.71;15.92) SR7. Cyber blackmail (3.67;11.81) SR1. Departure of workers to other companies (4.33;15.31) SR3. Changes in fees and taxes (4.00;14.16) SR4. Change in legislation (4.22;18.73) SR9. Emergence of innovative products (4.67;17.5)

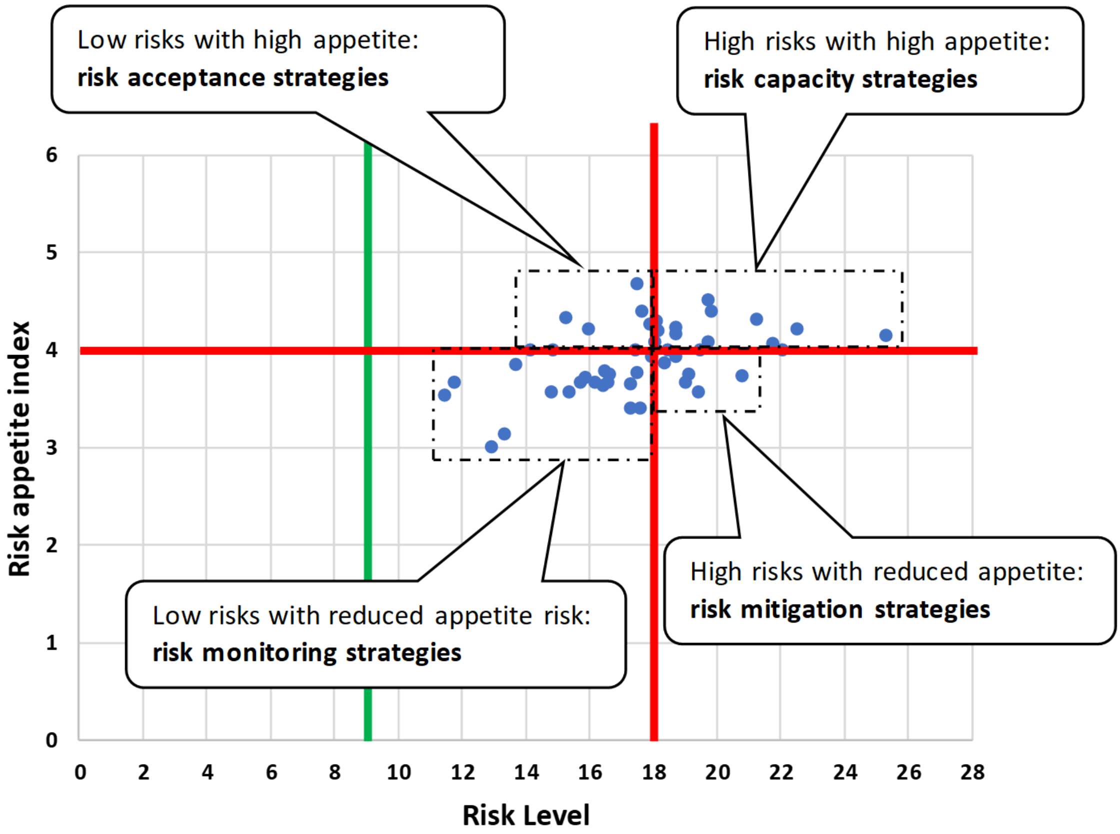


Figure 5.4 - Analysis of the key risks.

Therefore, it is extremely relevant to consider the level of risk and the associated risk appetite index levels for strategic scenario development as for high risk that have also high-risk appetite organizations have to develop internal risk capacity strategies in place. Also risk with less risk appetite index but higher risk levels are key risks as risk mitigation strategies scenario companies have to develop risk mitigation plans headed to be aligned with the risk capacity plans stage scenario. In this case, the key risks to be mitigated are: R6. New training requirements (W), R11. Difficulties in implementing I4.0 (W), R12. Infrastructure reliability (T), R13. Technological maturity (W), R21. Knowledge of data-driven business models (O) and R22. Technological obsolescence (W).

5.4.3.4 Characterization of the Strategic Scenarios

As exposed in Figure 5.4, the first identified scenario for 2030 comprises "risk acceptance strategies" associated with reduced risk and high appetite. As internal (Weakness) and external (Threats), this scenario is a negative approach, looking for companies' external aspects. The vision of this scenario is regarding labor and financial risk factors mainly. Also, there is a concern about competition, legal and new business models and market conditions risk factors. The influence of these risks on the strategic vision is related to external partnerships regarding the development of the three types of integration on companies.

The second identified scenario for 2030 comprises “risk monitoring strategies” of the low risks with reduced appetite. The negative external aspects (Threats) are presented mainly in this scenario, following the negative internal aspects (Weakness). This high negative scenario weight is composed with “talent retraining” and “infrastructure reliability” positive risks as opportunities, and “knowledge of data-driven business models” as strengths for companies. The vision of this scenario is regarding to the infrastructure, cybersecurity, and labor. Also, there is a concern about new business models and market conditions, financial, organizational structure and competition. The influence of these risks on the strategic vision is related with external partnerships mainly related to the companies’ infrastructure, on performing I4.0 transition as partnerships can lead to cybersecurity and labor issues.

The third scenario for 2030 comprises "risk mitigation strategies” associated with high risks and reduced appetite. These key risks composes a negative scenario mainly internal aspects (Weakness), following the “infrastructure reliability” risk as an external aspect (Threat), and “knowledge of data-driven business model” risk as the only external positive risk (Opportunity). The vision of this scenario is regarding to the infrastructure. Also, there is a concern about labor, organizational structure, new business models and market conditions, and financial. The influence of the key risks on the strategic vision is related to internal aspects such as companies’ infrastructure and labor, and external aspect as the development of data-driven business models.

The fourth scenario for 2030 comprises the “risk capacity strategies” associated with high risks and high appetite. This scenario is composed mainly by internal negative aspects (Threats), following positive external aspects (Opportunities). Also, this scenario contents “resistance and organizational culture” and “existence of network infrastructure” risks as internal aspects (Weakness), and one internal aspect (Strength) as the “Interoperability” risk. The vision of this scenario is regarding to the infrastructure, new business models and market conditions, and labor mainly. Also, there is concern about cybersecurity, organizational structure, legal, sustainability, and financial. The influence of these risks on the strategic vision is related to negative external aspects with the companies’ infrastructure as central rule. On the other hand, the positive external aspects comprises “online transactions” risk that can lead to the will of companies to look at the benefits of availability, labor and facilities' renting low-costs, and for instance, worldwide transactions.

5.4.4 Risk Management

The proposed risk management phase was carried out in two stages: the selected risks for the fulfillment of the strategic vision with risk management on the four scenarios, and a critical analysis of the current situation of the Setúbal peninsula on the "mitigation strategies" scenario in which the risk mitigation plans are proposed to companies to reduce or eliminate the selected risks.

5.4.4.1 Scenarios' Analysis for the Fulfillment of the Strategic Vision

On "risk acceptance strategies" scenario, companies want to invest in the I4.0 transition with low risk. To fulfill the strategic vision, companies will have to elaborate strategic answers to face the market pressure, and regarding three types: 1) the habit, meaning the total acceptance of the market pressure, 2) imitation, meaning making a copy of competitors' practices on I4.0 adoption, and 3) conformity, meaning the conscientious adoption of I4.0 enabling technologies.

On "risk monitoring strategies" scenario, companies don´t want to invest to much in the I4.0 transition because companies don't want to have risks. To fulfill the strategic vision, companies will have to develop a progressive evaluation process to measure the effectiveness of the I4.0 transition, and if needed, implement corrective actions. There are some techniques that companies can use to monitor I4.0 transition as: risk reassessment, audits, trend analysis and measurement of technical performance and progression meetings.

On "risk mitigation strategies" scenario, companies assume the risks related to the I4.0 transition but companies don't want the needed risk appetite to have them. To fulfill the strategic vision, companies will have to develop preventive and detective mitigation measures. As preventive measures, companies will have to act on risks to reduce its vulnerabilities or likelihood of occurrence. The preventive mitigation measures allow the risk exposure through the risk reduction or elimination, reducing the vulnerabilities that origins the risk occurrence. The detective mitigation measures act on the impact of the risks, reducing the impact caused by the risk occurrence.

On "risk capacity strategies" scenario, companies want to invest on the I4.0 transition and have the need risk appetite to the associated risks. To fulfill the strategic vision, companies will have to develop the maximum risk capacity maintaining its liquidity/treasury management, i.e., maintaining its sustainability as company. Thus, companies can reduce risk capacity by making its capacity to I4.0 transition more flexible, i. e., use the same resources to implement I4.0 enabling technologies to a wider number of products or services.

5.4.4.2 Critical Analysis and Development of Risk Mitigation Plans

A characterization of the current maturity of companies in the region of the Setubal peninsula is essential to understand the starting point for the maturity objective defined in the elaborated vision by the representative stakeholders. This level of maturity of the current situation was established according to the study by Alcácer et al. (2021) carried out on the Setubal peninsula in 2020, which used the IMPULS model to assess the region's level of maturity. Thus, the starting point was defined to elaborate the vision for 2030. By this, proposals for risk mitigation measures were prepared to help companies to reduce risks and maximize their likelihood of reaching the maturity level of the elaborated vision.

Considering the views of representative stakeholders regarding what the trends will be in 2030, it is useful to make a characterization of what is the region's starting point in the I4.0 transition. In their study, Alcácer et al. (2021) measured, using the IMPULS model, the maturity level of companies in the Setubal peninsula region in 2020. The average maturity level of the 15 companies analyzed in the Setúbal peninsula region was 1.74, that is, between the beginner and intermediate categories. Since the description of each of the levels reveals information related to vertical, horizontal and end-to-end integrations, it is possible to assess their state of development in the year 2020. Level 1.74 is closer to level 2 (Intermediate) which, regarding the types of integration, states that:

- There is some data collection in the production processes, but they are used in a limited way;
- Integrated systems with internal information sharing exist to a certain extent and the first steps are being taken towards sharing information with business partners.

It is concluded that in the year 2020 there was a very limited version of vertical integration, that although steps were being taken in this direction, horizontal integration still did not exist and that end-to-end engineering was not even discussed.

By analyzing the IMPULS model scale, it is possible to reach another conclusion: the three types of integration are not developed simultaneously, and there are strong dependencies between them. In the process of I4.0 transition, it is observed that vertical integration is the first step, followed by horizontal and, finally, end-to-end engineering. This idea is reinforced by the response given by one of the stakeholders in the elaboration of the vision (Table 5.6). When asked about the existence of horizontal integration in 2030, he stated that "integration will be achieved as a result of vertical integration (...)". Considering the strategic scope of the present study and the opinion of the stakeholders of the Setubal peninsula, vertical integration will be the focus of the proposed risk mitigation plans, as it is the first barrier in the I4.0 transition.

Considering the predictions for the vertical integration for 2030 state and doing the reverse process, of attributing to the results obtained in the content analysis a level of the IMPULS model, it’s possible to conclude that the statements obtained in the interviews reveal that the expectations of the stakeholders for 2030 are that, on average, companies in the Setúbal peninsula will be at a level equal to or greater than 3 (Experienced), a level beyond which vertical integration is no longer limited. In this sense, to maximize the speed and quality of companies’ progress, to approach the vision drawn up by the representative stakeholders, risk mitigation plans will have to be prepared for the identified risks on the “mitigation strategies” scenario.

The weakness of the “new training requirements” risk was evaluated by key-experts with a red severity level, considered the most serious. On the other hand, the training and training of employees has evident positive impacts on all selected key risks, without any exception. This dissonance that key-experts reveal when they identify as very serious what constitutes one of the main solutions to minimize the remaining deviations could have one of two reasons: 1) the specialists do not see training as a beneficial proposal; 2) experts consider that there are no resources to invest in training. Considering that the second reason justifies the assessment attributed, it becomes evident that companies in the Setubal peninsula region need to take advantage of the European Union's structural funds and Portugal 2030 incentives in order to introduce training and training of employees in their strategic plan.

The opportunity brought about by the multiannual financial framework and Portugal 2030 does not only allow for the training of employees, but investment in the acquisition of technologies that allow companies to reach higher levels of interoperability sooner. Regarding the opportunity of the “difficulties in implementing I4.0”, it is up to the Portuguese government to make the network infrastructure market more competitive, attractive and innovative so that Portuguese companies can accelerate their transition process to I4.0, reaching consequently, vertical integration faster.

According to Birkel et al. (2019), the “infrastructure reliability” risk can be reduced by using digitalization and networking so companies can find their way into the economy. The “infrastructure reliability” poses a major risk into companies’ competitiveness, specially into the global market. Thus, it is necessary to analyze the infrastructure before migrating to an integrated environment with the necessary timeline to achieve high quality infrastructure. It is necessary define what the company has, what the company wants and its deadline to achieve the integrated environment.

The “technological maturity” risk it’s not new. Companies will have to continuing on supporting the development of technology. As mitigation strategies, companies can have partnerships

with technological companies and frequent workshops to minimize the risk to implement immature technology. Thus, companies have to develop progressive technologies' implementation plans with pilot projects, and step by step, to reduce the risk impact.
In order for companies in the Setúbal peninsula region to take advantage of the opportunity of "knowledge about data-based business models", it is proposed that companies invest in the training of their employees. Joint projects with universities and polytechnics in the region could constitute another way for companies to acquire knowledge and vision.
For the risk of "technological obsolescence" there are no generic or immediate risk mitigation measures. The reduction of this risk requires the elaboration of new, more in-depth studies. To reduce the risk of "technological obsolescence", Rojo et al. (2012) suggests the elaboration of an assessment of the risk of obsolescence for each component of the bill of materials considering factors such as the number of suppliers, the useful life of the components, the existing inventory, the rate of consumption and the operational impact. Based on this risk assessment, proactive strategies should be developed for components with a high risk of obsolescence, if financially viable. A study carried out in 2019 by Deloitte (s.d.) suggests a similar solution. Companies must assess legal risks related to regulatory, compliance, contractual and reputational factors, setting priorities and putting controls in place. Examples of risk minimization measures are the definition of new policies and investment in training to make employees aware of events that may constitute legal risks for the organization.
Applications by companies from the Setubal peninsula to the incentives of the recovery and resilience plan and to Portugal 2030 will act as a stimulus to empower companies with resources so that they become more competitive. However, these resources will only be available if the companies' strategic plans align with the vision that the European Union has planned for the coming decades. This counterpart will oblige companies to frame their strategic objectives within the scope of incentive programs, forcing long-term planning.
Table 5.9 presents a summary of the risk mitigation measures and the proposed plans for key risks reduction of the "mitigation strategies" scenario.

5.5 Concluding Remarks

Strategic scenarios are presented as a relevant tool that can inform companies of the impacts of risks and risk factors present in the industry, which may affect their I4.0 transition, exposing the consequences that may arise from their strategic decisions. in this sense, the RQ4 was formulated as: what will be the I4.0 future strategic scenarios on 2030-time horizon? and what will be the risk mitigation plans on 2030-time horizon due to I4.0 implementation? The answer on this study is that there is no evidence of studies to date with strategic scenarios for I4.0 technologies adoption for 2030-time horizon. Studying an important industrial regional sector regarding to the I4.0 transition risks, It was developed four strategic scenarios, respectively, "acceptance strategies" scenario, "monitoring strategies" scenario, "mitigation strategies" scenario, and "risk capacity strategies" scenario. In this study, each one of the developed strategic scenarios were analyzed and it was proposed strategies to each scenario. Regarding mitigation plans related to the "mitigation strategies" scenario, the Table 5.9 presents mitigation plans to help companies on I4.0 transition.

This study also concludes that the main risks and factor risks are new training requirements (labor risk factor), difficulties in implementing I4.0 (organizational structure risk factor), infrastructure reliability and technological maturity (infrastructure risk factor), knowledge of data-driven business models (new business models and market conditions), and technological obsolescence (financial risk factor).

Table 5.9 - Proposed risk mitigation plans.

Risk factor	Risk	Proposed risk mitigation plan
RF2. Labor	R6. New training requirements	• Use of Portugal 2030 structural funds and incentives to create conditions for initiating training and training programs for employees; • Improvement of working conditions in order to expand the number of workers and increase the retention of existing staff; • Bet on collaborative strategies between companies and universities.
RF4. Organizational structure	R11. Difficulties in implementing I4.0	• Promotion of an internal culture aware of the importance of I4.0 on company; • Bet on the transparency of top management decisions to foster an I4.0 environment of trust; • Raising the awareness of company employees on the topic of the I4.0 benefits through training; • Commitment of company employees to the adoption of new technologies and innovative processes.
RF5. Infrastructure	R12. Infrastructure reliability	• Elaboration of more in-depth studies with specialized partnerships to identify and assess the lack of reliability risks and implementation of controls and policies on the identified priority risks; • Use of structural funds to create conditions for the acquisition of technology and resources that allow higher levels of reliability.
RF5. Infrastructure	R13. Technological maturity	• Elaboration of more in-depth studies with specialized partnerships to identify and analyze trends on the needed enabling technologies; • Strategic use of structural funds by the government in order to improve national network infrastructures;
RF8. New business models and market conditions	R21. Knowledge of data-driven business models	• Bet on collaborative strategies between companies and universities; • Investment in training and training of employees; • Application of the incentive programs to force companies in the Setúbal peninsula region to align their goals with the European Union's vision for the digitalization.
RF9. Financial	R22. Technological obsolescence	• Elaboration of more in-depth studies with specialized partnerships in order to identify and evaluate the components that constitute the highest risks of technological obsolescence and implementation of proactive obsolescence management strategies for the components that present the highest risks; • Implementation of consistent policies and procedures to minimize the occurrence of technological obsolescence.

In this study, the strategic vision of the representative stakeholders is that vertical, horizontal and end-to-end integration will be implemented in the year 2030. The study of Alcácer et al. (2021) reveals that in the same region in 2020 there was vertical integration and that this was very limited. By this, it was identified and positioned using the SWOT analysis quadrants forty-eight risks, distributed by nine main risk factors characterizing four scenarios for 2030 with different risk management processes, and differentiated each one from the risk and appetite levels. These different strategic scenarios can help companies to position themselves and prepare for the I4.0 transition based on each scenario. Nevertheless, it is suggested that companies use the proposed methodology to better understand their position regarding the four strategic scenarios.

This study results revels that to overcome treasury limitations and gain liquidity to implement the proposed measures, companies in the Setubal peninsula region need to take advantage of the opportunity brought by the EU structural funds and the Portugal 2030 incentive program. Incentive programs will force companies in the Setubal peninsula region to align their goals with the European Union's long-term strategic vision.

The first main study limitation of the present is related to the size of the study samples in the establishment of the vision as well as of the limited vision information retrieved from the strategic vision key-experts as well as the limited sample of professionals' key-experts used in the SWOT validation and risk identification and assessment, both reducing the possibility to out the desired deeper qualitative analyzes on risks analysis and scenarios determination.

A second main limitation is due to the fact that in the stage of elaboration of the vision concrete strategic objectives were not identified nor their quantification was obtained, which values could be used for other strategic scenarios development. In future studies, it is suggested to deepen the interviews to collect strategic objectives and their quantification with the panel of stakeholders, or, alternatively, try to extract quantifiable strategic objectives from the European Union's incentive directives or from other bodies that promote the I4.0 concept development.

A third last study limitation is related to the generic nature of the risk mitigation plans proposals, as they still need to be deepened, considering the existing knowledge and the specificities of each organizational structures where they will be placed. Thus, and for future development studies, it is suggested that a new interaction be carried out in order to detail the risk mitigation and capacity measures proposed to the type of structures to be applied.

6

CONCLUSIONS

This chapter presents an overview of the thesis, from the problem area, objectives of the thesis, methodology used, and relating it to the main results and achievements, matching the research questions. At the end, future research opportunities are proposed to continue the research on the topic of I4.0 focusing the adoption of enabling technologies in manufacturing systems.

6.1 Thesis Overview

The I4.0 or the fourth industrial revolution makes use of enabling technologies causing deep effects on manufacturing systems as well as on business models. This is the moment the world is living now and it's possible to assist with cost reductions, the increase the companies' production capacity with the use of portable technologies such as smartphones, tablets, or laptops, making the world live online with the internet making part of it every day. This internet is the central role of all enabling technologies and makes the enabling technologies' integration possible.

The I4.0 seeks the methodological and technological transformation of the production model at all manufacturing systems. By this, and as all transformation process, it is necessary to analyze the starting point, what is the time horizon to reach and define the way to make it possible on building the path.

In the first chapter, the problem area of the thesis established the starting point. The need for a new vision to access the new industrial environment is essential to look further to a close future. This new future is no longer a future trend as companies need to find their path to digital transformation. The research objectives presented on this thesis were aligned to support companies to accelerate the adoption of the I4.0 enabling technologies over their manufacturing systems. The used research methodology was proposed to study first the I4.0 concepts and the smart factory vision on manufacturing systems, to study the I4.0 maturity levels on an important industrial regional sector, to study in deep how an international company is adopting the I4.0 enabling technologies and to study 2030-time horizon strategic scenarios to propose risk mitigation plans.

In the second chapter, there was a need to establish the vision of the smart factory and its enabling technologies. The academic community, and the general community in general, had a lack of understanding of how to create the I4.0 environment. The research presented in the chapter proposed a vision for the I4.0 smart factory to manufacturing systems.

In the third chapter, as a way to study an important industrial regional sector, it was presented the I4.0 maturity level using the IMPULS model. It was possible to analyze how companies are making their digital transition, and what are the needs regarding the adoption of the I4.0 enabling technologies. There was a need to study the I4.0 maturity so far because the I4.0 concept first appeared in 2012.

The output of the second chapter influenced the research of the fourth chapter as there was a need to understand in deep how an important industrial company is implementing the I4.0 enabling technologies into its manufacturing system. The IMPULS model was also used and allowed to analyze what were the company's needs to perform higher maturity levels. This research brought a company close analysis with the objective to study and show how a company is integrated into its departments and their different visions about the digital transition.

As the investigation progressed, it was necessary to understand how companies looked to the future. the milestone defined was the 2030-time horizon, considering the funds created to support the digital transformation of the industry. By this, the fifth chapter proposes the development of strategic scenarios and proposed risk mitigation plans to help companies to face the I4.0 adoption.

The output of this thesis is reached with the research flow presented reaching the conclusions of this sixth chapter. It was studied in detail the necessity that companies have to perform the digital transformation and in a general way, it can be concluded that the main factor that is limiting the I4.0 adoption on manufacturing systems is the human factor, that is, the human is the center of all transformations. This factor is reflected on several barriers such as "lack of support from top management", "workers demotivation", "lack of employees' skills", "lack of technical knowledge", "need for continuous formation", "lack of trust between business partners", "high effort for coordination" or "lack of an implementation methodology". Related to the risks of the I4.0 adoption, the human factor is reflected in risks such as "lack of skilled labor", "new training requirements", "perception of I4.0 as increased surveillance", "resistance and organizational culture", "difficulties in implementing I4.0" or "knowledge of data-driven business model". As showed, the human factor is the link to all of the barriers and all of the risks. There is a continuous path to improve the role of the human factor on the digital transition of the manufacturing systems.

6.2 Contributions to Theory and Practice

This thesis provides some contributions to the body of knowledge related to the I4.0 thematic. The answers to the research questions contributes not only to the academic community but also to professionals on how to understand and develop the I4.0 environment into their manufacturing systems.

The literature review in the second chapter, presented the I4.0 enabling technologies to perform the vision of the smart factory. In this way, this literature review brought to both communities (academic and professionals) an exhaustive study to the understanding of the I4.0 thematic and had simplified its knowledge. Professionals can better understand how to develop the I4.0 environment on their manufacturing systems.

The first case study provides a study of an important industrial regional sector on the understanding on how are the I4.0 adoption. Thus, with the use of the IMPULS model, It was reached the maturity level of this regional sector and it was analyzed the different dimensions of this model to understand what the main companies' needs are. This study has showed how to use the IMPULS model to check a company' maturity model and in this way, it can be used by professionals to check their companies' maturity level. It also can be used by the academic community to be compared results with other studies. Moreover, in this study it's possible to perceive new barriers that professionals brought the academic community and it´s possible to assess the perception of the barriers' importance to implement I4.0.

The second case study showed how and manufacturing company is implementing the I4.0, and how company' departments are connected to implement the I4.0. Considering the company' departments as the internal value chain, this study brought to both communities what are the challenges that these departments can make to have better I4.0 maturity levels. It can be replicated to other companies.

The fifth chapter presented a systematic literature review whit the intention to identify strategic scenarios for I4.0. This objective was reached with this chapter, filling a gap in academia.

Moreover, this chapter also presents a methodology to develop strategic scenarios. It can be used by the academic community in other studies or in another sample to compare with this study. It also brought a collection of risks and risk factors on the I4.0 adoption to both communities. Professionals can assess their position on the four strategic scenarios and perform the suggestions to better face the digital transition. This methodology can be used also for both communities to reach strategic scenarios, develop and implement risk mitigation plans to accelerate the I4.0 adoption on manufacturing systems.

This thesis highlights the importance of companies' perception regarding the I4.0 adoption giving to the general community the understanding of its evolution. It can be seen that, along several years, there is no significative evolution on I4.0 adoption as its main barriers remain. To face these highlights, this thesis brings contributions for the community in general, it has a research line align to improve knowledge about the I4.0 thematic to better understand how to reach the smart factory of the I4.0 with its enabling technologies to perform the digital transformation on manufacturing systems. It brings the understanding of the maturity and readiness models so companies can check their I4.0 maturity levels and understand how they can reach better maturity levels. Another contribution is the use of the proposed strategic scenarios and its strategic plans leading to the "risk capacity scenario", that is, the higher risk appetite level that companies must reach to face the I4.0 adoption.

Companies can follow this research line to improve their I4.0 adoption with the combination of innovations and digital technologies to improve their production and face the I4.0 as an opportunity and not as a negative risk. Due to lack of time of industrial managers, another way to spread knowledge is with the support of industrial associations like AISET, who can promote seminars, or meetings with their associate members and present this research line to clarify the I4.0 thematic and promote networking between the associates.

6.3 Future Research Opportunities

Some research opportunities aroused from the development of this thesis. The opportunities for future research in the second chapter highlighted the need to continue identifying case studies of the I4.0 enabling technologies implementation in manufacturing systems to boost its adoption in companies. The increase in these case studies will influence companies to look further to the next level, that is, to think about their business model with the enabling technologies for the creation of the I4.0 environment. Moreover, it will be very interesting to have the opportunity to study the competitive advantage of the I4.0 adoption on companies.

The research of the third chapter also brought several future research opportunities. This study could be replicated in other regional sectors, in other countries, to compare and find patterns and differences. Also, this study can be replicated in the same industrial regional sector to check the evolution because this study was made in 2020. In the same way, as the sample size is a limitation, this study can be replicated with a higher sample size to analyze patterns and differences in the results. In a similar way, this study can be replicated with the use of another maturity model so it can be possible to analyze maybe different perspectives and different results. As mentioned in this study, it will be very interesting to have the opportunity to analyze companies' maturity levels in the same value chain.

The fourth chapter brought a different perspective of a value chain. This company' internal value chain can be studied wider with all of its departments and can be compared with the results obtained. It will be interesting to replicate this study in the same company in order to analyze its evolution with this version. Moreover, this study can be replicated to other companies and in several countries to analyze patterns and differences on the results. Another research opportunity is the study the economic impact associated to the I4.0 adoption in every company' department and the study of the economic impact related to the analyzed improvements observed in every company' departments.

The necessity of creating strategic scenarios to "put companies thinking about the future", in order to accelerate the I4.0 adoption also brought opportunities for future research. The research developed in the fifth chapter can be used to develop other strategic scenarios in other areas by using the methodology developed. The same study can replicate with a different sample size and/or a different population characteristic, and/or different experts, to analyze different results and potential different strategic scenarios.

Despite of the abovementioned opportunities for future research, there is a line of investigation that needs to be pursued in a near future regarding the COVID-19 impact outbreak in the I4.0 adoption. Many countries around the de world had declared a state of emergency to control the COVID-19 spread affecting also industrial activity. It will be interesting to further analyze the COVID-19 impact, negative and positive, on the I4.0 adoption regarding manufacturing systems.

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A

Appendix A. Mapping the Adoption of Industry 4.0 Technologies in the Setubal Peninsula Survey

Exmo(a). Senhor(a),

Com o objetivo de desenvolver sinergias entre os associados da AISET e promover a sua capacitação para a transformação digital, está a ser desenvolvido um estudo relativo à adoção das tecnologias da Indústria 4.0. Este estudo, conduzido pela Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa (FCT/UNL), será complementado com o presente inquérito "Mapeamento da Adoção das Tecnologias da Indústria 4.0 na Península de Setúbal", no âmbito do Projeto Driving I4.0, disponível em: http://drivingi40.unidemi.com/.

O presente inquérito tem a duração aproximada de 15 minutos e a sua realização poderá ser interrompida e retomada sempre que necessário.

Muito agradecemos a conclusão do seu preenchimento até dia 31 de julho de 2020.

Declaração de confidencialidade: Todos os dados pessoais recolhidos no âmbito do presente inquérito serão exclusivamente utilizados para fins estatísticos, garantindo-se que o seu tratamento será efetuado de acordo com o Regulamento Geral de Proteção de Dados Pessoais - Regulamento nº2016/679 do Parlamento Europeu e do Conselho (27 de Abril).

A.1 Company Characterization

A1.

Nome da Empresa (opcional): [ ]

Respondente (opcional): [ ]

Função: [ ]

Correio eletrónico (opcional): [ ]

A2. Anos de experiência profissional:

Menos de 1 ano	Entre 1 e 2 anos	Entre 2 e 5 anos	Mais de 5 anos
☐	☐	☐	☐

A3. Setor principal de atividade económica (CAE):

A4. Por favor, indique a(s) principal(s) atividade(s) da sua Empresa:

A5. Qual o número de colaboradores da sua Empresa?

- Até 9 colaboradores ☐
- De 10 a 49 colaboradores ☐
- De 50 a 249 colaboradores ☐
- A partir de 250 colaboradores ☐

A6. Qual o valor aproximado do volume de negócios da sua Empresa no ano 2019?

- Inferior a 2 milhões de Euros ☐
- Entre 2 milhões e 10 milhões de Euros ☐
- Entre 10 milhões e 50 milhões de Euros ☐
- Superior a 50 milhões de Euros ☐

A.2 Strategy and Organization

B1. Como se pode descrever o nível de implementação da estratégia para a "Indústria 4.0" na sua Empresa?

- Não existe uma estratégia ☐
- Um projeto piloto está em execução ☐
- A estratégia está em desenvolvimento ☐
- A estratégia está formulada ☐
- A estratégia está em implementação ☐
- A estratégia está implementada ☐

B2. Utiliza indicadores para medir o nível da implementação da estratégia para a "Indústria 4.0" na sua Empresa?

- Sim, existe um sistema de indicadores na Empresa que considero apropriado. ☐
- Sim, existe um sistema de indicadores na Empresa que nos dá alguma orientação. ☐
- Não, a abordagem na Empresa ainda não está claramente definida. ☐

B3. Da seguinte lista, quais são as tecnologias que a sua Empresa utiliza?

- Sensores ☐
- Dispositivos móveis ☐
- RFID (Radio Frequency ID) (Identificação por radiofrequência) ☐
- Dispositivos e sistemas de localização em tempo real ☐
- Big Data (grande volume de dados) para armazenar e avaliar dados em tempo real ☐
- Tecnologias cloud (nuvem) como infraestruturas escaláveis de TI (Tecnologias de Informação) ☐
- Comunicações M2M (Machine-to-Machine) (Máquina para Máquina) ☐
- Nenhuma das tecnologias acima mencionadas ☐

B4.

Nos últimos 2 anos, qual o nível de investimento em tecnologia para a implementação do conceito "Indústria 4.0" nos vários departamentos da sua Empresa? No cenário atual de pandemia, qual o investimento planeado para os próximos 5 anos?

Investimento nos últimos 2 anos

	Grande	Médio	Pequeno	Nenhum	Não sabe
Investigação e desenvolvimento (I&D)					
Produção / Fabrico					
Compras					
Logística					
Vendas					
Serviços					
TI (Tecnologias de Informação)					

B5.

Nos últimos 2 anos, qual o nível de investimento em tecnologia para a implementação do conceito "Indústria 4.0" nos vários departamentos da sua Empresa? No cenário atual de pandemia, qual o investimento planeado para os próximos 5 anos?

Investimento planeado para os próximos 5 anos

	Grande	Médio	Pequeno	Nenhum	Não sabe
Investigação e desenvolvimento (I&D)					
Produção / Fabrico					
Compras					
Logística					
Vendas					
Serviços					
TI (Tecnologias de Informação)					

B6. Em que áreas da sua Empresa existe uma gestão sistemática da tecnologia e da inovação?

- TI (Tecnologias de Informação) ☐
- Tecnologias da Produção ☐
- Desenvolvimento de Produto ☐
- Serviços ☐
- Centralizada, em gestão integrada ☐
- Não existe ☐

A.3 Smart Factory

C1. Como avalia as infraestruturas da sua Empresa de acordo com as seguintes funcionalidades?

	Não disponível	Disponível para alguns equipamentos	Totalmente disponível
Máquinas / Sistemas podem ser controlados através das TI's	☐	☐	☐
M2M - Comunicações máquina para máquina	☐	☐	☐
Interoperabilidade - integração e colaboração possíveis com outras máquinas / sistemas	☐	☐	☐

C2. Como avalia a adaptabilidade das infraestruturas existentes na sua Empresa de acordo com as seguintes funcionalidades?

	Não é relevante	Relevante mas não atualizável	Relevante e atualizável	Altamente relevante pois a funcionalidade já está disponível
M2M - Comunicações máquina para máquina	☐	☐	☐	☐
Interoperabilidade - integração e colaboração possíveis com outras máquinas / sistemas	☐	☐	☐	☐

C3. A sua Empresa já recolhe dados das máquinas e dos processos durante a produção (produtos e/ou serviços)?

- Sim, de tudo ☐
- Sim, alguns ☐
- Não ☐

C4. Quais dos seguintes sistemas a sua Empresa usa?

- MES - Manufacturing Execution System (Sistema de Execução de Fabrico) ☐
- ERP - Enterprise Resource Planning (Planeamento de Recursos Empresariais) ☐
- PLM - Product Lifecycle Management (Gestão do Ciclo de Vida do Produto) ☐
- PDM - Product Data Management (Gestão de Dados do Produto) ☐
- PPS - Production Planning System (Sistema de Planeamento de Produção) ☐
- PDA - Production Data Acquisition (Aquisição de Dados de Produção) ☐
- MDC - Machine Data Collection (Recolha de Dados de Máquina) ☐
- CAD - Computer Aided Design (Desenho Assistido por Computador) ☐
- SCM - Supply Chain Management (Gestão da Cadeia de Abastecimento) ☐

C5. Dos sistemas indicados anteriormente, quais têm um interface com o sistema principal?

- MES - Manufacturing Execution System (Sistema de Execução de Fabrico) ☐
- ERP - Enterprise Resource Planning (Planeamento de Recursos Empresariais) ☐
- PLM - Product Lifecycle Management (Gestão do Ciclo de Vida do Produto) ☐
- PDM - Product Data Management (Gestão de Dados do Produto) ☐
- PPS - Production Planning System (Sistema de Planeamento de Produção) ☐
- PDA - Production Data Acquisition (Aquisição de Dados de Produção) ☐
- MDC - Machine Data Collection (Recolha de Dados de Máquina) ☐
- CAD - Computer Aided Design (Desenho Assistido por Computador) ☐
- SCM - Supply Chain Management (Gestão da Cadeia de Abastecimento) ☐
- Nenhum dos sistemas utilizados pela Empresa tem interface com o sistema principal ☐

A.4 Smart Operations

D1.

No sistema principal da sua Empresa existe partilha de informação entre os vários departamentos? Indique se a partilha de informação também ocorre com entidades externas à Empresa (clientes e/ou fornecedores).

Internamente entre departamentos

	Sim	Não
Investigação e desenvolvimento (I&D)	☐	☐
Produção / Fabrico	☐	☐
Compras	☐	☐
Logística	☐	☐
Vendas	☐	☐
Finanças	☐	☐
Serviços	☐	☐
TI (Tecnologias de Informação)	☐	☐
Em nenhum departamento	☐	☐

D2.

No sistema principal da sua Empresa existe partilha de informação entre os vários departamentos? Indique se a partilha de informação também ocorre com entidades externas à Empresa (clientes e/ou fornecedores).

Externamente entre clientes e fornecedores

	Sim	Não
Investigação e desenvolvimento (I&D)	☐	☐
Produção / Fabrico	☐	☐
Compras	☐	☐
Logística	☐	☐
Vendas	☐	☐
Finanças	☐	☐
Serviços	☐	☐
TI (Tecnologias de Informação)	☐	☐
Em nenhum departamento	☐	☐

D3. **Na sua Empresa é utilizado o transporte autónomo de produtos / componentes / matérias-primas?**

- Sim, dentro de toda a Empresa ☐
- Sim, mas apenas em algumas áreas ☐
- Sim, apenas em testes e no projeto piloto ☐
- Não ☐

D4. **A sua Empresa tem processos produtivos que respondem automaticamente e em tempo real às alterações das condições de produção?**

- Sim, dentro de toda a Empresa ☐
- Sim, mas apenas em alguns departamentos ☐
- Sim, apenas em testes e no projeto piloto ☐
- Não ☐

D5. Como estão as TI (Tecnologias de Informação) organizadas na sua Empresa?

- ☐ Não existe departamento de TI na Empresa (o serviço é subcontratado)
- ☐ Existe um departamento central de TI
- ☐ Existe um departamento local em cada área operacional (produção, desenvolvimento de produto, etc.)
- ☐ Existem especialistas de TI em cada área operacional

D6. Qual o nível de implementação das seguintes soluções de segurança nas TI's?

	Solução implementa da	Solução em progresso	Solução planeada	Não é relevante para a Empresa
Segurança no armazenamento interno dos dados	☐	☐	☐	☐
Segurança de dados através de serviços cloud (nuvem)	☐	☐	☐	☐
Segurança de comunicações dentro da Empresa na partilha de dados	☐	☐	☐	☐
Segurança das comunicações na partilha de dados com empresas parceiras	☐	☐	☐	☐

D7. A sua Empresa usa atualmente serviços *cloud* (nuvem)?

	Sim	Não, mas está planeado	Não
Software baseado na cloud (nuvem)	☐	☐	☐
Para a análise de dados	☐	☐	☐
Para o armazenamento de dados	☐	☐	☐

A.5 Smart Products

E1. A sua Empresa oferece produtos / serviços com a seguintes funcionalidades baseadas em TIC (Tecnologias de Informação e Comunicação)?

	Sim	Não
Produtos com memória	☐	☐
Auto informativos	☐	☐
Integração	☐	☐
Localização	☐	☐
Sistemas de assistência	☐	☐
Monitorização	☐	☐
Informações do objeto	☐	☐
Identificação automática	☐	☐

A.6 Data-Driven Services

F1. O processo de recolha de dados na fase de produção e na fase de utilização do produto promove o desenvolvimento de novos serviços. A sua Empresa oferece estes serviços?

- Sim e a Empresa está integrada com os nossos clientes ☐
- Sim, mas sem integração com os nossos clientes ☐
- Não ☐

F2. A sua Empresa analisa os dados recebidos durante a fase de utilização dos produtos?

- Sim ☐
- Não, a Empresa recolhe dados na utilização dos produtos, mas não são analisados ☐
- Não, a Empresa não recolhe dados na fase de utilização dos produtos ☐

A.7 Employees

G1. Como avalia as competências e qualificações dos recursos humanos da sua Empresa nas sequintes áreas?

	Não são relevantes	Não existem	Existem, mas são inadequadas	Adequadas
Infraestrutura de TI (Tecnologias de Informação)	☐	☐	☐	☐
Tecnologias de automação	☐	☐	☐	☐
Análise de dados	☐	☐	☐	☐
Segurança nos dados / comunicações	☐	☐	☐	☐
Desenvolvimento e aplicação nos sistemas de assistência	☐	☐	☐	☐
Software colaborativo	☐	☐	☐	☐
Competências não técnicas como o pensamento sistémico e a perceção do processo	☐	☐	☐	☐

A.8 Contacts

H1. De que forma é que este cenário atual de pandemia influenciou a sua empresa na utilização destas novas tecnologias? As realidades criadas serão continuadas no futuro?

H2. Deseja ser contactato para esclarecimentos ou para que se possa efetuar uma análise mais detalhada da sua Empresa?

Sim ☐

Não ☐

H3. Por favor, deixe aqui o seu contacto direto:

A.9 Declaration of Consent for Data Processing

I1. Nenhum dado pessoal ou de alguma empresa será fornecida a terceiros. Os dados recolhidos durante este inquérito serão utilização apenas para efeitos estatísticos e serão armazenados na FCT/UNL (Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa). A proteção da privacidade de dados pessoais constitui um compromisso fundamental para a FCT/UNL, com a aplicação do novo RGPD (Regulamento Geral de Proteção de Dados), a partir de 25 de maio de 2018 e disponível em: https://www.fct.unl.pt/noticias/2018/05/nota-informativa-regulamento-geral-de-protecao-de-dados-pessoais.

Dou o meu consentimento à FCT/UNL para a recolha e tratamento de dados recolhidos no presente questionário que serão utilizados de forma anonimizada para fins meramente académicos. Declaro que li os termos da Política de Privacidade e aceito. ☐

MUITO OBRIGADA(O) PELA SUA COLABORAÇÃO!

B

Appendix B. Questionnaire Adapted from the IMPULS Model

B.1 First part of the Questionnaire

1) Em que âmbito se insere a atividade do departamento?

R: ____

2) Indique o número aproximado de trabalhadores da empresa no departamento mencionado anteriormente?
   - Até 9 colaboradores
   - De 10 a 49 colaboradores
   - De 50 a 249 colaboradores
   - 250 ou mais colaboradores
3) Qual o valor aproximado do volume de negócios em 2018 no seu departamento?
   - abaixo de 2 milhões de euros
   - entre 2 e 10 milhões de euros
   - entre 10 e 50 milhões de euros
   - acima de 50 milhões de euros
   - não especificado
4) Conhece o conceito i4.0?
   - Não, nunca ouvi falar
   - Vagamente e não é importante para a empresa
   - Superficialmente e pretendo saber mais para avaliar o seu potencial na empresa

- O suficiente para já termos alguns projetos piloto a decorrer
- Dominamos o conceito e já o aplicamos de forma transversal na empresa

5) O que motiva este departamento a abraçar os desafios i4.0?
   - Oportunidade para se diferenciar no mercado
   - A empresa tem espírito inovador, pelo que tem de experimentar novos conceitos
   - Faz parte da sua condição de líder de mercado
   - Os requisitos de mercado e a pressão competitiva
6) Que objetivos se pretende atingir com a adoção dos conceitos i4.0?
   - Aumento da eficiência do sistema de produção
   - Aumento dos proveitos
   - Aumento da eficiência do sistema de gestão
7) Tipifique atividades i4.0 planeadas/em curso/implementadas neste departamento.

	Planeada	Em curso	Implementada	Não relevante
Digitalização de processos com a implementação de sistemas de informação				
Integração entre sistemas e/ou máquinas com recurso ao IoT				
Implementação de sistemas que permitam o controlo eficiente dos processos, produtos e serviços e a análise do desempenho em tempo real				
Contratação de técnicos essenciais para a transformação digital				
Reconversão de técnicos para dar resposta à transformação digital				

B.2 Second part of the Questionnaire

1) Como descreve o nível de implementação da estratégia i4.0 no departamento?
   - Não existe estratégia
   - Foram lançadas algumas iniciativas piloto
   - A estratégia está em desenvolvimento
   - A estratégia está formulada
   - A estratégia está em implementação
   - A estratégia está implementada
2) Existem indicadores para monitorizar o estado de implementação da estratégia i4.0?
   - Sim, possuímos um sistema de indicadores considerado adequado
   - Sim, possuímos um sistema de indicadores que nos dá alguma informação
   - Não, a nossa abordagem ainda não está claramente definida

Se sim quais: ____

3) Que tecnologias são usadas no seu departamento dentro da empresa?
   - Sensores
   - RFID
   - Dispositivos móveis
   - Sistemas de localização em tempo real
   - Grande volume de dados (Big Data) para armazenar e avaliar dados em tempo real
   - Tecnologias em nuvem como infraestruturas escaláveis de TI – Tecnologias de Informação
   - Sistemas TI embebidos
   - Comunicação M2M
   - Outras. Quais: ____
4) Houve algum investimento neste departamento em i4.0 nos últimos dois anos?
   - Não
   - Sim. Em que subdivisões: ____
5) Está previsto algum investimento em i4.0 no seu departamento nos próximos 5 anos?
   - Não
   - Sim. Em que subdivisões: ____

6) Existe uma gestão sistemática da tecnologia e inovação?

- Sim
- Não

7) Como avalia as funcionalidades da infraestrutura de equipamento do seu departamento?

	Não disponível	Disponível para alguns equipamentos	Totalmente disponível
Máquinas e sistemas podem ser controlados através de TI			
M2M: Comunicações Máquina para Máquina			
Interoperabilidade: possível a integração e colaboração com outras máquinas/sistemas			

8) Como avalia a adaptabilidade das funcionalidades existentes na infraestrutura do seu departamento?

---

9) A digitalização de fábricas torna possível criar um modelo digital da fábrica. O departamento onde se insere já recolhe dados das máquinas e dos processos durante a produção?

- Sim, todos
- Sim, alguns
- Não

10) Como é realizada a recolha de dados?

- Principalmente de forma manual
- Os dados relevantes são recolhidos de forma digital, parcialmente
- Todos os dados são recolhidos digitalmente
- Todos os dados são recolhidos digitalmente de forma automática

11) Que utilização faz dos dados recolhidos?

- Criar transparência através do processo de produção
- Gestão da qualidade
- Gestão logística

- Gestão de armazenagem
- Otimização do consumo de recursos (material, energia, etc.)
- Manutenção preditiva
- Controlo automático da produção através da utilização de dados em tempo real

12) Quais destes sistemas são utilizados?
- MES – Manufacturing Execution System
- ERP – Enterprise Resource Planning
- PLM – Product Lifecycle Management
- PDM – Product Data Management
- PPS – Production Planning System
- PDA – Production Data Acquisition
- MDC – Machine Data Collection
- CAD – Computer-Aided Design
- SCM – Supply Chain Management
- Outro. ______________________________

13) Dos sistemas utilizados, quais possuem alguma interface com o sistema central de armazenamento e tratamento de dados?
- MES – Manufacturing Execution System
- ERP – Enterprise Resource Planning
- PLM – Product Lifecycle Management
- PDM – Product Data Management
- PPS – Production Planning System
- PDA – Production Data Acquisition
- MDC – Machine Data Collection
- CAD – Computer-Aided Design
- SCM – Supply Chain Management
- Outro. ______________________________

14) A informação interna do seu departamento partilhada com outros departamentos, está integrada no sistema central?

- Não
- Sim

Que subdivisões: ____

15) a informação partilhada com o exterior, clientes/fornecedores?

- Não
- Sim

Que subdivisões: ____

16) O seu departamento tem já experiência de casos de controlo autónomo de produtos através da cadeia de produção?

- Sim
- Não

17) No seu departamento existem processos de produção que consigam responder autonomamente, em tempo real, a mudanças nas condições de produção?

- Sim, transversalmente
- Sim, mas só em subdivisões selecionadas
- Sim, mas só em teste e fase piloto
- Não

18) Como está organizada a área das Tecnologias de Informação (TI) no seu departamento?

- Não existe departamento TI interno (recorre-se a um fornecedor de serviços)
- Existe departamento TI central
- Existe um departamento local de TI nesta área operacional

19) Qual o estado das suas soluções de segurança TI?

	Solução implementada	Solução em desenvolvimento	Solução planeada	Não é relevante para nós
Segurança no armazenamento interno de dados				
Segurança dos dados através de serviços em nuvem				
Segurança das comunicações para troca interna de dados				
Segurança das comunicações para troca de dados com parceiros de negócio				

20) Utiliza serviços nuvem?

	Sim	Não, mas estamos a planear	Não	Não é relevante para nós
Segurança no armazenamento interno de dados				
Segurança dos dados através de serviços em nuvem				
Segurança das comunicações para troca interna de dados				
Segurança das comunicações para troca de dados com parceiros de negócio				

21) Os produtos já vêm equipados com funcionalidades baseadas em tecnologia de informação e comunicação (TIC)? Que funcionalidades são essas?

	Sim	Não
Produtos com memória		
Auto informativos		
Integração		
Localização		
Serviço de apoio		
Monitorização		
Informação do objeto		
Identificação automática		

22) Analisa os dados recolhidos na fase de utilização?

- Sim
- Não. Recolhemos dados, mas não os analisamos nem utilizamos
- Não, não recolhemos dados na fase de utilização

23) Se sim, qual é a finalidade da recolha?

- Desenvolvimento de produto
- Apoio ao serviço de vendas
- Serviço pós-venda
- Análise do comportamento dos utilizadores
- Outros serviços

24) Os dados de processo recolhidos nas fases de produção e de utilização permitem novos serviços? Oferece tais serviços?

- Sim, e estamos integrados com os nossos clientes
- Sim, mas sem integração dos nossos clientes
- Não

25) Qual a importância dos serviços baseados em dados, no seu departamento, nas receitas da empresa?

Nenhuma

- Contribuem em menos de 1%
- Contribuem em menos de 2.5%
- Contribuem em menos de 7.5%
- Contribuição mais significativa, inferior a 10%
- Contribuição importante superior a 10%

26) Qual o nível de utilização dos dados recolhidos no seu departamento?

- Dados não utilizados
- 0-20% dos dados recolhidos são utilizados
- 20-50% dos dados recolhidos são utilizados
- Mais de 50% dos dados recolhidos são utilizados

C

Appendix C. Support Documentation for the Interviews

C.1 Invitation to participate on the stakeholder's panel

Exmo.(a). Senhor(a),

Enquadrado no programa doutoral em Engenharia Industrial da Faculdade de Ciências e Tecnologia da Universidade NOVA de Lisboa, este contacto pretende a vossa colaboração para a continuidade do estudo sobre a adoção das novas tecnologias da indústria 4.0 na península de Setúbal, enquadrado no Projeto "*Driving I4.0*", disponível em: http://drivingi40.unidemi.com/index.html.

A primeira fase do estudo, já se encontra realizada. Desta forma, todos os pressupostos estão garantidos para o início da segunda fase do estudo.
A segunda fase do estudo tem como objetivo a projeção de cenários para 2030 no tecido industrial da península de Setúbal, relativamente à adoção das tecnologias facilitadoras da indústria 4.0. O objetivo destas projeções é pensarmos estrategicamente no futuro por forma a nos preparamos para o receber.
Os métodos de trabalho desta segunda fase passam por algumas pequenas entrevistas com recurso a plataformas de comunicação online (cerca de 15 minutos). Esperamos contar com a vossa importante colaboração para juntos podermos atingir o objetivo do estudo, ou seja, prepararmo-nos para receber o futuro.

Aguardo o vosso contacto.

C.2 Remote interview presentation to the stakeholders' panel

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

UNIVERSIDADE NOVA DE LISBOA

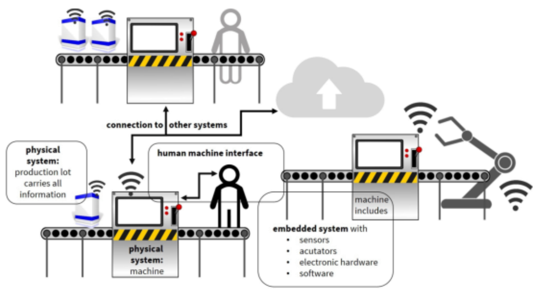
Os Desafios da Fábrica Inteligente para 2030

Vítor Alcácer, Francisco Araújo

Junho de 2021

"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

CONTEÚDOS



- **INDÚSTRIA 4.0**
  - Conceitos e objetivos
- **AS TECNOLOGIAS DA INDÚSTRIA 4.0**
- **A FÁBRICA INTELIGENTE**
  - A Smart Factory da Indústria 4.0
  - Componentes da Smart Factory
- **DESENVOLVIMENTOS DE TECNOLOGIAS DA INDÚSTRIA 4.0**
- **INCENTIVOS PT 2030**
- **VISÃO DA INDÚSTRIA 4.0 PARA 2030**
- **OBJETIVOS ESTRATÉGICOS PARA ATINGIR A VISÃO 2030**

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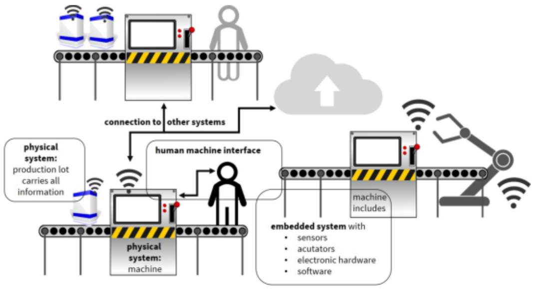
2

CONTEÚDOS



- **INDÚSTRIA 4.0**
  - Conceitos e objetivos
- **AS TECNOLOGIAS DA INDÚSTRIA 4.0**
- **A FÁBRICA INTELIGENTE**
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- **INCENTIVOS PT 2030**
- **VISÃO DA INDÚSTRIA 4.0 PARA 2030**
- **OBJETIVOS ESTRATÉGICOS PARA ATINGIR A VISÃO 2030**

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2

“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

INDÚSTRIA 4.0

- **A REALOCAÇÃO DAS ATIVIDADES INDUSTRIAS:**
  - A estratégia da redução de custos de produção resultou na deslocação das atividades industriais para países de mão-de-obra low-cost;
  - De forma a alterar esta estratégia, o setor industrial, de vários países, envolveu-se num compromisso para a recuperação da competitividade, aliciando a recuperação do seu tecido industrial;
  - Na Alemanha em 2011 foi lançado um novo *heading* com o nome *“Industrie 4.0”* e rapidamente foi adotado como a Quarta Revolução Industrial;

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3

"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

A FÁBRICA INTELIGENTE

DESENVOLVIMENTOS

INCENTIVOS

VISÃO PARA 2030

OBJETIVOS 2030

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

INDÚSTRIA 4.0

- **PRINCÍPIOS DE CONCEÇÃO:**
  - Interconexão – colaboração (máquinas e pessoas), *standards* e segurança;
  - Informação clara – fornecimento de informação para análise, processamento e transformação de dados;
  - Decisões descentralizadas – utilização de informação local e global em simultâneo;
  - Modularidade – produção de acordo com a procura do mercado;
  - Adaptabilidade – sistemas produtivos que se otimizam de acordo com as condições;
  - Assistência técnica – assistência virtual e física.

4

"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

A FÁBRICA INTELIGENTE

DESENVOLVIMENTOS

INCENTIVOS

VISÃO PARA 2030

OBJETIVOS 2030

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

INDÚSTRIA 4.0

- **ABORDAGEM DO CONCEITO PARA SISTEMAS PRODUTIVOS;**
  - A matéria-prima no seu fluxo em chão de fábrica, de máquina em máquina, numa constante comunicação em tempo real com as máquinas;
  - A Fábrica Inteligente pode ser definida como uma fábrica que reconhece o contexto, auxilia pessoas e máquinas na execução das suas tarefas.

5

“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
- A FÁBRICA INTELIGENTE
- DESENVOLVIMENTOS
- INCENTIVOS
- VISÃO PARA 2030
- OBJETIVOS 2030

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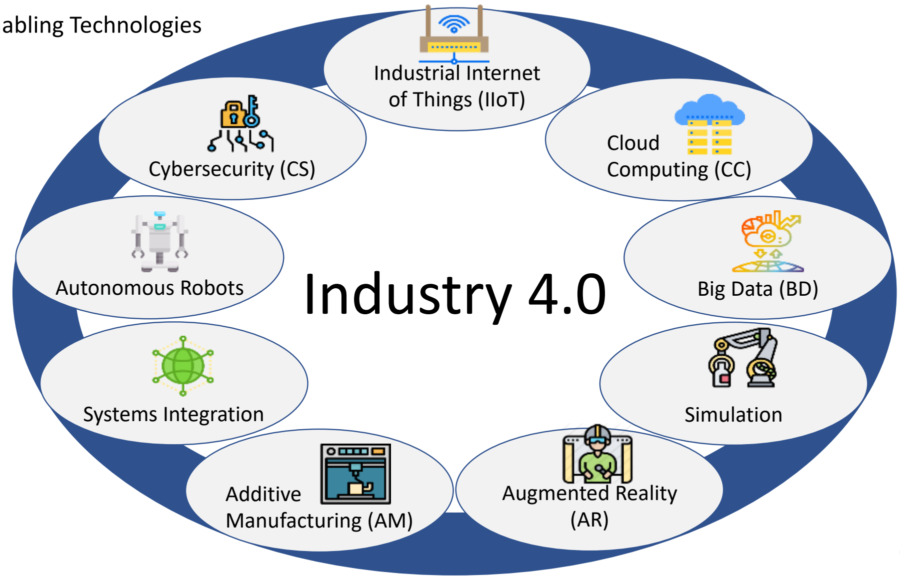
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Enabling Technologies



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
- A FÁBRICA INTELIGENTE
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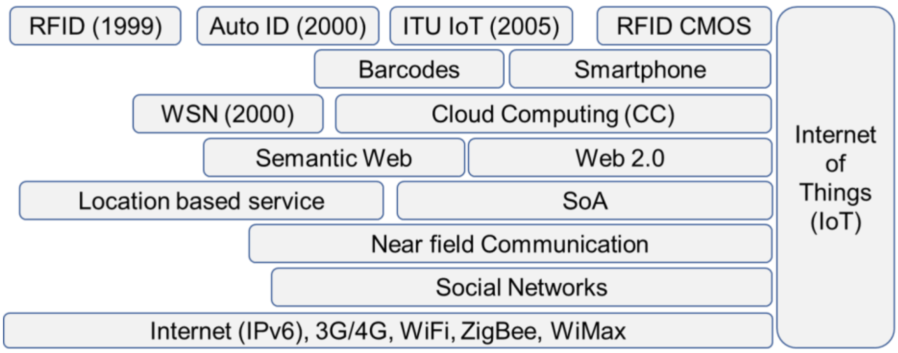
- OBJETIVOS 2030

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Industrial Internet of Things (IIoT):



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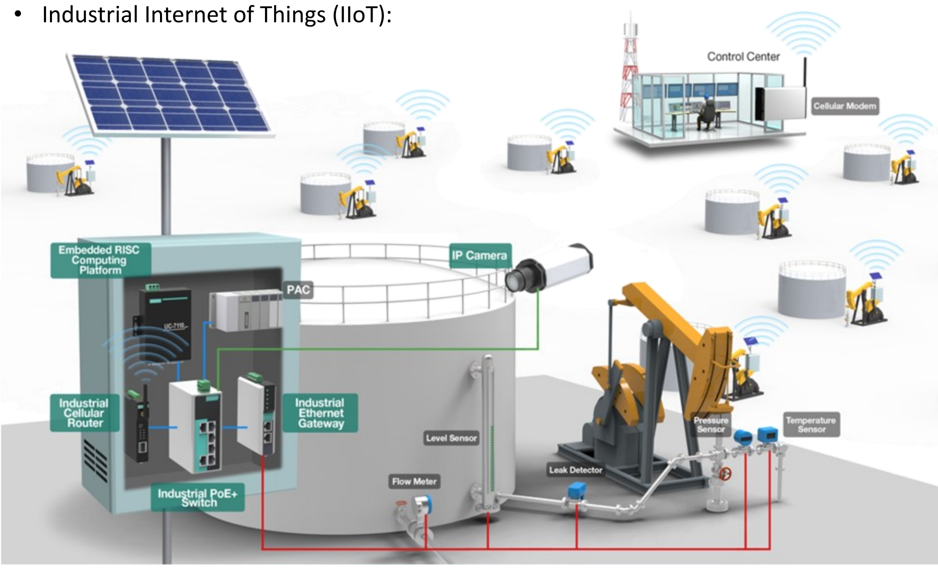
“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Industrial Internet of Things (IIoT):



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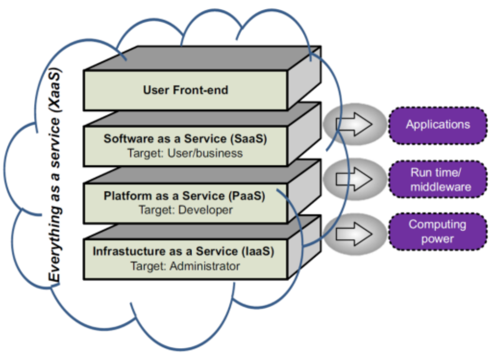
“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Cloud Computing (CC):



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"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

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- AS TECNOLOGIAS DA INDÚSTRIA 4.0
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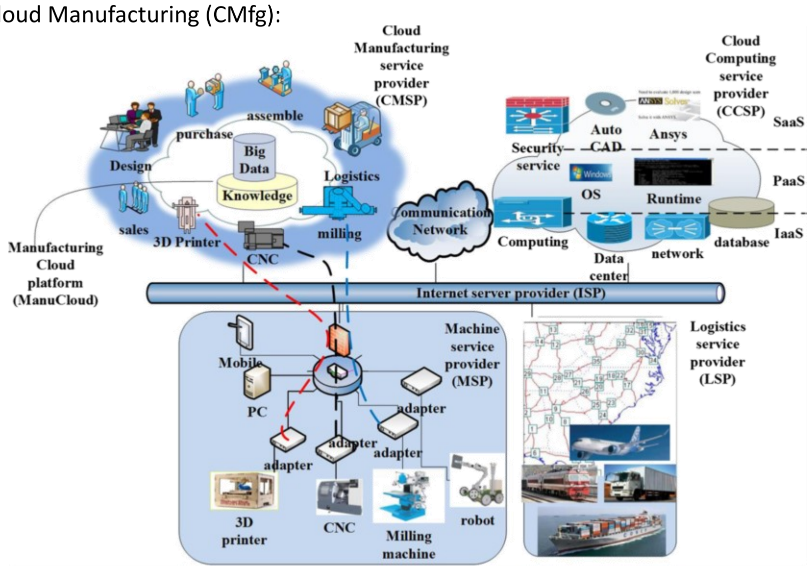
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Cloud Manufacturing (CMfg):



"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
- A FÁBRICA INTELIGENTE
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- VISÃO PARA 2030
- OBJETIVOS 2030

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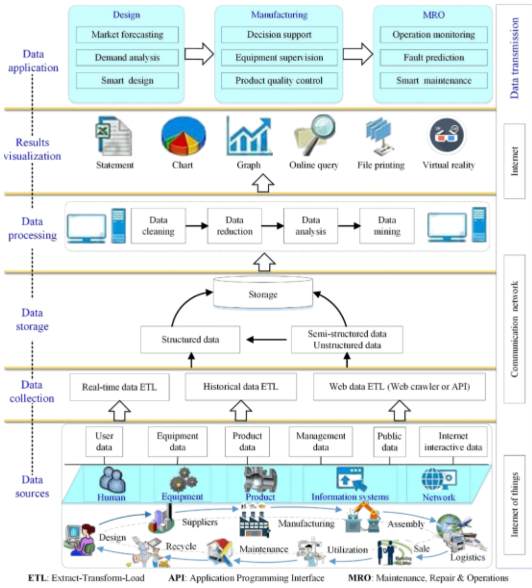
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Big Data (BD):



“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

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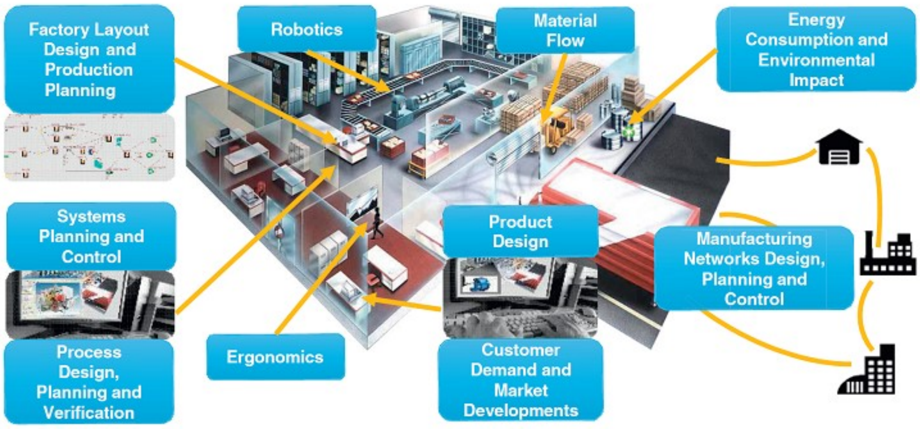
NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Simulation:



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

A FÁBRICA INTELIGENTE

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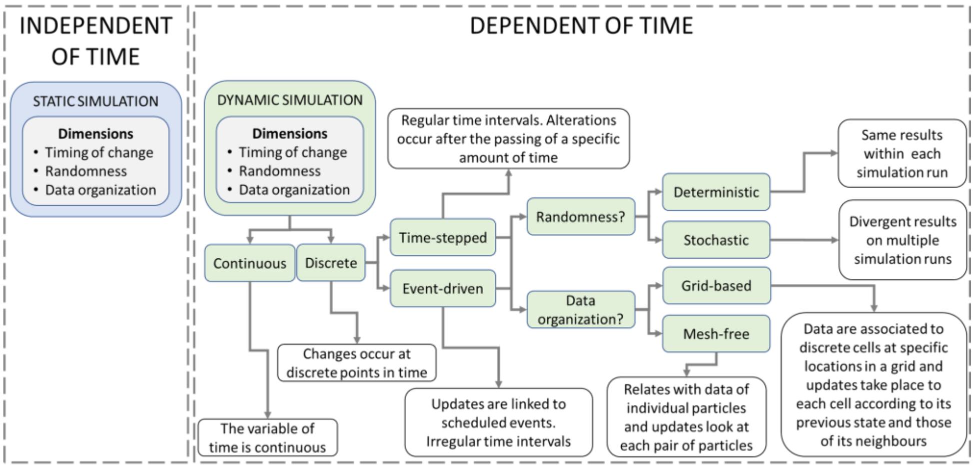
NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Simulation:



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

A FÁBRICA INTELIGENTE

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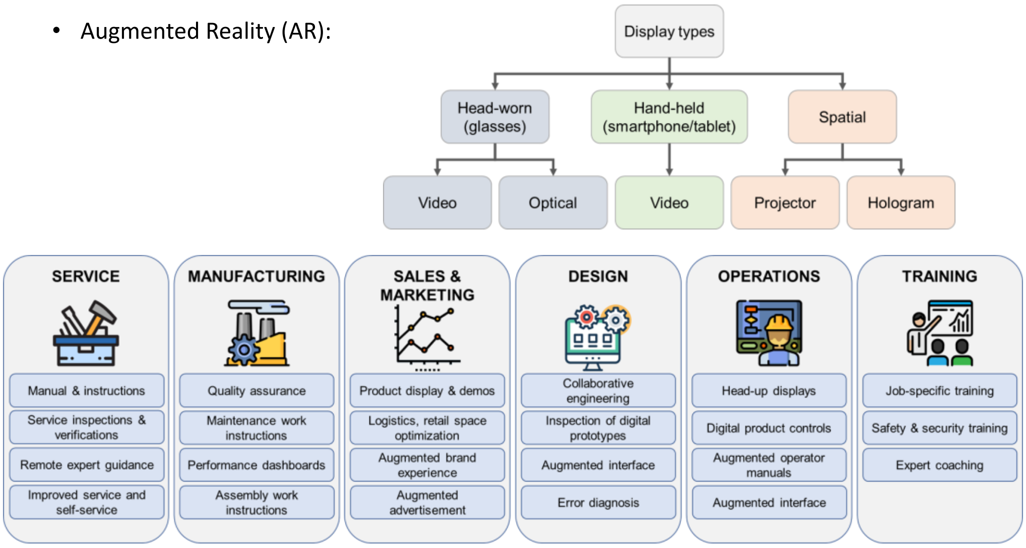
NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Augmented Reality (AR):



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

INDÚSTRIA 4.0

AS TECNOLOGIAS DA INDÚSTRIA 4.0

A FÁBRICA INTELIGENTE

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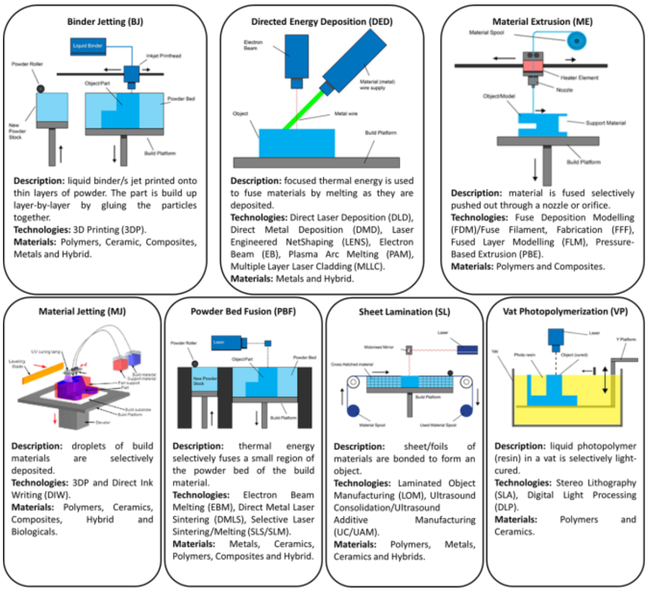
NOVA SCHOOL OF SCIENCE & TECHNOLOGY

AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Additive Manufacturing (AM):
- ISO/ASTM 52900:2015.



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
- A FÁBRICA INTELIGENTE
- DESENVOLVIMENTOS
- INCENTIVOS
- VISÃO PARA 2030
- OBJETIVOS 2030

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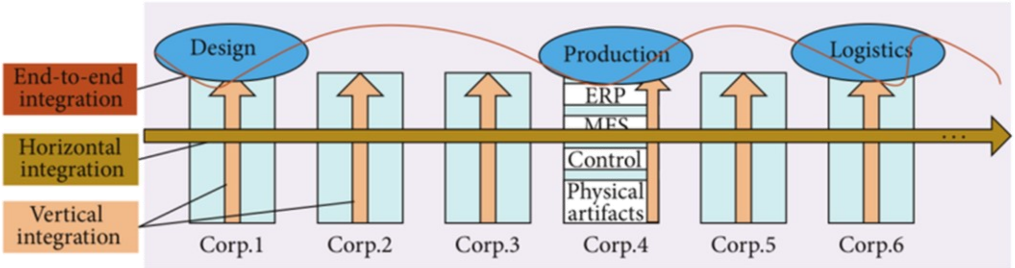
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Systems Integration:



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
- A FÁBRICA INTELIGENTE
- DESENVOLVIMENTOS
- INCENTIVOS
- VISÃO PARA 2030
- OBJETIVOS 2030

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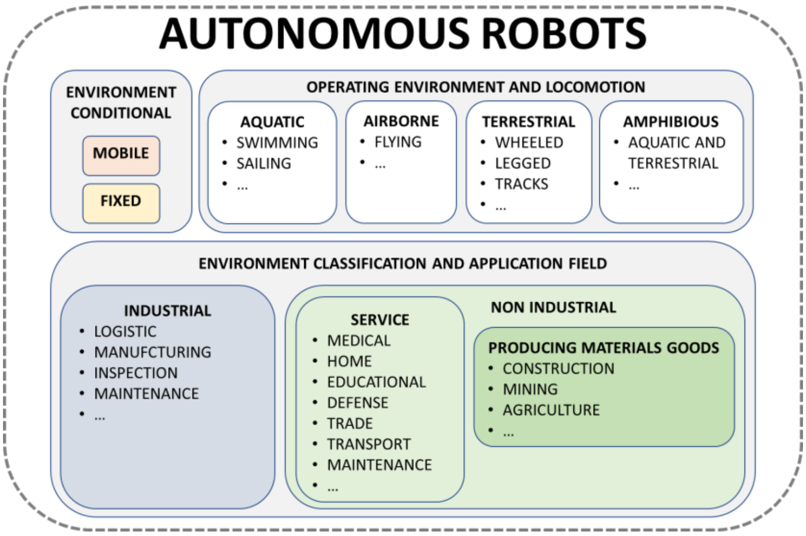
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Autonomous Robots:



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"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

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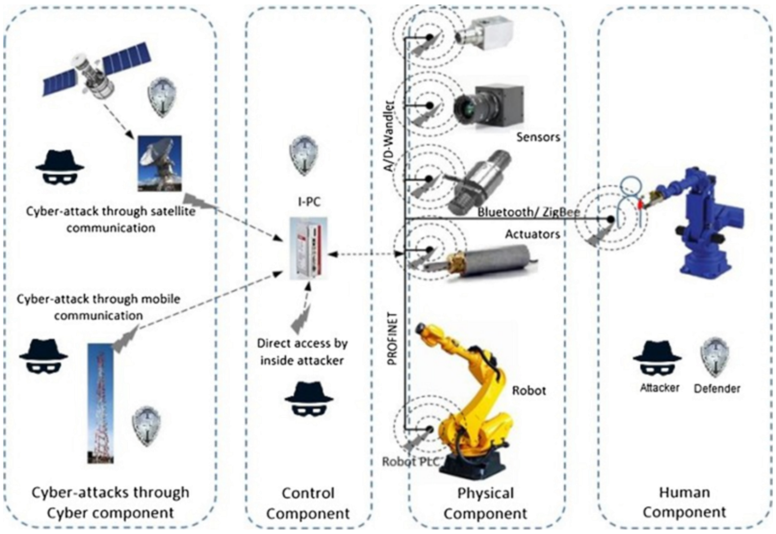
AS TECNOLOGIAS DA INDÚSTRIA 4.0

- Cybersecurity (CS):



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"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

INDÚSTRIA 4.0
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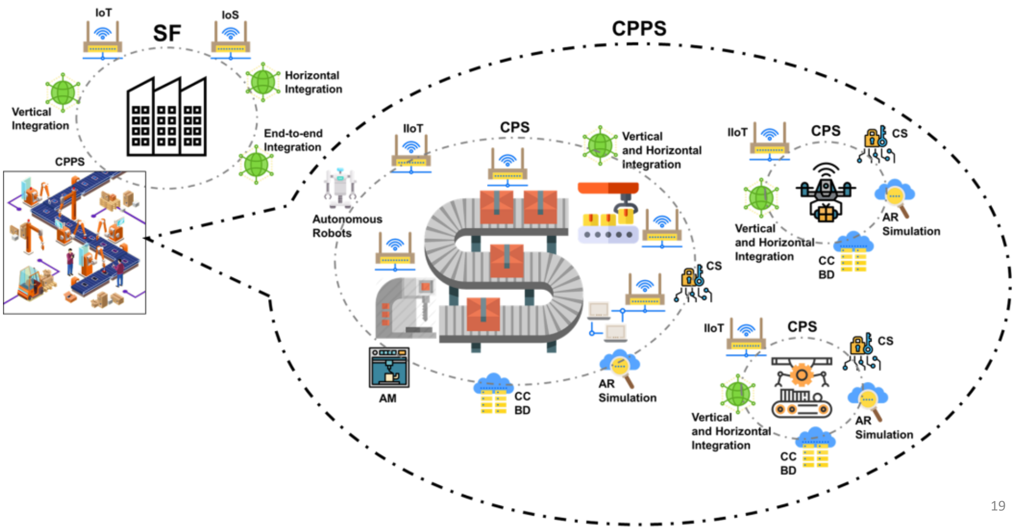
INCENTIVOS
VISÃO PARA 2030
OBJETIVOS 2030

NOVA SCHOOL OF SCIENCE & TECHNOLOGY

A FÁBRICA INTELIGENTE

- Smart Factory (SF):



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“OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030”

- INDÚSTRIA 4.0
- AS TECNOLOGIAS DA INDÚSTRIA 4.0
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SOLUÇÕES PARA A FÁBRICA INTELIGENTE

- Augmented Reality (AR):

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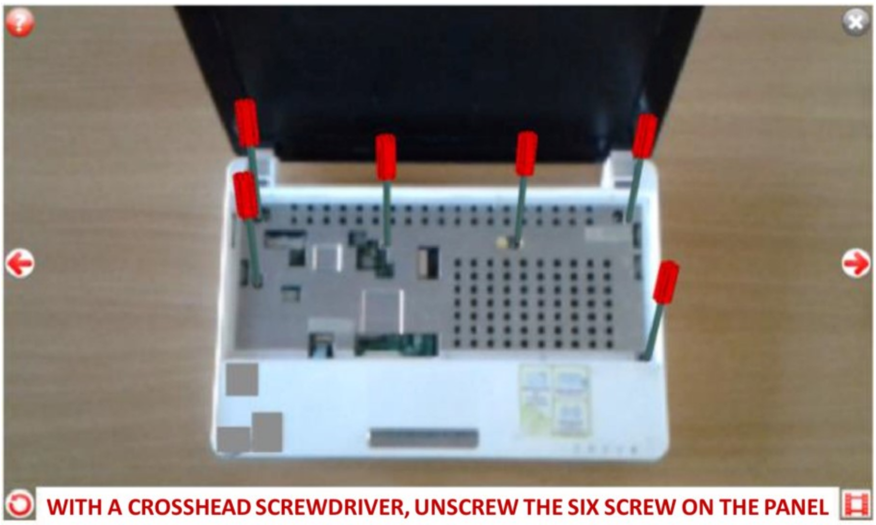

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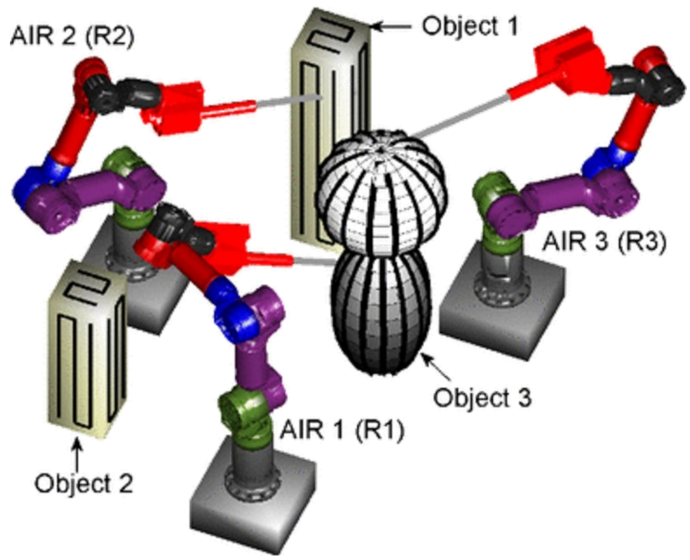
SOLUÇÕES PARA A FÁBRICA INTELIGENTE

- Autonomous Robots:



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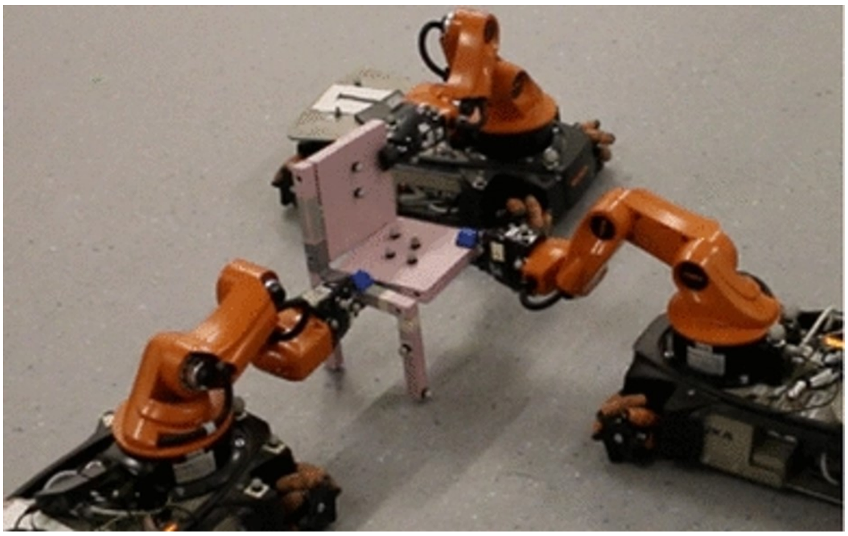

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REQUISITOS PARA A FÁBRICA INTELIGENTE

- Garantir bases sólidas da Indústria 3.0;
- Pensar em atingir ambientes *Lean*;
- Mapeamento de fluxos;
- Conhecer o conceito da indústria 4.0 e encontrar oportunidades de melhoria;
- Planear a transformação iniciando com um projeto piloto;
  - Implementação passo a passo;
  - Medir resultados e melhorias;

Pensar grande e começar pequeno!

- *"Scanning the Industry 4.0: A Literature Review on Technologies for Manufacturing Systems"*, disponível em: https://doi.org/10.1016/j.jestch.2019.01.006;
- *"Tracking the Maturity of Industry 4.0: The Perspective of a Real Scenario"*, disponível em: https://doi.org/10.21203/rs.3.rs-200705/v1;
- *"Industry 4.0 Maturity Follow Up Inside a Value Chain: A Case Study"*, disponível em: https://doi.org/10.21203/rs.3.rs-431651/v1.

"OS DESAFIOS DA FÁBRICA INTELIGENTE PARA 2030"

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INCENTIVOS PARA HORIZONTE TEMPORAL 2030

- **ESTRATÉGIA PORTUGAL 2030**:

Agenda 1	Agenda 2	Agenda 3	Agenda 4
As Pessoas Primeiro: um melhor equilíbrio demográfico, maior inclusão, menos desigualdade	Digitalização, Inovação e Qualificações como motores do desenvolvimento	Transição climática e sustentabilidade dos recursos	Um país competitivo externamente e coeso internamente
1.1 Sustentabilidade demográfica	2.1 Promoção da sociedade do conhecimento	3.1 Descarbonizar a sociedade e promover a transição energética	4.1 Competitividade das redes urbanas
1.2 Promoção da inclusão e luta contra a exclusão	2.2 Inovação empresarial	3.2 Tornar a economia circular	4.2 Competitividade e coesão na baixa densidade
1.3 Resiliência do sistema de saúde	2.3 Qualificação dos recursos humanos	3.3 Reduzir os riscos e valorizar os ativos ambientais	4.3 Projeção da faixa atlântica
1.4 Combate às desigualdades e à discriminação	2.4 Qualificação das instituições	3.4 Agricultura e florestas sustentáveis	4.4 Inserção territorial mercado ibérico
		3.5 Economia do mar sustentável	

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INCENTIVOS PARA HORIZONTE TEMPORAL 2030

- **ESTRATÉGIA PORTUGAL 2030 (Agenda 2)**:
  - Enfrentar os bloqueios das qualificações e da competitividade e transformação estrutural do tecido produtivo;
  - Resposta aos novos desafios tecnológicos e societais associados à transição digital e à indústria 4.0;
  - Resposta às novas dinâmicas de crescimento setorial pós-COVID.

2030 PORTUGAL

ESTRATÉGIA PORTUGAL 2030 DOCUMENTO DE ENQUADRAMENTO ESTRATÉGICO

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VISÃO DA INDÚSTRIA 4.0 PARA 2030

- **DEFINIÇÃO DE MATURIDADE (Schumacher et al., 2016):**
  - *"The maturity of an enterprise is seen as the state of progression of internal and external conditions under the concepts of horizontal, vertical, and end-to-end engineering integration of I4.0 on manufacturing systems."*

- **COMO SE PODE DESCREVER A MATURIDADE DA INDÚSTRIA 4.0 EM 2030 NA INDÚSTRIA DA PENÍNSULA DE SETÚBAL?**

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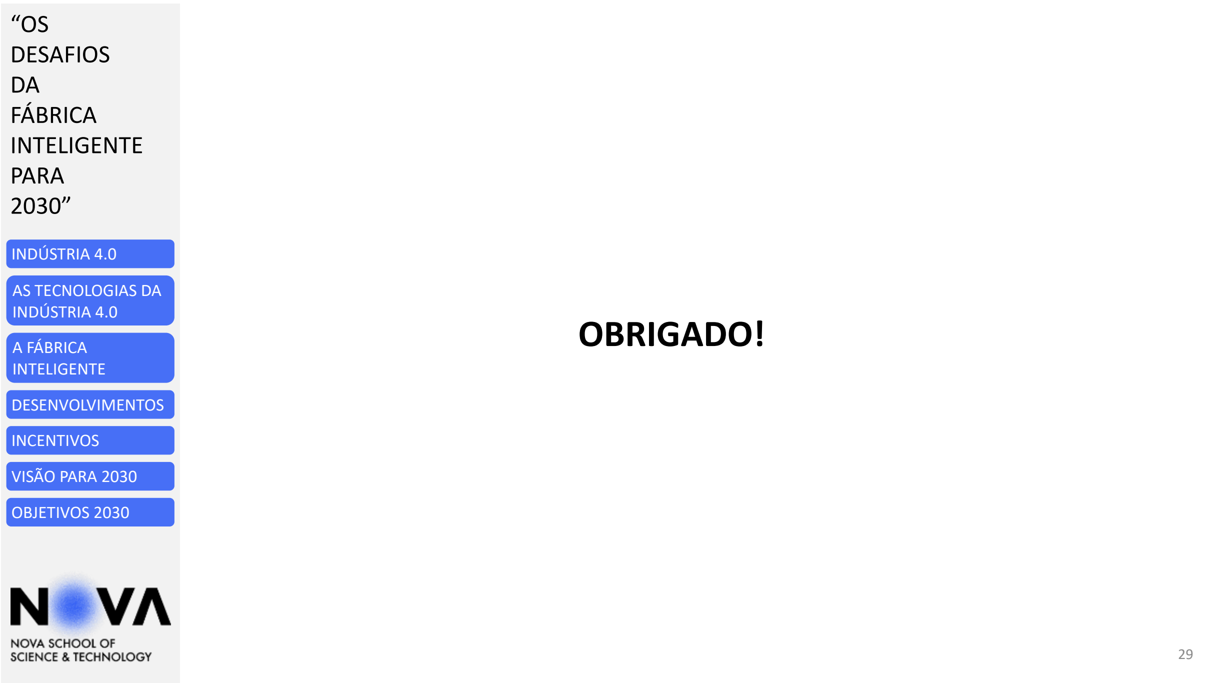

C.3 Excel Spreadsheet to interview the key-experts' panel

Questionário
Nome:
Empresa:
Cargo:
Contacto:

Glossário:
Apetite ao risco - nível de risco que uma organização está disposta a aceitar na prossecução dos seus objectivos, antes que qualquer acção seja determinada como necessária para o reduzir

Escala de Lickert:
0 - Não relevante
1 - Muito reduzida(o)
2 - Reduzida(o)
3 - Alguma(o), algo reduzida(o)
4 - Alguma(o), algo elevada(o)
5 - Elevada(o)
6 - Muito elevada(o)

Categorias de risco	SWOT	Riscos	Nível de Ocorrência (1-2-3-4-5-6)	Nível de Impacto (1-2-3-4-5-6)	Apetite ao Risco (1-2-3-4-5-6)
RC1. Cibersegurança	Ameaça	R1. Perda de informação sensível			
	Ameaça	R2. Espionagem industrial			
	Ameaça	R3. Sabotagem industrial			
	Ameaça	RS1. Chantagem cibernética			
RC2. Mão de obra	Ameaça	R4. Desaparecimento de empregos			
	Ameaça	R5. Falta de mão de obra com a qualificação necessária			
	Fraqueza	R6. Novos requisitos de formação			
	Ameaça	R7. Novos requisitos de formação			
	Ameaça	R8. Possibilidade de a mão de obra percecionar a indústria 4.0 como aumento da vigilância			
	Ameaça	RS2.Saída de trabalhadores para outras empresas			
	Oportunidade	RS3. Reconversão de talento			
	Fraqueza	RS4. Contratação de talento			
RC3. Concorrência	Ameaça	R9. Aparecimento de novos concorrentes			
	Ameaça	RS5. Surgimento de produtos inovadores			

Categorias de risco	SWOT	Riscos	Nível de Ocorrência (1-2-3-4-5-6)	Nível de Impacto (1-2-3-4-5-6)	Apetite ao Risco (1-2-3-4-5-6)
RC4. Estrutura Organizacional	Fraqueza	R10. Estratégia de curto prazo			
	Fraqueza	R11. Resistência e cultura organizacional			
	Fraqueza	R12. Dificuldades na implementação da indústria 4.0			
	Fraqueza	RS6. Agilidade e flexibilidade da estrutura organizacional			
	Oportunidade	RS7. Agilidade e flexibilidade da estrutura organizacional			
RC5. Infraestrutura	Oportunidade	R13. Fiabilidade das infraestruturas			
	Ameaça	R14. Fiabilidade das infraestruturas			
	Ameaça	R15. Maturidade tecnológica			
	Oportunidade	R16. Existência de infraestruturas de rede			
	Fraqueza	R17. Existência de infraestruturas de rede			
	Ameaça	R18. Existência de infraestruturas de rede			
	Força	R19. Interoperabilidade			
	Oportunidade	R20. Interoperabilidade			
	Fraqueza	R21. Interoperabilidade			
	Ameaça	R22. Interoperabilidade			
	Fraqueza	RS8. Dificuldade em encontrar soluções para a infraestrutura			
	Fraqueza	RS9. Maturidade tecnológica			
	Fraqueza	RS10. Fiabilidade das infraestruturas			
RC6. Legais	Ameaça	R23. Proteção de dados			
	Ameaça	R24. Crescente complexidade legal			
	Ameaça	RS11. Alterações de taxas e impostos			

Categorias de risco	SWOT	Riscos	Nível de Ocorrência (1-2-3-4-5-6)	Nível de Impacto (1-2-3-4-5-6)	Apetite ao Risco (1-2-3-4-5-6)
RC7. Sustentabilidade	Fraqueza	R25. Desperdício			
	Ameaça	RS12. Alteração da legislação			
	Oportunidade	RS13. Desperdício			
RC8. Novos modelos de negócio e condições de mercado	Ameaça	R26. Instabilidade na procura			
	Ameaça	R27. Requisitos mais exigentes de individualização de produto			
	Força	R28. Conhecimentos sobre modelos de negócio assentes em dados			
	Oportunidade	R29. Conhecimentos sobre modelos de negócio assentes em dados			
	Fraqueza	R30. Conhecimentos sobre modelos de negócio assentes em dados			
	Oportunidade	RS14. Requisitos mais exigentes de individualização de produto			
	Oportunidade	RS15. Transações online			
	Oportunidade	RS16. Procura crescente de mercado			
RC9. Financeiros	Fraqueza	R31. Obsolescência tecnológica			
	Ameaça	R32. Obsolescência tecnológica			
	Ameaça	R33. Investimentos ineficientes			
	Ameaça	R34. Custo de mão de obra			
	Ameaça	R35. Retorno do investimento incerto			
	Fraqueza	RS17. Liquidez / gestão de tesouraria			

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DRIVING MANUFACTURING SYSTEMS FOR THE FOURTH INDUSTRIALREVOLUTION

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2023

VÍTOR ALCÁCER

DRIVING MANUFACTURING SYSTEMS FOR THE FOURTH INDUSTRIAL REVOLUTION

UNIVERSIDADE NOVA DE LISBOA