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"OPERATIONAL EXCELLENCE, DIGITAL TECHNOLOGIES AND BEHAVIOURAL PRACTICES: A CONFIGURATIONAL APPROACH"

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LIST OF ABBREVIATIONS

ERP	Enterprise Resource Planning
EU	European Union
GIM	Green Intelligence Manufacturing
GIS	Geographic Information System
GPS	Global Positioning System
HCPS	Human Cyber Physical System
HDT	Human Digital Twin
HRC	Human Robot Collaboration
HRM	Human Resource Management
ICC	Intraclass Correlation Coefficient
INUS	Insufficient but Necessary part of an Unnecessary but Sufficient condition
IoE	Internet of Everything
IoT	Internet of Things
JA	Job Autonomy
JIT	Just In Time
MES	Manufacturing Execution System
PB	Proactive Behaviour
QCA	Qualitative Comparative Analysis
RFID	Radio Frequency IDentification
ROA	Return On Assets
SPS	Systematic Problem Solving
TPM	Total Productive Maintenance
TQM	Total Quality Management

INTRODUCTION

A business approach purely focused on profit and technological performance is no longer sufficient. The issues of environmental sustainability and employees' well-being in the workplace are becoming increasingly socially relevant. Industry 5.0 aims to implement the current economic and production system by placing technological and production performance together with values of human centricity, sustainability, and resilience. Although this approach is promising, it is still in its early stages of development. In this dissertation, the question was posed on what conditions make it possible to efficiently implement the Industry 5.0 approach within a company. In order to do that, the technological and the human aspects were considered. In particular, the focus was on the behavioural practices adopted by workers and practices that facilitate the diffusion of the human-centricity principle. Literature suggest that they are practices of operational excellence.

A qualitative comparative analysis was conducted on data from different manufacturing companies which investigated what are the combinations of operational excellence, digital technologies and behavioural practices that lead to superior performance. The configurations considered in this study consist of just in time, proactive behaviour, job autonomy, ERP and MES systems, and RFID systems.

From analysis it emerges that proactive behaviour and the implementation of integrated ERP and MES systems are conditions that generally lead a company to have a high ROA value in comparison to its industry. However, it is crucial to consider the entire configuration set with a holistic approach. For example, the effect of implementing just in time is not always the same: it depends on the organisational environment and contingencies that influence the work characteristics. The configurations analysed in this study show that just in time leads to ROAs above the industry average when its implementation makes the operator feel connected to the production needs of the entire production chain. In this way, the worker has to make operational decisions, which increase the perception of job autonomy. However, this implementation tends to impose standards and rules that limit task variability and reduce proactive behaviour. Moreover, if the rules imposed are dictated only by the need to make an implemented technology work, operators reduce their perception of job autonomy. This is the case revealed by the analysis of the implementation of RFID systems.

In order to delve into every aspect of the analysis conducted and the results that emerged, this thesis is structured as follows. The first part describes the Industry 5.0 approach, the reasons why it was developed and the pillars on which it is based. Subsequently, a brief literature review of studies concerning Industry 5.0 is provided. The third chapter introduces the research question and the methods used to answer it. In the fourth chapter, the results are reported. Finally, the findings are interpreted with the aid of the existing literature.

1. THE NEW INDUSTRIAL REVOLUTION: INDUSTRY 5.0

1.1 Industry 5.0 - Concept

'Industry 5.0 recognises the power of industry to achieve societal goals beyond jobs and growth to become a provider of prosperity, by making production respect the boundaries of our planet and placing the wellbeing of the industry worker at the centre of the production process' (Directorate-General for Research and Innovation European Commission & Müller, 2020). With these words, the European Commission formally refers to the fifth industrial revolution. This concept is very different from the definitions of the other industrial revolutions. The four previous revolutions were all driven by a radical change in production technology. Steam power started the first industrial revolution. Subsequently, Taylor's division of labour and the assembly line developed by Henry Ford led to the birth of mass production. Later, the Internet era led to a new revolution, the third. Finally, the idea of merging the physical and virtual worlds through cyber-physical systems initiated the fourth industrial revolution. Instead, Industry 5.0 turns out to be more of an approach that aims to steer the development of companies in a new direction. Centre for European Policy Studies highlighted how the industry 4.0 approach has developed as a framework for the digital transformation of companies (Renda & Schaus, 2021). The European Commission agrees that this is not enough to best address the current socio-economic and environmental situation. Industry 5.0 was born with the aim of extending and complementing the 4.0 approach by setting wider purposes. These aims are identified in the three pillars 5.0: human-centricity, sustainability and resilience (Directorate-General for Research and Innovation European Commission et al., 2021).

The idea behind this is that a purely profit-oriented business approach is no longer sufficient. For people everywhere, particularly for the younger generation, people's well-being and environmental sustainability are increasingly important issues. They are not issues that can be put on the background. On the contrary, a reversal in society's values seems to be taking place in these days. There is a shift from a society of profit to a society of sustainability, both for the environment and for people's well-being. Indeed, we are living through years marked by large waves of voluntary resignations of workers, who are no longer willing to accept high-stress situations. Moreover, the climate is marked by events that make climate change increasingly perceptible. All this, while the world is recovering from the Covid-19 pandemic. From this situation, the European Commission outlines the three basic pillars on which it builds the Industry 5.0 concept.

It is believed that companies are the actors who can really drive a change in this direction. Industry 4.0 has enabled them to exploit new technologies to increase efficiencies and reduce costs. The 5.0 approach aims to push companies towards strategic and systemic approaches to innovation based on the values of human-centricity, sustainability and resilience.

The definitive ambition should be to have 5.0 companies leading the European community towards a new type of society based on more sustainable values. Put worker welfare at the centre of the production process and develop economic growth models that respect the planet's production limits. (UNI – Ente Italiano di Normazione, 2021).

Industry 5.0 is a complement to the fourth industrial revolution, which the European Union is promoting in order to drive social change to meet the environmental and socio-economic challenges of the future.

For this reason, before proceeding with the detailed analysis of this approach, it is necessary to delve into the origins and nature of the industry 4.0 framework.

1.2 Industry 4.0 – Concept

Industry 4.0 is the next phase in the digitization of the manufacturing sector, driven by disruptive trends including the rise of data and connectivity, analytics, human-machine interaction, and improvements in robotics (McKinsey, 2022).

The first time that Industry 4.0 was mentioned was during the Hannover Fair in 2011 where the “Zukunftsprojekt Industrie 4.0” (Future project Industry 4.0) was pre-announced as part of the German high-tech strategy. In 2013, Acatech (the German academy of engineering sciences) published a research agenda and implementations recommendations at the request of the Federal Ministry of Research (BMBF). This document describes the impact of human-machine interactions and describes new digitalisation approaches for manufacturing with a focus on the Internet of Things. From that moment on, Germany first, and later the whole of the European Union, started to push their manufacturing companies towards digitalisation of their processes. In Europe, companies that adopt the technologies characteristic of this industrial revolution are rewarded with certifications and economic bonuses. The goal of the European Commission was to steer its economy to become more globally competitive.

However, the fourth industrial revolution remains a global phenomenon, and even though there has been a governmental institutional push in Europe, companies all over the world have started to adopt the new revolutionary technologies.

Factories using internet-connected devices, machinery and/or production systems that are able to collect, share and process data and change their behaviours accordingly are called smart factories (Shrouf et al., 2014). These production facilities are characterised by the cooperation between all elements present: machines with men and machines with machines. They have IT infrastructures that allow easy sharing of data and, finally, they have a strong propensity to make the production process more efficient in terms of energy savings, thus reducing costs. The emergence of these new technologies and, in particular, of systems enabling the interaction between the physical and the virtual, called cyber-physical systems, were the real key to the fourth industrial revolution. These technologies that have both enabled the emergence of Industry 4.0 and allowed it to develop are called enabling technologies.

1.2.1 Industry 4.0 – Enabling technologies.

Enabling technologies are crucial when it comes to Industry 4.0. The advent of these technologies has enabled the development of a new industrial revolution. This has had a key impact on the way of doing business, on the economy and on the society in a broad sense.

According to Boston Consulting Group (2015), there are nine pillars of technological advancement. Some of these technologies were already present within the production processes of companies for some time. Their use, however, has profoundly changed.

The first enabling technology is Biga Data. Indeed, with the development of computers and their computing power, it is now possible to make decisions based on an analysis of a huge amount of data. The most interesting aspect is the source of this data. They can originate from outside the company, such as external reports or databases, and they can also have an internal origin. In fact, internal processes are equipped with detection systems that allow a large amount of data to be stored, which, when processed, provide a complete view of a given situation. Furthermore, data from several different sources can be considered in these analyses. It is possible to put together information from market research, with data on the production efficiency of a machine and current market trends for example. In this way, make a business decision is extremely quicker, more comprehensive and efficient.

The use of these new forms of analysis have partly enabled the development of the second type of enabling technologies: autonomous robots. The use of robots in production plants was already widespread in factories around the world even before 2010. The great innovation of this new generation of devices is their ability to perform completely autonomously the entire process step for which they are programmed. Moreover, being connected to all other machinery in the production process. Thanks to internet of things, an enabling technology that it will be discussed later on this paragraph, they are also able to adapt their performance to the general conditions. Furthermore, they are machines capable of interacting with human operators in an extremely safe manner. With the implementation of artificial intelligence, they can also 'learn' from their previous work and autonomously optimise their way of working.

The third technology is simulation. Simulation software are software that allows the creation of virtual models capable of reproducing possible real-world conditions. Using these models, it is possible to test certain product functionalities even before they are produced. This allows to speed up the research and development process. It also reduces costs and increases the efficiency of newly developed products. Particularly relevant are the simulations used in safety-related tests.

The fourth enabling technology has already been partly covered in the previous points. It is the horizontal and vertical system integration. This term refers to the ability to connect and allow different systems, machines and devices to interact with each other. This connection is possible thanks to an advanced use of the Internet. Communication within the same department or production function is identified as horizontal integration. While vertical integration is that between different departments or stages of the same process.

One of the most important enabling technologies is the Internet of Things. This general concept is used to identify all “smart devices”. These are devices equipped with sensors capable of collecting various numbers and types of information. The peculiarity of these objects is that they are autonomously capable of analysing some of the information they collect. In this way, it is possible to programme them so that they make decisions autonomously without having to query. This makes it possible to be quicker and more flexible. These devices can also be connected in a single network allowing them to act as one large entity.

The sixth enabling technology is cyber security. As we have now entered a world in which all this enormous amount of data is stored and transmitted via internet, it is essential to protect the information contained therein. Cybersecurity refers to all those software and cryptographic procedures that allow data access to be restricted to designated users only.

As a consequence of the use of biga data, there is also a need for new forms of storage. This is how the cloud was born. This technology makes it possible to provide anyone with enormous virtual storage space. Furthermore, by using virtual storage that it is not physically hold, there are several advantages. The first is related to the maintenance, which is centralised and carried out by professionals. Secondly it is also possible to access this service at relatively low prices. Because of economies of scale of sharing one central and virtual warehouse.

Another enabling technology is additive manufacturing. This concept refers to a new way of producing physical products. Traditionally, this was done by cutting, finishing and then assimilating various parts. This involved generating waste and scrap. Sometimes it was also necessary to move various pieces in order to assemble them. With additive manufacturing, the philosophy of production is completely changed. In fact, the basic idea is to build an object through the gradual addition of material. This contrasts with the logic of cutting and finishing, which aim to subtract material in order to obtain the desired shape. The most significant example of this technology is 3D printing. It allows an object to be created with a single machine. In addition, the use of material is limited to the necessary amount, reducing costs and environmental impact. 3D printing does not require the handling of parts and their subsequent assembly. Finally, with this method, it is possible to construct parts with articulated designs more easily. Customisation of parts is also easier as setup times are very short, and it is easier to achieve one-piece flow production.

The latest enabling technology identified by the Boston Consulting Group is augmented reality. Of all nine, this is the most immature and still under development and implementation. This technology makes it possible to implement human vision with the visualisation of digital elements. In this way, it is possible to increase the amount of information available at the time of a particular action. For example, an operator can view work procedures directly on the product or machine he is working on. It can also be very useful in 3D simulation as it can make the testing experience more realistic and complete.

When describing an enabling technology of Industry 4.0, one often has to refer to other of the nine pillars. This underlines how the real revolution was not brought about by a single innovation. Precisely, the key aspect of Industry 4.0 is connection. The connection of multiple devices to each other, the connection of devices to humans and the connection of multiple technological innovations to each other. This new way of connecting is the real revolution. The result of that are the so-called cyber-physical systems.

The underlying objective of these systems is to streamline production processes by making them more precise, flexible and cost saving. One effect of this efficiency is a reduction in the consumption of raw materials and energy, which has the indirect effect of reducing environmental impact.

1.3 Three Pillars of Industry 5.0

After introducing Industry 4.0 and its enabling technologies, it is possible to delve further into the concept of Industry 5.0. In this section, the three fundamental pillars of this new industrial, economic and social approach will elaborate.

As discussed in the previous section, the main focus of Industry 4.0 revolves around the advent of new technologies and their use. The focus is directed towards process efficiency; towards reducing costs at the same time as increasing productivity, flexibility and quality. The desired end effect is an increase in profit. This is why these technologies have been developed and why companies around the world have started to adopt these new production systems.

The fourth industrial revolution also had a social and environmental impact. It has reduced the use of the planet's resources and completely changed the use of labour in production facilities. However, when it comes to Industry 4.0, these issues are seen as an indirect effect.

Industry 5.0 aims to complete this path, which has so far been developed with regard to economic and technological aspects, in such a way as to also integrate social and environmental aspects.

The new values on which the European community intends to base the new production system are identified in the three pillars of Industry 5.0: human-centricity, sustainability and resilience.

1.3.1 Human-Centricity

One of the main goals of Industry 5.0 is to put human at the centre. In recent years, the focus on the development of new technologies and digital infrastructures has led to humans being put in the background. The idea of the European Commission is to encourage the development of initiatives that are aimed at the well-being of the worker. The aim is to stimulate large investments in this direction, on a par with the investments made in the last ten years to update the technology of production facilities.

Human centricity for the European Commission often means safeguarding its citizens. In this sense, numerous initiatives have been taken such as the drafting of the General Data Protection

Regulation and the regulation of the use of artificial intelligence. In industry, this priority is translated into securing employment.

Every industrial revolution, by definition, changes the production and economic model. This has always led to the modification of many professions, the birth of new ones and even the elimination of some. As far as the fourth industrial revolution is concerned, this has resulted in an increased probability of job loss for those engaged in the manufacturing and assembly sectors (Shuttleworth et al., 2022). On the contrary, opportunities for high-skilled workers have increased (Bonekamp & Sure, 2015). In general, the demand for jobs has grown for anyone with a high level of education and/or very specific and in-depth technical expertise, regardless of the sector and subject. However, the most significant increase was seen in the demand for digital skills (Tandi, 2022). Digital skills encompass a range of basic to highly advanced skills that enable the use of digital technologies and, in addition, all basic cognitive, emotional or social skills necessary for the use of digital technologies (Kiss, 2017).

Despite the fact that these skills are in such high demand, and that they increase the likelihood of finding a job, on average, in Europe only 54% of people aged 16 to 74 possess basic digital skills (Eurostat, 2022). Undoubtedly younger individuals have significantly higher percentages than older ones. However, in the 25-55 age group, where the majority of active workers are found, the percentage of people with basic digital skills is around 40% (Tandi, 2022). Furthermore, the geographical distribution of these skills is not uniform. And among the four European countries with the lowest percentage there is Italy (around 45%).

From this situation it can be concluded that digitisation on the one hand has brought benefits to companies in terms of profit and efficiency, but on the other hand has not brought the same benefits to workers. Digitisation can lead to the creation of a gap that can bring pain and unemployment to some people. For this reason, when talking about Industry 5.0 and human centricity, the European Commission first envisions initiatives to ensure education and training for workers (Directorate-General for Research and Innovation European Commission et al., 2021). There is already a number of policy initiatives envisaged in the EU Skills Agenda that goes in that direction. In the Digital Education Action Plan (2021-2027) the European Commission highlights its vision for high-quality, inclusive and accessible education and training system fit for the digital age.

The aim is to ensure that everyone has equal access to the benefits generated by new technological innovations. This safeguards people's jobs and enables them to expand their opportunities for growth. At the same time, it develops a society that is more competitive globally, and this is another strategic objective that Europe intends to pursue.

Of course, this is not the only goal of identifying human centricity as a pillar of Industry 5.0. Indeed, by placing a relevant focus on the worker, it is intended to try to increase his or her well-being by reducing his or her stress and work-related disease.
Central to this new industrial revolution is mental health, which World Health Organization defined as "*a state of wellbeing in which every individual realises his or her own potential, can cope with the normal stresses of life, can work productively and fruitfully, and is able to make a contribution to her or his community*".
Among the effects levied by the fourth industrial revolution is the increased risk of work-related distress. Job insecurity and the fear of not being sufficiently trained or that job may be automated in the future grow. This growth is related to the increasement of skills required by employers and the complexity of tasks (Brougham and Haar, 2018; Nazareno and Schiff, 2021). This reinforces the importance of improving peace of mind to the worker and the importance of providing adequate training and education to all citizens. Indeed, the certainty of one's abilities reduces the anxiety associated with overly demanding jobs. The negative effect of this policy could be the reduction of the work-life balance. By requiring workers to be more and more prepared in order to be certain of not losing their jobs, there is a risk of a knock-on effect leading to an increase in cases of bornout. That, according to the World Health Organization is a syndrome conceptualized as resulting from chronic workplace stress that has not been successfully managed.
Balancing work effort is also an issue analysed by the European Commission. Human centricity also means pursuing policies to ensure adequate benefits and welfares and guaranteeing a healthy work-life balance.

1.3.2 Sustainability

Another pillar on which Industry 5.0 is based is sustainability. This theme can have many facets. There are various types of sustainability, and the European Union believes that they are all part of the key to meeting the challenges of the future. In fact, even when talking about human centricity, however, we are talking about sustainability. In that case we refer to sustainability in terms of health and balance for workers.
This pillar refers to environmental sustainability. Climate change has been a scientifically proven fact for years now and recently its effects have become increasingly visible to all. This

poses a huge threat to the entire ecosystem in which we all live, and in order to preserve it, it is essential to act in a way that reduces the impact of human actions on the environment.

Industry 4.0 innovations have led to increased efficiency in production systems and reduced costs. This implies that new production facilities are able to generate less waste and scrap. This makes it possible to limit the use of natural resources. Furthermore, the reduction in costs is also due to the reduction in energy consumption. These benefits relate to individual companies or production facilities. The benefit of reduced energy consumption may in fact be due to the fact that machines are faster and/or produce less waste. This makes the individual process step more energy efficient.

On an overall level, the issue deserves further investigation. Historically, industrial revolutions have always led to an increase in global production and consumption. This has led human beings to use more natural resources. Each revolution is based on a new technology using a specific raw material. For the first, it was coal. For Industry 4.0, the technology is the digital, the virtual, something intangible. However, this is based on the use of electricity that is produced using natural resources.

In any case, innovation over the past 30 years has sought to increase overall energy efficiency and reduce consumption. Between 1990 and 2026, in end-use sectors, this efficiency has been improving by a total of 30%, at an annual rate of 1.4%. But in recent years the situation has worsened. Efficiency is still improving, but this process has been slowed down considerably. In 2005, in particular, the improvement went from 2.2% to 1.2% (Lapillone, 2020). Certainly, this is not related to specific digital 4.0 innovations. However, it is important to note that the general trend is slowing down, and this could be detrimental in the long term.

Another fact that is important to take into account when considering the environmental impact of Industry 4.0 was given by Frans Timmermans, executive vice-president for the European green deal, during a press release in 2020. He points out that currently only 12% of raw materials and secondary resources are fed back into the economy.

The circular economy and the reuse of materials is something Industry 5.0 strongly wants to work on. Indeed, by recycling resources, the efficiency of each natural source would be increased, and its consumption and environmental impact would be significantly reduced.

Actually, the European Union, by putting sustainability at the centre of a new industrial and economic system, wants to focus on reducing energy consumption and reducing the impact on the environment, both in terms of consumption and emissions. These goals are being pursued with Industry 5.0 and beyond. In fact, the European Green Deal was presented in December 2019. It constitutes an agreement between the 27 countries of the European Union in which all commit themselves to the above-mentioned objectives. The pact is part of the strategic line for European growth.

There are eight key areas that make up the Green Deal (Fetting, 2020):

- Increasing the EU's climate ambition for 2030 and 2050
- Supplying clean, affordable, secure energy
- Mobilising industry for a clean and circular economy
- Building and renovating in an energy and resource efficient way
- A zero-pollution ambition for a toxic-free environment
- Preserving and restoring ecosystems and biodiversity
- Farm to Fork: a fair, healthy and environmentally friendly food system
- Accelerating the shift to sustainable and smart mobility

In general, the agreement sets two main deadlines: 2030 and 2050.

The ultimate goal is to make Europe the first climate neutral continent by 2050. Accordingly, several intermediate targets have been set. By 2030, the aim is to reduce greenhouse gas emissions by 55% compared to 1990 levels. It is also intended to plant three billion new trees. By 2050, the aim is to make Europe the first continent with zero greenhouse gas emissions. Furthermore, by that date, the aim is to decouple economic growth from resource consumption. There is also a long series of initiatives all aimed at environmental sustainability. The idea is also to convey that the ecological transition is not simply an ecological initiative. Companies that undertake paths towards reducing their emissions and impact are companies that become more competitive, both in terms of production and in terms of appealing to new resources. Today, more and more young people are sensitive to these issues and are looking for companies with which they can share core values.

For this reasons European Commission believed that companies should be the first ones to convey environmental sustainability messages and initiatives, and thus it supports the Industry 5.0 approach.

1.3.3 Resilience

The last pillar of Industry 5.0 is resilience. This value has become increasingly important since the Covid-19 pandemic. The pandemic revolutionised the world, including the economic and production system, within a couple of weeks. It showed the whole world how the 'old normality' could collapse in a matter of hours and how few things could be certain. Especially during 2020 and the first European ‘lockdown’, the employment situation was precarious for everyone. This highly dramatic situation has had many negative impacts in many areas and has forced society to adapt. A new normality was rebuilt to cope with the emergency. Faced with this situation, the European Commission identified an opportunity.

As society has been forced to build a new normality, this gives room for the possibility of not going completely back to the pre-covid situation. Even though we have emerged from the emergency, the European Commission wants to promote the development of a new normality model, namely that of Industry 5.0. In this way, the issues of human centricity, sustainability and resilience can be given greater emphasis. The latter is to be understood as stabilising. It is the pillar that makes it possible to maintain the stability of this new economic and social system that we aim to build through 5.0 initiatives.

The resilience pillar aims to ensure that production and economic models, based on new technologies and implementing the policies promoted in the strategic plan of the European Union, will be able to withstand possible future shocks. This value is extremely relevant in this historical period when uncertainty about tomorrow is very high. This is due to social changes, climate change and wars on the borders of European territories.

In order to ensure this stability within the 'next generation EU' plan, € 750 billion has been allocated. This money will be used to invest at the public level and to invest privately mainly in strategic supply chain policies and behaviour. One of the priorities identified by the European Commission is to ensure an autonomous and self-sufficient supply chain for all production activities within Europe.

With these policies, the aim is to increase the resilience of the whole system. It is also important to consider that the resilience of a system is given by that of its weakest sub-system. In this case, therefore, personal resilience must also be considered, in addition to systemic resilience (Romero & Stahre, 2021). By focusing on the individual dimension, the aim is to stimulate the emergence of cooperation systems between man and machine. They are made possible by the behaviour of human operators who first have to trust these new technologies. Therefore, it is important that operators are enabled to perform their work safely and that they are sufficiently trained. They must have skills that enable them not to suffer from anxiety of being replaced by a machine. In this sense, individual resilience is part of the human-centredness elements discussed earlier in this section.

1.4 Enabling technologies for Industry 5.0

To conclude a description of Industry 5.0, it is also necessary to mention its enabling technologies. As mentioned above this new industrial approach was born as an evolution of Industry 4.0 and is based on 4.0 technologies. The main innovations are related to the three pillars identified by the European Union: human-centricity, sustainability and resilience. These pillars are to be understood as issues to be considered in the management of the technological aspect. They are values that are meant to guide corporate strategic choices in order to build a better and new society.

However, the technological aspect remains fundamental when it comes to Industry 5.0. Although it is a direct result of the enabling technologies 4.0, it is interesting to delve into it. Industry 4.0 was born about ten years after 4.0 and in that time the use of technologies has varied greatly and led to some significant changes.

Generally, six categories of enabling technologies for Industry 5.0 are identified. Reference is made to the classification proposed by Julian Müller and the Directorate-General for Research and Innovation of European Commission (2020).

1- Individualised Human-machine-interaction.

   These technologies refer to all those tools that enable the development of cyber-physical systems. These systems have been the main output of the fourth industrial revolution.

   These kinds of enabling technologies allow the creation of systems of machines and humans. This takes place at the physical level; we speak of collaborative robots ('cobots') which are devices designed to perform all the productive tasks necessary to support the operator. Interaction can also take place on a cognitive level, combining human creativity with digital computing power. This is referred to decision support software. Then there are all forms of interaction, such as devices that can handle voice commands in different languages or gesture commands. Finally, this category includes all augmented reality technologies that have already been discussed in depth as one of the enabling technologies of Industry 4.0.

2- Bio-inspired technologies and smart materials.

   Bio-inspired technologies stem from the concept that natural biological transformation can be used as an example in identifying and/or producing new materials. This leads to the development of materials that are recyclable or generated from waste. Otherwise, adaptive/responsive and ergonomic surfaces can be developed. All this up to materials that are self-repairing and self-healing. All these new technologies can also be equipped with built-in biosensors that can monitor the status of a material or an operator. This enables a much more immediate and precise response to any need. It also allows both better performing materials and increased safety in the workplace.

3- Digital twins and simulation.

This point refers to simulation, i.e. the possibility of creating digital models of real objects, phenomena or situations. This technology has also been listed among the enabling technologies of Industry 4.0. Of all the enabling technologies identified by Müller, this is the only one that almost totally echoes one of those identified by the Boston Consulting Group for 4.0. The new definition here emphasises the term 'digital twin' to stress how it is possible to design, test and analyse the data of a product/phenomenon without actually having to do so in reality, but by exploiting its digital version. By now, this version can be identified as a twin in that it is extraordinarily similar to the real version, in all its behaviours.

4- Data transmission, storage, and analysis technologies.

This category includes all developments in four of the nine 4.0 pillars, namely Big Data, Cyber security, Cloud and Internet of Things. This refers to all the hardware and software tools that make it possible to collect and process the ever-increasing amount of data available at each stage of a process. Among this group of technologies, it is interesting to delve into sensors. In fact, a series of devices, even extremely small ones, have been developed that are capable of detecting a great deal of data, thus giving rise to the whole process of analysing and storing information. Among these devices, RFID (Radio Frequency IDentification) are very popular. They are small devices that can automatically recognise, validate and/or store a set of data by connecting to and sensing other active devices in the vicinity. They are extensively used in logistics to ensure high traceability.

5- Artificial intelligence.

Artificial intelligence is the new frontier of computing. It is based on advanced analysis and correlation. Thanks to this, it is possible to find complex correlational and even causal relationships. This even in systems with different scales of measurement and dynamic situations. Thanks to this computing power, it is possible to have software that can respond to unexpected conditions without human support. Finally, interaction with humans can become extremely simple and effective. In fact, it is possible to dialogue with this software almost on a par with dialoguing with a human being. The output is complex research or processing of information that is extremely useful to support both decision-making and operational phases.

6- Technologies for energy efficiency, renewables, storage and autonomy.
As pointed out in the section on sustainability, all the technologies that characterise Industry 4.0, and consequently Industry 5.0, are based on high energy consumption. Consequently, a whole range of technologies have developed that allow for increased efficiency in the use of energy and/or allow for the production of new renewable energy. As far as energy production is concerned, the development and integration of new renewable energy sources is encouraged, and all hydrogen technologies are supported. As far as efficiency is concerned, the focus is on power-to-x technologies that make it possible to convert and store excess energy produced from renewable sources when demand is not at its peak. Finally, this group of technologies also includes all systems that enable complex data analysis or transmission with low energy consumption.

1.5 Society 5.0

Each industrial revolution has not only led to radical changes in manufacturing systems and the economy. With such drastic changes in production methods, the world of work changes and the products available to consumers also change. The relative prices of products change and so do the possibilities of access to goods and services at the same income level. In essence, every industrial revolution starts within production systems, but it generates a cascading effect that leads to substantial changes in society.

With the first industrial revolutions, the industrial society developed, which then over time became the information society, thanks to Industry 4.0 and the advent of the digital age. In this sense, Industry 5.0 will also have a social impact. In fact, the goal set by the European Commission is precisely to spur this change towards society 5.0. Industry 5.0 in this sense is the tool and the approach that is proposed to develop a broader, society-wide change.

Therefore, society 5.0 is the end point of the Industry 5.0 approach.

Society 5.0 is a vision of a future society guided by scientific and technological innovation, aiming to create a human-centred, super-smart, and lean society (Narvaez Rojas et al., 2021). The Japanese government was the first to talk about this concept in January 2016. Their goal is to harness emerging innovative technologies, such as cyber-physic systems and Artificial Intelligence, in order to solve current social problems such as an ageing population with a

concomitant reduction in birth rates and a lack of international competitiveness. These issues and goals were also common to other nations, in particular European Union decided to pursue these goals through Industry 5.0. The aim is to build a society in which all citizens are guaranteed a high-quality standard of living. This is done by acting at the level of both goods and opportunities and services. In fact, it is intended to have a wide range of innovative and technological products at prices everyone can afford. And at the same time, it is crucial for the European Union to have a society in which everyone has access to the education and training necessary to acquire all the skills required by the new labour market. In this way, every citizen will have products and services that enable them to live comfortably and have the means to access this lifestyle. All while respecting the productive limits of natural resources and reducing environmental impact. Moreover, there will be no discrimination of access to all these possibilities.
This, in short, is the vision of Society 5.0 that the European Union hopes for. All the strategic operations and policies that the European commission is implementing in the area of Industry 5.0 have the common ultimate goal of driving society towards the ideal of society just described.

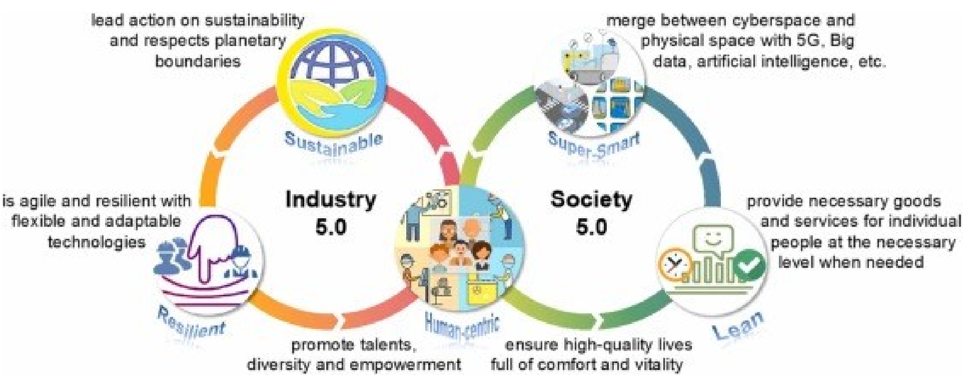

Figure 1 – Industry 5.0 and Society 5.0
Source: Huang et al., 2022

Industry 5.0 and Society 5.0 are extremely linked concentrations, as also shown in figure 1. Both aim to meet the same challenges, and both highlight the emergence of new opportunities. These possibilities are linked to the emergence of new professions and the development of various human-machine interaction systems (Huang et al., 2022).
Certainly, the development of new technologies leads to the automation of more physical and/or repetitive tasks and this may lead to the extinction of certain types of jobs. The jobs lost are counterbalanced by the emergence of new professional figures related to the development and management of the new machines. In addition, completely new subjects based on scientific

discoveries can develop. They can only be achieved through the most innovative technologies. As far as technological opportunities are concerned, these are mainly related to systems that enable and implement the interaction between machine and human, between digital computing power and human practical and logical sense. In particular, these are the human-cyber-physical systems (HCPS), the human-robot collaboration (HRC) and the human-digital twin (HDT). All developed from greentelligent manufacturing (GIM), i.e. production systems that can be extremely efficient in the use of energy and raw materials, and that have a low emission footprint in the environment.

2. INDUSTRY 5.0 LITERATURE REVIEW

2.1 Introduction to literature review

After introducing the concept of Industry 5.0 from a general point of view, the reasons for the development of a 5.0 approach were summarised and the objectives to be achieved through the deployment of Industry 5.0 were analysed. This chapter will continue to explore the Industrial 5.0 approach and will focus on scientific studies conducted in this area. Then, in the following pages, the results from the main strands of studies that have been concerned with Industry 5.0 will be reported.

In order to conduct this brief literature review, database such as Scopus and Google Scholar were used. They were searched by title, abstract and keywords. The search began with a search for general terms such as "Industry 5.0" and was then refined during the process. The following paragraphs will report on what emerged.

Before going any further, it is important to emphasise one point. The first thing that emerged from searching for articles on Industry 5.0 is that there is a lack of material on this subject. In general, there are not many articles focusing on this topic, but most of them aim to introduce the concept or they are studies in other areas that may have an impact in the development of industry and society 5.0 (Leng et al., 2022). This phenomenon is not surprising as this concept is relatively new. The European Union officially defined it for the first time in 2020. Moreover, there is a big difference to the previous concepts of Industry 3.0 or 4.0. In the past, these terms were used to describe a technological change that was taking place in the industrial world. A name was given to what was observable and already present. With Industry 4.0, people started naming the phenomenon before it was widespread with the aim of emphasising and encouraging its development, as has been the case in Germany since 2011. In any case, the change was technological and tangible, although not yet widespread. As far as Industry 5.0 is concerned, the technological change is less disruptive and not so different from that introduced by Industry 4.0. The change in this case is of a social nature. What is changing are the values that drive industrial production. Therefore, the change is less tangible and more difficult to measure. Moreover, when we speak of Industry 5.0, we are not describing a change that has spontaneously developed in society. Rather, it refers to an approach formalised by institutions that aim to drive change to enable society to meet the challenges emerging in this historical

period. Industry 5.0 is an approach that has first been formalised and defined and then it will spread.
Considering all these elements, it emerges that talking about Industry 5.0 means dealing with a topic that is extremely young and currently difficult to measure as it is still not widespread.
However, even with regard to Industry 4.0 most of the relevant scientific studies were published several years after its introduction. If we consider the branch of studies related to the development of assessment tools that measure the degree of maturity of production systems, we notice that studies in this field started to be published mainly from 2014 onwards, i.e. three years after the introduction of the Industry 4.0 concept. The peak of production in terms of scientific articles is then reached between 2018 and 2020 (Hein-Pensel et al., 2023). This shows how it can be expected that even regarding Industry 5.0, the peak production of scientific articles is still a long way off.

2.2 Industry 5.0 – Main study topics

In order to gain an overview of Industry 5.0 studies, it is first essential to search for term "Industry 5.0" as a keyword. This section summarises the content of the most relevant papers found as a result of this search.
Among the few papers founded, many of them focus on defining Industry 5.0. They try to summarise the information on the subject and investigate what kind of change it can bring and what implication it could have. In these papers, ample space is devoted to possible future research directions.
Furthermore, there is another field of study that focus on studying the technological aspect of Industry 5.0. They aim to define the enabling technologies for this new type of production and study how they can make production and/or make more efficient the human-machine interaction. In particular, the main themes of these articles seem to relate to artificial intelligence, big data, supply chain, digital transformation and machine learning. (Akundi et al., 2022).

2.2.1 Industry 5.0: Academic definition

First the articles that give a definition of the Industry 5.0 concept are analysed. Chapter 1 of this thesis already defines this concept. In order to define it, institutional sources and company reports from consulting firms were considered. The view that emerged is a general one. This paragraph is to be understood as a conclusion of the first chapter, which focuses only on academic sources.

Conducting a cluster analysis of existing literature, Dmitry Ivanov outlined a framework for Industry 5.0. It is based on the three pillars defined by the European Union: human-centricity, sustainability and resilience. The analysis shows that Industry 5.0 comprises four areas, namely organisation, management, technology and performance assessment. Moreover, it emerges that Industry 5.0 acts on three distinct levels: social level, network level and plant level. In this way, the concept of Industry 5.0 can be fully considered (Ivanov, 2023).

Industry 5.0

	Resilience	**Sustainability**	**Human-Centricity**
Society Level	*Viability of intertwined supply networks*	*Sustainable usage of resources and energy on the earth*	*Viability of human-centric ecosystems*
Network Level	*Supply chain resilience* *Reconfigurable supply chain*	*Supply chain sustainability* *Life cycle assessment of value-adding chains*	*Cyber-physical supply chains* *Digital supply chains*
Plant Level	*Resilience of manufactur-ing and logistics facilities* *Reconfigurable plants*	*Reduction of CO2 emissions* *Energy-efficient manufacturing and logistics*	*Human-machine collaboration* *Health protection standards and layouts*

Organisation:
Resilient Value Creation and Usage - Human's Well-being – Sustainable Manufacturing and Society

Management:
Viability as Integrative Perspective of Resilience, Sustainability and Human-Centricity

Technology:
Collaboration – Coordination – Communication – Automation – Identification – Data Analytics

Performance:
Efficiency – Productivity – Resilience – Viability

Figure 2 – Action level of Industry 5.0
Source: Ivanov, 2023

Industry 5.0 covers the area of management as it consists of an approach that aims to bring human-centricity, sustainability and resilience values into the management strategies of companies. They must become integrated values within the definition of the corporate mission. This inevitably leads to Industry 5.0 that also cover the area of organisation. Indeed, with the change of values within corporate strategies, it is necessary to act on the organisational level.

In this sense, it is essential to act in order to create a structure that can guarantee the well-being of workers. This structure must be created putting the human aspect always at the centre. It also must be resistant to possible external upheavals to guarantee maximum effectiveness. In fact, the other area covered by this new industrial approach is performance. Inevitably, being a productive approach, it aims to improve the efficiency, effectiveness and productivity of the realities in which it is implemented. To achieve these aims, the fourth area, technology, is crucial. The focus is on collaboration, coordination, identification, data analysis and communication. In essence, the technology aspect consists of developing advanced human-machine interaction systems and advanced analysis systems.

All this acts on a social level with the aim of creating the 5.0 society. A society in which the general level of well-being of all citizens is higher. Everyone is guaranteed a level of education and preparation to be competitive and to fit harmoniously into the new production paradigm. In every productive activity, man will be at the centre of development to best guarantee food, health, communication, mobility and every other essential good to everyone (Ivanov & Dolgui, 2021).

At the network level, this approach has implications for the supply chain. it is crucial that the entire value chain is sustainable. This is both at the economic and profit level and at the environmental level, minimising ecological impact. Furthermore, to ensure the robustness of this production chain, it is important to correctly design cyber-physical and digital systems that guarantee flexible resilience. That is, the ability of production systems to adapt to external challenges while remaining stable on the basic principles of the Industrial 5.0 approach (Aldrighetti et al., 2021). Finally, at the plant level, it emerges that Industry 5.0 focuses on designing the operator's workstation and his tasks in such a way that they are highly ergonomic, integrate as well as possible with the machines required at that stage of work, and ensure worker safety. Also considering the safety protocols that emerged during the covid-19 pandemic (Choi, 2020, Sodhi et al., 2021).

Alternatively, again in order to obtain a complete view of the Industry 5.0 phenomenon, it is possible to define it as a revolution that affects three different dimensions. They are the technical dimension, the reality dimension and the application dimension (Leng et al. 2022).

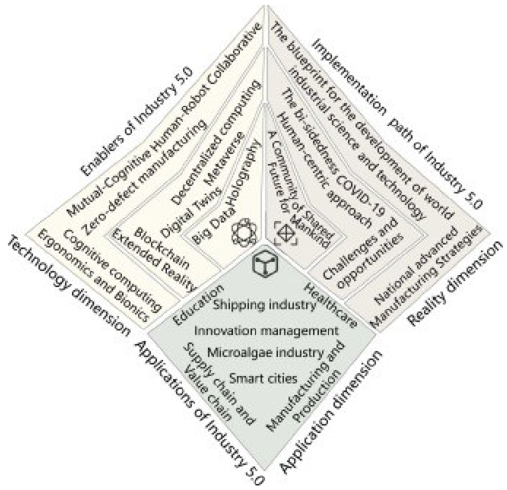

Figure 3 - Dimensions of Industry 5.0
Source: Leng et al., 2022

The technology dimension considers and encompasses the enabling technologies for the development of the industrial 5.0 system. In this framework, they are identified in human-machine collaboration, simulation, IT infrastructure and social needs.

In the previous sections, the concepts of these enabling technologies have already been discussed in detail, especially with regard to human-machine collaboration, IT infrastructure and simulation. Moreover, these topics constitute the second main strand of academic studies related to Industry 5.0. They will be discussed in more detail in the next paragraph. With regard to social needs, Leng's study refers to those practices that make a production system both resilient and sustainable. Thus, the development of more sustainable materials and the use of renewable sources are considered.

The reality dimension considers all existing governmental initiatives that aim to spread and develop Industry 5.0. Currently, besides the European Union, nations such as the United States of America, Japan, China and the United Kingdom have policies for the implementation of this production system. They all have the aim of alleviating economic declines due to decentralisation or de-industrialisation and generally promoting the competitiveness of their enterprises. They also aim to lead a recovery from the covid-19 pandemic. The pandemic period disrupted the entire world production system and generated various disruptions. But out of this situation has emerged an awareness of the need to establish a community of shared future for humanity (ACSFM). That is, an international community that acts globally in order to develop and integrate the values of the 5.0 society.

Finally, the application dimension considers all fields in which Industry 5.0 can bring benefits. Of course, these are many and include almost all production sectors. They include intelligent production based on the use of cobots, i.e. robots capable of interacting with humans, or they also include the development of new logistics possibilities and the development of Internet of Things systems useful for designing the cities of the future: smart cities. In addition, Industry 5.0 can also have an important implication in the medical field. It makes the production of customised medical implants such as artificial tissues and organs or body fluids economically viable and efficient (Haleem & Javaid, 2019).

The synergy between man and machine can also be used in the field of education. This is both with the aim of ensuring adequate training for the workers of the future, and with the aim of providing new educational tools. Indeed, enabling technologies such as augmented reality and artificial intelligence, although now extremely controversial and their use is yet to be fully regulated, constitute a rich source of new tools that are extremely useful for training and education purposes (Lantada, 2020).

2.2.2 Technological applications of Industry 5.0

This section explores the other major strand of studies related to Industry 5.0. This group of studies is interested in describing what are the enabling technologies of Industry 5.0 and what their applications might be. They analyse in what fields and with what effects. At present, these are mostly exploratory studies, as the real effect of all these technologies has yet to be observed. Moreover, each of these tools is constantly evolving.

The enabling technologies for Industry 5.0 have already been introduced in section 1.4 of this thesis. That classification refers to the one institutionally proposed by the European Union. Within the academic production, this classification is often different. The basic technologies referred to are always the same but may be classified differently. In this regard, one of the most frequently cited studies considers 12 enabling technologies. These include digital twins, cobots, artificial intelligence, big data and augmented reality (Maddikunta et al., 2022). These technologies have also been considered by the European Union and their concepts have already been introduced.

In addition, edge computing is also considered. It is the ability to analyse certain data and information in secondary devices in the network. It means that some sensors are able to record some data and perform operations on them autonomously. Then, they send the results to a central device that complete the processing. In this way, it is possible to increase computing efficiency, both in terms of time and in terms of energy consumption due to decentralisation.

This system also makes it possible to increase cyber security, as it involves several devices for a single calculation (Shi et al., 2016).
Another enabling technology is the Internet of Everything (IoE). It consists of the connection between people, processes, information and things (Li & Da Xu, 2021). Thanks to this, it is possible to find out a lot of information about possible customers interested in a product for example. This increases people's satisfaction and at the same time simplifies and speeds up the product development process. (Higginbotham, 2020)
Another enabling technology is blockchain, which allows for improved data management. Data needs to be transmitted and communicated in a reliable and secure manner. The blockchain enables this by exploiting a network of geographically distributed devices that verify the authenticity and provenance of information. This generates a system of distributed trust that is extremely secure (Viriyasitavat & Hoonsopon, 2019). Thanks to this security, it is possible to speed up the world of contracts, guaranteeing the veracity of even those concluded online, i.e. the smart contracts (Mohamed & Al-Jarooti, 2019).
Another key technology is 5G, 6G and all its future versions. Indeed, the radio infrastructure on which all modern digital communication is based is certainly fundamental. This technology is necessary for the operation of all other enabling technologies, such as edge computing, the Internet of Things and artificial intelligence (Chowdhury et al., 2020; Tariq et al., 2020). In fact, it is the technology that has the most impact in the development of the production system 5.0 (Maddikunta et al., 2022).
Finally, there are network technologies, such as network slicing and private mobile networking. They enable multiple networks to act together, or they generate local Internet connections. By combining these technologies, it is possible to interconnect multiple devices and make the most of cyber-physical systems. (Afolabi et al., 2018; Prasad et al., 2017).
One of the main areas of application of all these enabling technologies is cloud manufacturing. With this system, it is possible to locate the storage of decision-making information in a digital cloud. It is also possible processing them in remote. This makes possible to have a single processing centre for several plants and thus align a production located in different geographical areas (Akbaripour et al., 2018).
Staying within production systems, supply chain management is also strongly influenced by the development of these new technologies. In particular, in this field, studies suggest that digital twins are extremely relevant. Thanks to simulation, the entire supply chain can be reproduced virtually. For example, the supply chain structure in the pharmaceutical industry has been simulated. This made it possible to hypothesise and analyse a large number of scenarios in the

supply process as well as in the production and distribution of products. The output of this study were useful tools for the predictive analysis required to model supply chain management. (Marmolejo-Saucedo, 2020). Moreover, thanks to digital twins, it is possible to simulate the status of a product. For example, one study simulated the thermal behaviour of fruit, in particular a mango, during refrigerated transport. This made it possible to define the best transport conditions. In this case, it is the strategic logistical choices that benefit, as they can now rely on a greater awareness of the limits imposed by the transport of a perishable good. (Defraeye et al., 2019).

Leaving the manufacturing sphere, there is another sector that enjoys great development opportunities thanks to 5.0 key enabling technologies, it is healthcare. Staying on the subject of digital twins, they can be used to simulate a patient's condition and/or his or her reactions to particular interventions and medications. In this way, it is possible to increase personalisation and precision in the prescription of therapies (Reinhardt et al., 2020). To this end, it has been proven that the use of machine learning and artificial intelligence techniques has also led to an improvement in the process of diagnosing diseases (Deepa et al., 2020). In addition, the Internet of Things is being used to constantly monitor patients in need of such attention anywhere. The sensors used are capable of autonomously alerting the appropriate doctors in case of need. Finally, also cyber-physical systems have applications in the medical field. During surgical operations, thanks to these systems it is possible to improve precision and thus guarantee a greater chance of success (Haleem & Javaid, 2019).

Industry 5.0 can also be applied in the field of disaster prevention. Sukmono and Junaedi studied how the application of these technologies mitigated the effect of the earthquake in Indonesia in 2018. In that situation, the use of interconnected networks and sensors made it possible to better coordinate relief efforts. Furthermore, they discuss how artificial intelligence, machine learning and simulation technologies play an important role in natural disaster prevention and prediction (Sukmono & Junaedi, 2020).

2.3 Industry 5.0 and sustainability

Enabling technologies for Industry 5.0 aim to create an industrial system based on the three pillars identified by the European Union: human centricity, sustainability and resilience.
A review of the most relevant literature on Industry 5.0 revealed several studies focusing on the topic of sustainability. In these, it is shown how Industry 5.0 is a means to make sustainable industrial production.
A series of studies published between 2021 and 2023 by Ghobakhloo elaborate on this topic. First of all, functions were identified to promote a sustainable production system. They are value network integration, sustainable technology governance, sustainable business model innovation, sustainable skills development, work environment demarcation, manufacturing adaptability, manufacturing circularity, manufacturing production, sustainable employment, production responsiveness and renewable integration (Ghobakhloo et al., 2022).
Subsequently, the individual impacts of each were studied. The output is a roadmap identifying the main functions on which to act in order to achieve the greatest result in terms of change towards sustainable production.
The main function, the one that needs to be acted upon first, it is the integration of the value network. This function is an enabler for all others, so its effects are reflected in the other functions. Interconnection is precisely the key feature of Industry 5.0. Unlike Industry 4.0, its evolution is more focused on the interconnection of machines, people, data and computers. By interconnecting the various elements along the value chain, demand can be better predicted and managed. In this way, waste that would unnecessarily consume resources is eliminated. (Hao et al., 2018). Furthermore, interconnection reduces the risk of interruptions in the supply chain. This has a sustainable impact in the sense that it reduces the consumption required to restart a process and allows it to flow in a way that is aligned with market demand.
Another function with greater impact is sustainable skills development. It enables the dissemination of sustainability ideals to guide managers and operators in considering the impact of their actions. This makes it possible to adopt behaviours and choices that have a major impact in the long term.
Finally, manufacturing circularity is extremely relevant. It is well established that the circular economy brings benefits in terms of sustainability as it reduces the consumption of materials and resources. Economy 5.0 can extend this effect through traceability. Indeed, it is now possible to trace the history of an object and even measure its state of use. This makes possible

to use the best of its capacity and subsequently direct it towards the best reuse treatment (Ghobakhloo et al., 2023).

2.4 Industry 5.0 and human-centricity

The main difference between Industry 4.0 and Industry 5.0 are the pillars on which the new approach is based. Industry 5.0 wants to change the production paradigm, not through disruptive technological innovations, but through changing values. The fundamental idea is to no longer have a purely performance-based economic model, but a human-centred production system. In this sense, human centricity is the fundamental pillar among the three identified by the European Union.

This section aims to explore academic studies in terms of human centricity and Industry 5.0. As the topic is new and evolving, relatively few studies have been found. Of these, the most relevant and cited fall into two categories that are interesting for what it is intended to be explored in this thesis.

The first focuses on the use of enabling technologies to ensure adequate attention to human and their needs. In addition, topics related to ethics and the well-being of the operator are explored. The second focuses on management systems that favour a human-centredness, and among these emerges lean management.

2.4.1. Technologies for human-centricity

Technological advancement in recent decades has led to mechanical and digital systems that are able to perform many tasks autonomously. This possibility has rekindled a debate that has existed since the first industrial revolution, namely the issue of replacing man by machine.

Studies show that certainly some operational, repetitive and manual functions will gradually be uniquely assigned to machines. However, the management of the opportunities created by new technologies will create new jobs. Globally, it is estimated that more jobs will be created than will be eliminated, and humans will gradually shift to performing high-value tasks in manufacturing policies (Nahavandi, 2019). On the negative side of this, it must be considered that some individuals will still be adversely affected by the new production system. Older subjects will find it difficult to integrate. Furthermore, all those who cannot access to enabling technologies and training will be the disadvantaged parties in this phenomenon of change (Bernick, 2017).

This phenomenon is a constant already present in all previous industrial revolutions. What is new in Industry 5.0 is to review the use of technology even for manual tasks. In the choice between man and machine, where all previous industrial revolutions chose the machine, the fifth revolution chooses both. The idea is not to replace man but to work alongside him. This concept emerges from Industry 4.0 and in 5.0 it becomes the central pivot. Instead of using enabling technologies to improve process and performance, new technologies can now be used to understand the worker, to support, to educate and to help him. In this way, the maximum can be achieved. Mechanical speed and precision can be used alongside human judgement and common sense. This ultimately improves output and performance. But above all, this allows you to focus on the worker and his needs. (Nahavandi, 2019).

One of the ways in which technology can be used to support human beings is through sensors. Thanks to these devices, it is possible to measure certain variables that can give information about the state of a worker at any time. By having this information, it is possible to assign the most suitable task to the worker, both in terms of effort and time. Enabling technologies in this way are useful in defining the best management and organisational choices in the field of human resources.

To support these studies, Battini proposes a multi-objective work rotation model. A non-linear mathematical model that maximises the well-being of the worker by reducing aspects of boredom, fatigue and maximising aspects of safety and ergonomics. All this while taking into account an overall view of all operators and thus acting in a way that maximises the productivity of the system. The basic idea is to assign the right task to the right person. At the centre of these choices is placed the operator.

System characteristics such as safety and ergonomics are measured by creating an ergonomic risk score for work (Asensio-Cuesta et al., 2012; Otto & Scholl, 2013). In this way, it is possible to summarise a series of measurements made in a single number. For feel-good factors, the focus is on boredom. To measure it, the labour repetitiveness index is used. (Mossa et al., 2016). The largest source of information regarding well-being was a questionnaire in which each worker declared his or her state of boredom and his or her state of fatigue.

The resulting model is a mathematical formula that is capable of autonomously assigning operations to workers. This type of human resources management fully embodies the values of

Industry 5.0 in that it puts the employee's physical and mental well-being first. Overall productivity is maximised, but this is achieved based on the well-being of the individual.

The model is not linear and therefore as the number of workers increases, the difficulty in its application increases. In this sense, the enabling technologies of Industry 5.0 could be the solution. Using great deal of computing power, artificial intelligence and the Internet of Things it might be possible to develop a system that autonomously detects a series of input indicators of well-being variables and, at the same time, considers a memory in which the level of experience and competence of each worker is entered (Battini et al., 2022).

Going further into the issue of worker well-being, it is identified that the main problems brought about by enabling technologies are psychological problems identified in the lack of social interaction and competition with robots (Demir et al., 2019). These issues have already been studied in isolation, but it is the holistic approach that best allows for the identification of a system with which to build the factories of the future. Studies in this sense are still few, but those that do exist suggest a design based on Value Sensitive Design. That is, a design in which human needs are the basis.

Longo, after conducting an analysis within several companies already adapted to Industry 4.0, proposes three exemplary use cases of how engineering and design can be harnessed to ensure well-being.

First of all, sensors can be used both to perceive data about the operator, as seen above, but can also be used to extend the workers' perception of the context. These possibilities make extensive use of wearable technologies such as smart gloves or smartwatches. The second use case focuses on improving the training and education of workers through simulation and augmented reality experiences. Indeed, education is the main issue in the field of human centricity. With Industry 5.0, education is what most enables the worker to adapt to the new system and enjoy maximum well-being. Therefore, a difficulty in accessing education is one of the main problems.

The third use case is to integrate artificial intelligence with human intelligence by providing digital assistants useful in decision-making processes (Longo et al., 2020).

2.4.2 Lean management as enabler for human-centricity

Lean management was initially developed within Toyota in Japan and then it was spread globally in the 1990s. It constitutes a system of management, production planning and control and continuous improvement of processes of the entire organisation. The objective of lean management is to shorten production times, reduce production costs and at the same time increase product quality. The methodology that follows is more of a philosophy and a way of thinking and deciding rather than a list of tools (Liker, 2017).

By nature, this management philosophy is based on people. Indeed, at the centre are the end customers and the workers. Workers are regarded as the ones who actually make things happen, thus producing the end product, so it is on them that the greatest attention must be paid. They are at the centre of policies to improve their ergonomics, safety and training. The operators are also the first to be listened in order to design the continuous innovations necessary for continuous improvement. For this reason, the nature of lean management places this managerial approach very close to the values of Industry 5.0 (Mladineo et al., 2021).

As far as the quality aspect is concerned, the total quality management system emerges within the lean management world. It is a management approach first introduced by Deming. This approach has a strong focus on quality and customer satisfaction. Among the key principles of this methodology are people involvement, relationship management and customer focus. Therefore, the human component is strongly emphasised.

Based on this approach, a roadmap for the implementation of the human-centred approach was proposed. This is based on the quality circle, i.e. a group of workers who meet to discuss and find solutions to the elements that negatively affect their working environment (Anand Jayakumar & Krishnaraj, 2015).

Thanks to these working groups, it is possible to bring out the need for change towards greater human centricity directly from the workers. This creates and spreads the desire to implement new methods to innovate work roles. Subsequently, it is necessary to spread the knowledge and adequately train the people who now feel the need for change. At this point the quality circle starts its more operational work and begins to identify, analyse and propose solutions to all the problems that arise on a day-to-day level. The proposed solutions are based on proposals by the operators, which are then communicated to the management. In this way, change involves every employee at every level of the hierarchy. In the end, the most efficient solutions are implemented. From this point on, the role of quality circles is to continue to implement solutions in a way that supports continuous change and improvement (Chaabi, 2023).

Lean management is really a management model that implements human centricity in the organisations in which it is applied. To demonstrate this, Mladineo et al. conducted an extensive literature review and questionnaire from which he was able to identify the main success factors for implementing lean management and the most frequently used tools. The focus of this survey was on small and medium-sized enterprises (Mladineo et al., 2021).

This analysis shows that the main success factors are leadership, employee inclusion and employee empowerment. Among the success factors that follow, in descending order of importance, are employee training, organisation and communication. These clearly show that at the basis of lean management there are humans. Consequently, companies that decide to adopt this approach are companies that decide to change their point of view and start putting man at the centre of their focus. However, the ultimate goal remains to increase the quality of the service offered to the customer; a goal that is fully attainable. This managerial approach has spread thanks to the great achievements of the companies that first adopted it, Toyota in the first place. Thus, it can be inferred that lean management is an enabler of Industry 5.0 as it fosters the development of human-centric value and increase company's performance.

Considering the typical tools and techniques of the lean methodology, it emerges that it also conveys the other pillars of Industry 5.0, albeit to a lesser extent.

First of all, the tools are still human-centred, as the most widely used do not require the use of specific objects but are based on employee engagement. Furthermore, these techniques aim to improve the entire system and process. The goal is to be connected to demand and reduce the overall lead time. This requires the development of a flexible organisation that can adapt to circumstances while remaining fixed to its own standards. This peculiarity combines extremely well with the value of resilience.

Finally, the sustainability pillar is also linked to lean management as this approach is based on the elimination of waste. This concept stems from the idea of reducing costs and increasing quality. It certainly now becomes something more. This logic makes it easier to develop the adoption of sustainable practices (Mladineo et al., 2021).

2.5 Literature about assessment tool

To conclude the review of the existing literature in Industry 5.0, this paragraph will consider assessment tools. When one speaks about industrial revolutions, one speaks of a change in the production system, from a starting point towards an end point. Therefore, it is essential to study a system that allows to measure where a company is in this process of change. This is useful both on a global level to describe the macroeconomic situation and on a local level, considering the level of development of an individual company or plant.

The importance of the micro level has increased dramatically with Industry 4.0 in Europe. In fact, governments started to grant certifications and bonuses to companies that fulfilled an adequate level of adaptation to Industry 4.0. These policies aimed at the dissemination of more digital, modern and competitive production models. This generated the need for systems that could measure and certify a high degree of adaptation to Industry 4.0 principles.

The 5.0 approach is an industrial system that has been designed at an institutional level and that governments are keen to promote. It is reasonable to imagine that in the future merit bonuses will be awarded to companies that are more in line with the values of the three pillars of human centricity, sustainability and resilience. So, the need to measure the degree to which these values and new technologies are being adapted and implemented is existent.

In the area of assessment tool research, it turns out that there is very little academic production. As far as Industry 5.0 is concerned, there are still no studies on it. This is in line with the trend on maturity models. On average, they start to spread some years after the formalisation of the concept of a new industrial revolution. This figure is based on what happened for Industry 4.0 (Hein-Pensel et al., 2023). Furthermore, even for Industry 4.0 models, there are gaps. The first gap is at the academic level. Looking at the most comprehensive models for measuring the level of Industry 4.0, only a fraction is developed at the academic level, while most are developed privately at the industry level. This fuels the lack of academic production in this regard, as industrially developed models are made public only for general parts. The more precise details and evaluation systems are kept within the company structure (Dikhanbayeva et al., 2020).

Considering these premises, it is evident that it is not possible to analyse assessment tools for Industry 5.0, as they are not yet available. However, it is possible to study the maturity models of Industry 4.0 in order to try to identify how these may evolve towards the new measurement tools.

The concept of maturity refers to the attainment of an objective state of a system following development. This concept is based on the assumption that a series of intermediate stages between the initial stage and the mature stage exist. Maturity models describe the path of change of a system by indicating in which stage of the process it is. (Schumacher et al., 2016; Knackstedt et al., 2009).

The first to develop this type of model was Nolan, in 1973, studying the level of information technology progression within organisations (Nolan, 1973). Subsequently, these models were divided into three classes: descriptive, prescriptive and comparative.

Descriptive models identify and describe the current state of a system. Prescriptive ones also provide recommendations and guidelines for reaching the next stages of maturity. Comparative models identify and describe the current state of a system by comparing it with a similar one whose maturity stage is known in advance (Pöppelbuß & Röglinger, 2011).

By carefully analysing the maturity models of all three of these typologies, Hein-Pensel et al. came up with the top 24 assessment tools for Industry 4.0, in terms of Completeness and number of citations. Subsequently, they identified nine categories that enable the identification of aspects in Industry 4.0 that are related to the principles of Industry 5.0. The objective was to indicate how many of these categories were analysed by each maturity model. If one of these tools covers most of the areas, it could also be valid for measuring Industry 5.0 as it is very much in line with all areas related to the values of the three pillars identified by the European Union.

The categories identified are strategy and management, corporate culture, organisation and processes, products and services, employees, technology, data, customer and corporate environment.

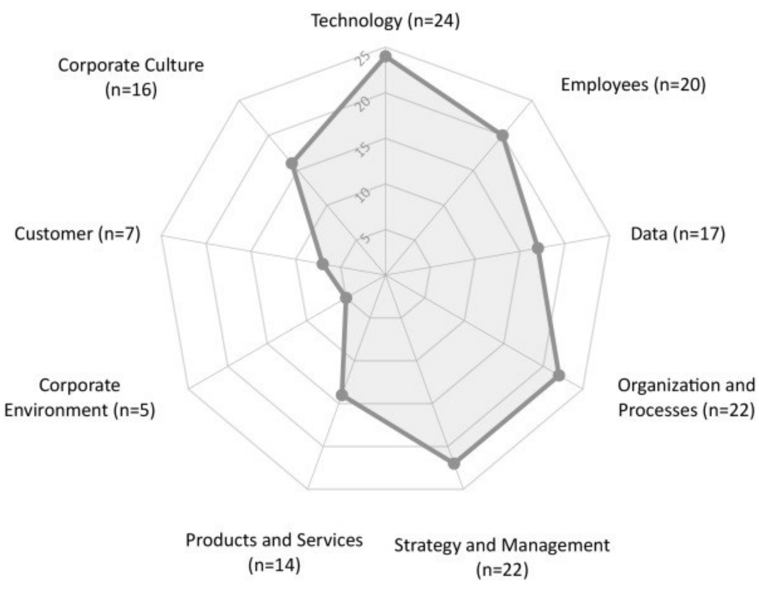

Figure 4 – Dimensions of Industry 4.0 Maturity Models
Source: Hein-Pensel et al., 2023

The analysis conducted summarises its results in the previous matrix. In figure 4, it is possible to see which areas are mostly covered. That they are the areas covered by the largest number of maturity models.
The analysis first intends to delve into the main and most recurring features within an assessment tool for Industry 4.0. It emerges that these tools are very focused on studying the degree of technological, organisational and managerial maturity. The focus is on the presence and use of enabling technologies. There is also a focus on ascertaining the degree of impact of these technologies on management. All this always using the yardstick of performance in terms of profit.
Among the most covered categories there is employees. This detail deserves further investigation. In fact, the study notes that these models have a focus on employee training. In particular, they have a deficit orientation, and they consider the lack of adequate training. Only a small percentage of the studies consider employee well-being. People orientation is never considered as a starting point, but the focus on the employee is only placed as a necessary constraint to performance. This shows that the 4.0 maturity models are not sufficient to measure the 5.0 maturity level as they do not take the human-centricity principle into account.
These are the general figures for the communicated values of all analysed maturity models. However, even in detail, no maturity model emerged that covered at least half of the categories considered. This shows that there is currently no model capable of reliably measuring the 5.0 maturity status within an organisation, considering the principles of human centricity, sustainability and resilience.
However, the models studied by Hein-Pensel et al. all cover the technology category well enough. This means that the 4.0 maturity models focus on enabling technologies. The enabling technologies of Industry 5.0 do not deviate much from Industry 4.0. They are its natural evolution. Moreover, as mentioned several times, Industry 5.0 is to be considered the evolution of Industry 4.0 where the values indicated by the three pillars are added. The technological aspect remains roughly unchanged. This means that the 4.0 maturity models can also be used to measure the technological level of Industry 5.0 (Hein-Pensel et al., 2023).

3. EMPIRICAL ANALYSIS: METHODS

3.1 Research question

The previous chapters have focused on defining and deepening what is Industry 5.0. It showed that this new economic and production system is still in its infancy, so it is difficult to measure its effects. Furthermore, with regard to measurement at the level of the individual company, the second chapter shows that there are currently no assessment tools that can indicate the level of adherence to the Industry 5.0 production model of a plant. It is only possible to measure the level of adoption of enabling technologies. This is thanks to tools designed to measure the level of Industry 4.0 adoption.

Therefore, if the goal is to measure the degree of Industry 5.0 adoption in a given territory, an appropriate tool must be developed. The most pertinent solution is to develop a survey investigating the main areas affected by the change proposed by the new paradigm.

First, it is essential to measure the technological aspect which is the foundation of any change to the production paradigm. With existing tools, it is possible to measure the degree of technological adoption of a company and the digital skills of its operators also for the Industry 5.0. Secondly, it is important to consider the fundamental principle of human-centricity. To do so, it is possible to study the behavioural practices present within the company of interest. Hence, it is necessary to interview the operators in order to study their perceptions of their daily tasks and of their working environment. As a final aspect, the managerial practices adopted within companies are considered. Indeed, Industry 5.0 stems from the enabling technologies of Industry 4.0 and implements the resulting productive change through the pillars and principles among which human centricity stands out. In order to combine these aspects within a company, it is necessary to adopt managerial practices suited to this strategic purpose. As reported in Chapter 2, literature suggest that operational excellence practices derived from the lean management culture are managerial policies that enable the development of the principle of human centricity.

These management techniques can be used to develop Industry 5.0 values, while still adhering to the goal of achieving a high performance. In fact, although the human-centred principles are shared and fundamental, in order to spread the new model proposed by the European Union, it is essential that the companies can continue to perform well enough to ensure their economic sustainability. Thus, although one of the motivations behind the shift in the production paradigm is not to put all the focus on the only output of financial performance, it still remains a key indicator. It is no longer the only and most important indicator, but it still needs to be positive for companies to start implementing Industry 5.0 principles.

Out of all this reasoning comes the question that this thesis aims to answer. Industry 5.0 is not yet a widespread paradigm, and in order to spread, it is important that it is a performing solution. Hence the question: what are the combinations of operational excellence, digital technologies and behavioural practices that lead to superior performance?

The 5.0 approach is still immature and for the time being, it is not possible to understand how well it is received by companies. Therefore, it is possible to study current companies in order to understand how they combine the various fundamental elements of the new approach. The aim is to see whether these combinations are performing. The idea is to break down the Industry 5.0 paradigm into three measurable components: operational excellence, digital technologies and proactive behaviour. Then the objective is to measure how these components can combine with each other. By studying this, it is possible to identify the configurations that perform best. These are the most interesting for an entrepreneur. In this way, Industry 5.0 is approached from a critical point of view. By studying current companies, it is possible to identify cases in which the proposed principles do not lead to financial sustainability and thus potential limits in the definition of Industry 5.0. Likewise, it is possible to identify the most efficient cases that can facilitate the adoption of the new approach.

3.1.1 Qualitative Comparative Analysis

In order to answer the research question posed, qualitative comparative analysis (QCA) appears to be the most appropriate methodology. It is both a qualitative and quantitative analysis technique. It makes it possible to capture and analyse the relationship between different combinations and degrees of implementation of conditions for a given outcome (Ragin, 2008). This technique allows the use of a configurational approach to analysing phenomena. This is made possible by dividing a phenomenon into its attributes or causal conditions. Cases are generated from the possible combinations of attributes. Each case is described by the membership degree of the causal conditions.

For example, in this thesis the cases are firms. They are described as a set of conditions that can cause the outcome, in this study financial performance. Each case (firm) is described by the presence or absence of each of the identified conditions. To do that, a score ranging between full membership to non-membership is assigned for each condition in each case. In this way, configurations can be identified. These are the combinations of conditions that are minimally necessary and/or sufficient to cause a specific outcome (Meyer et al.,1993).

Qualitative comparative analysis differs from regression models. The latter are very suitable in considering the net effect of a variable on an outcome. QCA, on the other hand, assumes conjunctural causation. This means that it is not possible to identify the effect of a single variable on the outcome. A condition that is present in a configuration that generates the desired outcome may not lead to that outcome if considered in isolation. This makes it possible to better study the complex relationships between different causal conditions. (Ragin, 2008; Fiss, 2007). Thus, QCA is very suitable for studying causal relationships in those phenomena in which there is no single causal variable, but in which different aspects contribute together to generating, or not generating, an outcome. This technique does not make it possible to identify whether among the various conditions there is one that correlates most strongly with the outcome. The focus is on identifying the configurations that generate the outcome.

An attribute of comparative qualitative analysis is that it assumes equifinality. It is able to identify the configurations that lead to an outcome, but it does not identify whether one of them is more related to the outcome than the others. This allows to go beyond the traditional logic of finding the best path to a given result. Instead, it is considered that there are multiple ways to achieve the same outcome. Each one is not more effective than the others in itself. This makes it possible to better consider the complexity of causal relationships within social phenomena (Bell et al., 2014). Indeed, it enables a fine-grained analysis of the differences between the various configurations. In this way, it is possible to define the relevance of an attribute based on how it combines with others. This makes it possible to overcome the limitations of traditional methods that consider each set as a black box (Fiss, 2007).

Finally, QCA allows for the consideration of asymmetrical relationships. This means that if a configuration generates an outcome, this does not imply that the absence of the same configuration leads to the absence of the outcome (Woodside, 2013).

Given all these properties, a qualitative comparative analysis was deemed appropriate to investigate all possible configurations of operational excellence, digital technologies and behavioural practices that perform financially. This analysis makes it possible to study the relationships between the conditions related to the elements of Industry 5.0, ensuring a comprehensive view of all variables simultaneously.

Qualitative comparative analysis is based on Boolean algebra. This means that this analysis allows numbers to be analysed in binary logic. However, there are two types of qualitative comparative analysis, crisp set QCA and fuzzy set QCA. The crisp set is characterised by

considering the presence or absence of a condition in a configuration as a dichotomous variable. In this case a variable may be present, case associated value 1, or it may be absent, case associated value 0. In contrast, the fuzzy set QCA also incorporates fuzzy set theory (Zadeh, 1965) and allows the degree of presence of each variable to be measured with a continuous value ranging from 0 to 1. The fuzzy set qualitative comparative analysis was used for the analyses performed to answer the research question of this thesis.
The QCA produces as solutions a set of configurations that lead to outcome. In order to assess the goodness of these solutions, there are 2 main measures: coverage and consistency. Both measures provide values between 0 and 1.

Consistency indicates the degree to which the terms of the solution and the solution as a whole are subsets of the result (Ragin, 2006). In fuzzy set theory, a subset relation is indicated when membership scores in one set (i.e. a condition or combination of conditions) are consistently lower than or equal to membership scores in another set (i.e. the outcome) (Zadeh, 1965). The membership score is the value between 0 and 1 associated with each condition analysed by the qualitative comparative analysis. These values indicate the degree to which a condition is present within an observed configuration. If, for example, the membership scores in a combination of conditions are consistently lower than or equal to their corresponding membership scores in the outcome, then a subset relationship exists, which in turn supports a sufficiency argument. The measure of this subset relationship is consistency. In other words, consistency measures the degree to which a condition or configuration is sufficient to produce the outcome. It is a measure of the relationship between cause and outcome. For example, if a condition has a consistency value of 1, this means that whenever the outcome is present, the condition is also present.
The consistency measure for the sufficiency relationship is calculated using the following formula:

$$\text{Consistency}\ (\text{Xi} \ \leq\ \text{Yi}) = \frac{\Sigma(\min(\text{Xi}, \text{Yi}))}{\Sigma(\text{Xi})}$$

where 'min' indicates the selection of the lower of the two values, Xi represents the scores of memberships in a configuration of conditions and Yi represents the scores of memberships in the outcome.

Coverage indicates the degree to which a condition or combination of conditions represent the given configurations in the result (Ragin, 2006). In other words, coverage measures the probability that repeating the analysis with other data on the same conditions the solution will have the same configurations as those already reported in the analysis performed. The interpretation of this measure is the same as that used for the coefficient of determination (r^2) in statistical analysis (Woodside, 2013). In the QCA, this measure is calculated by comparing the number of paths leading to the identified solution against the total number of possible configurations of all given conditions.
The coverage value for the sufficiency relationship is calculated using the following formula:

$$\text{Coverage}\ (Xi \leq Yi) = \frac{\Sigma(\min(Xi, Yi))}{\Sigma(Yi)}$$

where 'min' indicates the selection of the lower of the two values, Xi represents the scores of memberships in a configuration of conditions and Yi represents the scores of memberships in the outcome. These formulae also show that coverage for inconsistent results is not a significant indicator (Schneider & Wagemann; 2007).
To summarise, consistency is an indicator of how well a solution is able to produce the outcome, while coverage indicates the empirical relevance of the solution, i.e. it indicates the probability of obtaining the same result by reproducing the experiment.

3.2 Data collection

In order to best investigate the situation of manufacturing companies, it is necessary to obtain the data on which to perform the Qualitative Comparative Analysis. In this thesis, the analysis focuses on manufacturing companies located in Northern Italy. The choice was dictated by geographical proximity. This facilitated a phase of continuous data exchange necessary for the constitution of the data set.
The dataset consists of data obtained through surveys carried out on some manufacturing companies in northern Italy between November and December 2023.

3.2.1 Structure of the surveys

The purpose of this analysis is to study how elements of operational excellence, digital technologies and behavioural practices are mixed together within companies in order to identify the best performing configurations.

First, it is necessary to identify these elements individually. The objective is to quantify how much each of the above-mentioned conditions is present within a company.

Hence, in this analysis the concept of Industry 5.0 was first divided into the elements of operational excellence, digital technologies and behavioural practices. Subsequently, each of these 3 elements was divided into its own sub-categories. Each of these sub-categories was investigated and measured through a series of questions posed via a survey.

In order to effectively measure each identified variable, it was necessary to construct two separate surveys. To investigate the behavioural practices adopted within a plant, the most effective choice is to directly interview the workers employed there. Conversely, to investigate the managerial practices adopted and the degree of technological implementation, it is necessary to talk to the manager responsible for production.

Therefore, a survey directed at workers was created for behavioural practices and one directed at managers to investigate operational excellence and digital technologies. The two surveys also differ in the style of language used: the workers' questionnaire is designed to be easily understood by everyone and there are no overly technical words in it. In addition, with regard to the number of questions, and thus the time required to complete it, the workers' survey is designed to be shorter and quicker so as not to slow down normal operational activities.

Both surveys consist of a series of statements. For each of them, the respondent has to indicate to what extent he or she agrees with them by using a 7-point Likert scale. In it, 1 indicates complete disagreement, 7 indicates complete agreement and 4 indicates indifference.

The managers' survey is the longest. The compilation time is about 45 minutes and a general knowledge of the managerial practices adopted in the plant is necessary to answer it. The language used is precise and often the statements concern the adoption of specific techniques.

This survey is divided into two parts, the first one dedicated to the study of operational excellence practices and the second one to the implementation of digital technologies and the average level of competence of the workers related to the use of these technologies.

The survey starts with some demographic questions such as identifying the number of employees, their average age and the company's turnover. Subsequently, the first section studies Total Quality Management practices (TQM). This section investigates the presence and use of andon boards within the department, the quality measurement practices adopted by managers, and the level of statistical analysis adopted for measurements.

The second condition analysed is human resources management (HRM). Questions on this variable investigate the selection practices adopted by the company and the incentive methods offered to workers. In addition, it is investigated to what extent each employee is replaceable by another and what skills are required to move to the next career level.

The third condition related of operational excellence's adoption is Just in Time (JIT). This is perhaps the most famous lean management practice currently found in companies. In this section, the presence of pull production logic is studied. The presence and use of kanban systems is verified. Finally, the punctuality of deliveries is checked and relations with the supply chain are analysed. The objective is to analyse how many, and which lean management practices have been adopted to achieve a lean, flexible, demand-driven production system that is linked to all previous supply stages.

The fourth condition is total productive maintenance (TPM). The associated questions investigate fault analysis techniques, equipment upgrading practices and inspection and monitoring of equipment deterioration and cleanliness.

The fifth observed condition is deployment. That is, this section investigates how corporate strategy is translated into operational tactics. In addition, the involvement of managers in the various levels of strategy and tactics decision-making is investigated. Also the frequency of updating the strategic plan is investigated.

The section on managerial practices of operational excellence concludes by asking for certain KPIs such as the percentage of scrap cost out of the cost of production, delivery lead time and others related to product quality.

The second part of the managers' survey investigates the adoption of digital technologies. In this section there is a table that aims to verify the level of adoption of advanced technologies such as collaborative robots, 3D printing systems, the Internet of Things and use of virtual or augmented reality. Furthermore, the questionnaire investigates the level of digital integration of processes within the company and between the company and its supply chain. In addition, there are a number of questions concerning the use of nanotechnology and/or intelligent and adaptive materials.

Subsequently, the survey investigates the presence and implementation of digital management systems. Both ERP and MES systems are considered in this section, as well as general digital infrastructure, and the use of clouds for data storage.

The following section focuses on advanced logistics and the use of technology in procurement. Reference technologies are RFID, GIS and GPS used in order to implement ideal product tracking in logistics operations.

The latest technologies analysed are the use of specific artificial intelligence algorithms and the implementation of human-machine interface.

The final part of the managers' survey lists all the technologies just mentioned for the previous section, and for each of them it asks to indicate with a 7-point Likert scale the average level of competence of the operators. A value of 1 means that the operators have no specific competence related to the use of this technology, while a value of 7 means the highest level of competence.

The second survey administered to companies is the one on workers' perceptions. This questionnaire investigates the behavioural practices within the reference plant.

The first section of the survey is devoted to the study of systematic problem-solving (SPS) practices. This section investigates how workers approach problems occurring during their shift. The objective is to understand whether they are used to carrying out analytical thinking before taking action to solve a problem.

The largest part of the survey generally investigates both the worker's perception of the workplace and the common practices adopted during the main activities performed. This section investigates the level of engagement of employees by ascertaining how happy they are with the positions they hold. The level of attention paid during work is investigated. It also tests the level of passion workers have for the tasks they have to perform. Subsequently, the level of autonomy that is left to the workers is analysed. Autonomy is identified both as the freedom to make decisions and organise one's own shift, and as the freedom to choose the methods by which to achieve the objectives set by management.

Following this, the questions aim to quantify the variety of tasks that an individual operator is used to performing within his or her job description. Of these tasks, the level of complexity is also investigated. This is done by examining whether these tasks require a large amount of information to be handled, or whether there is a frequent need to solve problems. Other questions ask if these tasks require to be creative. The survey also studies the company's internal feedback system. The aim is to verify whether a structured system of information exchange between management and employees is in place aimed at sharing strategic objectives and exchanging feedback on the individual performance of operators.

Finally, the survey closes with some questions on proactive behaviour. In this section, the questions analyse the extent to which the operator makes changes to procedures in the

workplace. It is investigated whether the operator has opportunities to suggest innovations and whether the operator is personally inclined to suggest such improvements.
These are all the conditions investigated through the two surveys. A different number of statements were used for each of them. The questions chosen to create the questionnaire were taken from previous validated questionnaires. This thesis refers to the work carried out by Andrea Furlan and Ambra Galeazzo (Furlan et al., 2019; Galeazzo & Furlan, 2018). They have already analysed all these conditions separately, but there has never been a study that aimed at analysing all of them from a configurational perspective like the one proposed in this thesis.

3.2.2 Sample composition

To obtain the data analysed in this thesis, 6 companies answered the two surveys created.
The managers' survey was submitted to two managers from each company. The questions within it concern an objective description of the operational excellence practices and digital technologies adopted by the company. Since it is an objective description, it is not relevant to have a big sample to obtain answers of appreciable significance. The survey was answered by 2 managers for each company. This allows to verify the information of one manager through the answers of the second.
The workers' survey focuses on aspects of perception. By definition they are subjective aspects. For this reason, it is necessary to interview several employees. Each company was suggested to interview approximately 10 employees. Depending on the size and availability of the company, each of them decided for itself to whom it would run the questionnaire.
The first step was to talk to and interview managers. Subsequently, the same managers took care of the interviews within the plant. In this way, each company could independently manage the conduct of the interviews without interrupting or slowing down the normal course of business.
The companies selected for this study were chosen mainly for geographical proximity. This facilitated the exchange of information between university and companies. For this reason, all the companies are located in northern Italy. Furthermore, all the companies chosen are monoplant companies. Having to evaluate the configurations generated by the QCA from a performance point of view, it was considered useful to select companies with a single production plant. In this way, the performance indicators in the financial statement certainly refer to the same plant where the employees responding to the survey work.

Only manufacturing companies were considered. The sample obtained is composed as follows:

	NACE code	Industry description	Turnover 2022 (in millions)	No. of employees	Average age of employees	No. of key informants	Job description
Firm 1	1623	Manufacture of wooden doors and windows	8,59	33	31-45 years	17	2 managers, 15 workers
Firm 2	1330	Finishing of textiles	4,79	25	31-45 years	25	2 managers, 23 workers
Firm 3	1320	Weaving of textiles	13,41	63	46-60 years	12	2 managers, 10 workers
Firm 4	1310	Preparation and spinning of textiles fibres	12,33	69	46-60 years	21	2 managers, 19 workers
Firm 5	2562	Machining	2,82	15	31-45 years	12	2 managers, 10 workers
Firm 6	1320	Weaving of textiles	15,37	71	46-60 years	5	2 managers, 3 workers

Table 1 - Sample composition

3.2.3 Performance outcomes

As anticipated in section 3.1, the idea behind this study is to evaluate the configurations produced in terms of performance. With the objective of analysing which Industry 5.0 enabling practices are the most implementable, it is essential that they are profitable for entrepreneurs. For this reason, it is decided to consider financial performance as an outcome.

Given the presence of operational excellence practices among the variables, the best financial indicators for this thesis would be indices that are influenced by the use of such practices. However, the literature does not identify a direct link between the use of lean practices and good financial performance (Bevilacqua et al., 2017; Hayes & Wheelwright, 1984). Scholars have identified many factors that can act as contingencies in inhibiting the positive effect of lean management on performance. These include organisational context and misalignment with strategy (Naor et al. 2010; Netland, 2016; Zhang et al., 2012). Nevertheless, some research suggests that by stemming the effect of contingencies, operational excellence practices have a positive impact on ROA. In particular, companies that adopt these managerial systems record a higher ROA than non-adopters (York & Miree, 2004; Demeter and Matyusz, 2011; Hofer et al., 2012; Swink and Jacobs, 2012). For these reasons, the ROA index is considered as a performance indicator in this thesis.

In order to carry out a qualitative comparative analysis, it is necessary to associate each sample element with an outcome value. Therefore, each company needs to have its ROA value. These data are obtained thanks to the AIDA database (developed by Bureau Van Dijk with the financial statement of about 200,000 Italian companies).

The average ROA of the last 3 years was considered. Furthermore, this value was subsequently normalised according to the values of its sector. The ROA of the companies was compared with average ROA of the same period of all companies with the same NACE code (sector values were obtained from the AIDA database). In this way, it was possible to compare the ROA values of companies in different sectors, without considering structural differences due to the industry sector of reference. This aspect is discussed in more detail in section 3.4. However, the general idea is to classify a company as performing if its ROA is high compared to that of its sector. Consequently, it is a non-performing company if it has a lower ROA than that of its sector.

3.3 Preliminary analysis

After collecting all the data on the practices adopted by the companies in the sample, some preliminary analyses were carried out.

First, a database was created containing all the values of the answers to the surveys. For each question, there is a number from 1 to 7 corresponding to each respondent. This value indicates the degree of agreement that the respondent stated regarding the statement presented.

The surveys collected information on a different number of conditions that may contribute to the generation of the outcome. Each of them is investigated with a series of questions. In order to create the dataset required for qualitative comparative analysis, it is necessary for each condition to be associated with a unique value for each item in the sample. This means having a dataset with the 6 companies and representing each of them with a unique value for each of the conditions investigated.

To obtain this dataset, it is necessary to calculate an average of the value of all responses related to the same condition within the same company. Before doing this, it is necessary to verify that the information conveyed by the average accurately represents the information collected by the survey. Therefore, the first analysis required for the creation of the dataset is a consistency analysis.

Consistency, in this case, is a desirability property of estimators. When a measure's consistency is high, as the sample size increases, the probability distribution concentrates around the value returned by the estimator. In the case of an average, it is consistent when even if the sample number on which it is calculated increases, it continues to effectively represent the population. Before understanding the most effective way to calculate the consistency of the data told, it is necessary to understand the type of data. Two surveys were used in this thesis. The first collected information about the objective presence or absence of specific management practices and digital technologies. In this survey, the data is objective and thus exits a "correct value" towards which all respondents should strive. The managers' survey was submitted to two different managers from each company. It is assumed that the “correct value” is the one they both reach if interviewed separately.

The index to be calculated to test the degree of agreement between independent observers assessing the same phenomenon is the inter-rater reliability. There are various ways to calculate this value. In this thesis, it is decided to use the intraclass correlation coefficient (ICC). This coefficient is specific in calculating how similar two individuals are in terms of the answers given. It is also capable of computing continuous values. For this reason, it was chosen as the consensus index for the answers given to the managers' survey. The threshold value above which consistency is considered good enough is 0.6 (Cicchetti, 1994).

The workers' survey, on the other hand, analyses perception. In this case, there is no correct value. Even if all observers describe the same phenomenon, everyone can have a different opinion. For this reason, it is not correct to calculate a coefficient measuring the agreement between the answers, as done for the managers' survey. In these cases, the literature often uses Cronbach's alpha as a measure of internal consistency. This indicator is based on measuring the correlation between different items relating to the same condition. In this thesis, the Cronbach's alpha was calculated for each condition analysed in each company in the sample. The threshold value above which consistency is considered good enough is 0.7 (Hair et al., 2006).

Table 2 shows all the values resulting from the analyses. All exceed the necessary threshold values, so it is possible to proceed with calculating the average and construct the dataset required for the qualitative comparative analysis.

	ICC	**α Proactive Behaviour**	**α Job Autonomy**
Firm 1	0,976	0,914	0,881
Firm 2	0,787	0,956	0,915
Firm 3	0,648	0,930	0,703
Firm 4	0,833	0,914	0,958
Firm 5	0,722	0,783	0,814
Firm 6	0,687	0,964	0,962

Table 2 - Results of the preliminary analysis

Table 2 shows a single ICC value for each firm because this index was calculated on the entire managers' survey. Cronbach's alpha, on the other hand, requires to be calculated for each condition. However, only the values corresponding to proactive behaviour and job autonomy are shown in table 2. This is because not all conditions investigated by the surveys were used in the analysis. In fact, when conducting a qualitative comparative analysis, there is a tendency in the literature to choose a number of conditions that generate a number of possible configurations smaller than the number of respondents. The number of configurations generated by the QCA is equal to 2^k, where k is the number of conditions considered (Fiss, 2007). The surveys used for this study were answered by 92 people. This means that, in this study, the number k of conditions cannot exceed 6.

Given this constraint, not all the conditions were chosen to carry out the qualitative comparative analysis. The choice of these conditions is discussed more in detail in chapter 4.

3.4 Calibration

After averaging all survey item values for the same condition within the same company, it is possible to create the dataset required for qualitative comparative analysis. The values of these averages are values between 1 and 7, as they are derived from measurements using a 7-point Likert scale. However, QCA is a technique based on Boolean algebra, and even using fuzzy set QCA, it is necessary for all computed values to be between 0 and 1. The process of transforming any value into a number between 0 and 1 is called calibration.

There are different types of calibration. One of these is a simple proportion to the reference Likert scale. Using a 7-point scale as an example, this method transforms the value 1 into the value 0, as it indicates the absence of the condition, and it transforms the value 7 into the value 1, as it indicates the complete presence of the condition. All intermediate values are assigned accordingly. This method is the simplest, but it does have its drawbacks. In fact, if the values associated with a condition all revolve around the same value, internal variability within the distribution is lost. To retain all the variability of the observed data, and to avoid considering effects due to the specific nature of the conditions, values can be calibrated according to their observed distribution. This second method allows more precise comparisons to be made. In addition, solutions found via QCA are empirically found to have higher overall coverage and consistency values. This is due to the greater variability of the conditions analysed.

In the following analyses, the values were calibrated according to their observed distribution. The software "fsQCA 3.0" allows to do this type of calibration by entering the minimum, maximum and mean value of the observations of the same condition.

In this study, the calibration of the outcome deserves special attention because it is the only value calibrated in a different way. The value of ROA as a performance indicator was extracted from published financial statements and therefore did not undergo reliability analysis. However, this value also needs to be calibrated.

In order to obtain a comparable result beyond the sector to which each company belongs, it was decided to compare ROA with the ROA of the sector to which it belongs. The comparison was made by calculating the quartiles of the sector's ROA distribution. Subsequently, it was checked to which quartile the ROA of each company in the sample belonged.

For calibration, a ROA value was assigned according to the quartile to which it belonged. The fourth quartile was assigned the value 0.95. This value indicates the best performing companies and thus the complete presence of the outcome. In QCA logic, this value should be 1, but wishing to be slightly more conservative, it was assumed to assign the end-of-range value reduced by 0.05. Consequently, the first quartile is assigned the value 0.20, the second 0.45, the third 0.7 and the fourth 0.95.

With these calibrations and assumptions, it was possible to create the final dataset used for the comparative qualitative analysis in this thesis. The dataset is shown in Table 3.

	JIT	**Proactive behaviour**	**Job autonomy**	**ERP**	**MES**	**RFID**	**ROA**
Firm 1	0,36	0,95	0,05	0,29	0,39	0,66	0,70
Firm 2	0,08	0,52	0,95	0,77	0,11	0,37	0,95
Firm 3	0,86	0,56	0,95	0,57	0,58	0,24	0,45
Firm 4	0,05	0,59	0,47	0,95	0,95	0,95	0,45
Firm 5	0,95	0,05	0,92	0,89	0,73	0,05	0,70
Firm 6	0,06	0,09	0,06	0,05	0,05	0,66	0,20

Table 3 - Dataset

3.5 Data analysis

In this study, the main analysis applied is fuzzy set qualitative comparative analysis. This analysis was carried out using the fsQCA 3.0 software. This software uses the Quine - McCluskey algorithm.

The purpose of this analysis is to create configurations of the selected conditions. The analysis of the configurations makes it possible to identify which conditions are related to the outcome and how they are related to it. Please note that the link between condition and outcome expressed by this analysis is not a correlational link. The identified link exists in the presence of the entire configuration. Variation in configuration may or may not lead to the same condition leading to the desired result (equifinality and asymmetric assumption). Furthermore, there is no hierarchy between the identified configurations. That is, each configuration describes a possible relationship between the conditions and the outcome, without identifying one as more likely than the others (Greckhamer et al., 2008; Ragin, 2008).

Qualitative comparative analysis allows to classify conditions as necessary or sufficient. A necessary condition must always be present for the phenomenon in question to occur, but whose mere presence is not sufficient for the effect to occur. While a sufficient condition is sufficient to produce the phenomenon but is not the only one capable of causing it: there may be several sufficient conditions and none of them individually is necessary.

The software used allows to analyse the presence of necessary conditions. This is the first analysis carried out in this study. The necessary conditions analysis classify condition as necessary one when it can explain the presence of the outcome almost completely, i.e. the presence of that condition is highly related to the presence of the outcome. It means that the presence of the outcome implies the presence of the condition, and this is the definition of a necessary condition. This relationship is exactly what the consistency value measures. Thus, by calculating a level of consistency for each condition involved in the generation of an outcome, it is possible to identify necessary conditions. If the consistency exceeds a threshold of 0.9, the condition is considered a necessary condition.

In order to identify and describe the sufficient conditions, it is necessary to carry out the second analysis in this study. This is the "truth tables analysis". This algorithm makes it possible to create the various configurations that lead to the specified outcome. The configurations can lead to the presence of the outcome or to its absence. Each configuration is a sufficient condition for the outcome. Thus, the sufficient condition is not a single element considered by the analysis, but all elements contribute together to lead to the outcome. This is a special feature of QCA.

Each element, intended as a single causal condition inside a configuration, is only a part of the entire sufficient condition. This single causal condition is formally called INUS condition (Insufficient but Necessary part of an Unnecessary but Sufficient condition). An INUS condition can be identified as present, absent, or indifferent for the configuration. Present means that the presence of INUS condition is necessary for the whole configuration to be sufficient. In contrast, absent means that its absence is necessary for the configuration to be sufficient. Finally, the presence of the INUS condition may be indifferent. Its presence or absence being irrelevant for the configuration to be sufficient to generate the outcome (Wu et al., 2014).

There are two types of INUS conditions: core conditions and peripheral conditions. Core conditions are those that are present in all configurations, leading to the same outcome in the same solution. These conditions are those that can also be necessary conditions if they exceed the necessary threshold in the consistency values. Peripheral conditions, on the other hand, are those conditions present in only some of the configurations that lead to the same outcome within the same solution (Fiss, 2011).

In this study, both truth table analysis and necessary analysis were performed. The results obtained, the description of the configurations obtained and the categorisation of the conditions as necessary, core and peripheral are discussed in detail in the next chapter.

4. CONFIGURATIONS FOR EFFICIENT INDUSTRY 5.0 ADOPTION

4.1 Choice of causal conditions

Comparative qualitative analysis generates configurations given certain causal starting conditions. The number of these configurations, as seen in section 3.3 depends on the conditions observed. However, for the analysis to be meaningful, it is necessary to limit the number of observed conditions based on the number of survey respondents. In this thesis, having 92 respondents, the literature recommends considering no more than six causal conditions. This imposes the need to make a choice. Surveys have collected information for many more items, and it is necessary to choose the most appropriate ones for analysis.

The research question focuses on three aspects that can contribute to the development of Industry 5.0. They are operational excellence, digital technologies, and behavioural practices. Therefore, it is necessary that in the choice of the items to be analysed, each of these three aspects is represented appropriately.

With regard to operational excellence measures, it was decided to analyse Just in Time practices. JIT is one of the most widely used systems in the field of lean management. It is a set of practices and techniques that lead production to be flexible. That is, to be ready to respond to demand in the best possible way. This is possible by overcoming the traditional planning and production system called push system. In that system, production starts from a company forecast and this pushes every stage of planning and production. With JIT, we move to the pull system. In this case, it is demand that pulls production. Without demand, production is not active. This reduces waste and increases efficiency. However, to make the implementation of this system possible, it is necessary to have production linked to all stages of the production chain. Ideally, the consumption of a material should be followed immediately by its replacement. Realising that this is not always possible, the kanban technique is used. Kanbans are tags that are used for reordering the materials needed when they are consumed. This makes it possible to switch from stocks of large quantities of materials to stocks of only the minimum number of materials needed for production. In this way, costs are reduced considerably, increasing financial performance.

Therefore, because of all the properties listed, because of its close link to financial performance, because of its great influence on a company's productivity, and because many of the managers'

survey questions were on this topic, it was decided to choose Just in Time as the condition to represent operational excellence.
With regard to the part on behavioural practices, it was decided to focus on proactive behaviour and job autonomy. These two conditions are among those most studied in the employee survey. Moreover, they are strongly linked to the concept of Industry 5.0, which is why they were selected. The dimension of job autonomy describes the extent to which a worker has the freedom to decide the order of his or her tasks and the methods to be used to perform them. Proactive behaviour describes the aptitude of workers to propose creative solutions and/or improvements to the processes in which they are involved. Academics indicate that both job autonomy and proactive behaviour enhance employee well-being within the company (Warr, 1999; Cangiano et al. 2018). Well-being is a fundamental aspect of the human centricity principle. Moreover, both of these dimensions describe dimensions of the freedom left to the worker. Freedom to act within their role and freedom to contribute to the development of the whole process. High levels of job autonomy and proactive behaviour indicate that within the company the human being is highly relevant. The employee is regarded as a thinking being, with ideas and the ability to solve problems. The worker is not merely a user of machines. His purpose is not to be a part of a production chain. This is another fundamental aspect of the human centricity principle. Therefore, since measures of proactive behaviour and job autonomy are indicators of the human centricity principle, then these two items were analysed within this analysis.
Finally, a different reasoning was used for the choice of digital technologies to be considered. The survey of managers analysed the presence and implementation of 21 different technologies. However, many of them were not implemented in the majority of the companies in the sample. Thus, in the dataset created, many technologies have low variability within the data representing them. This greatly impacts the QCA and makes the created configurations less meaningful. In order to obtain more meaningful results, the technologies with the highest variability were chosen. That is, the technologies that are also widely adopted within the sample. From this selection, ERP, MES, and RFID emerged.
ERP (Enterprise Resource Planning) and MES (Manufacturing Execution System) are software used to facilitate management and administrative functions. ERP allows the integration of all business functions within a single software package to support management in its management control and strategic planning operations. MES works in a similar way to ERP but is specific to production functions. It allows all the necessary production indicators to be monitored in real

time. It can be integrated within the ERP to communicate more effectively, and automatically, with other business functions.

RFID (Radio Frequency IDentification) are small devices that can automatically recognise, validate and/or store a set of data by connecting to and sensing other active devices in the vicinity. They allow high traceability of products and raw materials. This makes it possible to implement an advanced logistics system. Moreover, they allow to have greater control over the entire supply chain and over movements of materials within the company.

In conclusion, in this thesis, the analysis is aimed at creating and analysing possible configurations of just in time (JIT), proactive behaviour (PB), job autonomy (JA) and the use of ERP, MES and RFID.

4.2 Analysis of necessary conditions

Analysis of necessary conditions

	Consistency
Just in Time	0,4927
Proactive behaviour	0,6550
Job autonomy	0,7710
ERP	0,7855
MES	0,6231
RFID	0,5710

Figure 5 - Analysis of necessary conditions

The first analysis carried out in this study is the analysis of the necessary conditions. The objective of this calculation is to identify which of the chosen conditions are necessary to generate the outcome.

For this purpose, the "fsQCA 3.0" software calculates the consistency of each condition. It measures the degree of relationship between each variable and the outcome, in this case the ROA index. The interpretation of this value, in this analysis, is that consistency indicates the probability of finding the causal condition within the configurations generating the outcome. Thus, a condition with very high consistency is a necessary condition to generate the outcome, as it is almost always present when the outcome is present. The Quine - McCluskey algorithm identifies the threshold value above which the consistency is sufficiently high at 0.9. As shown in figure 5, no condition exceeds the threshold value in this study. This means that none of the conditions such as the presence of Just in Time, proactive behaviour, job autonomy, ERP, MES and RFID is necessary to generate a ROA above the industry average. This is not a surprising finding as it was clear that none of these elements was a key element within the factors that generate a company's ROA. Even the literature suggested so (Biggart, 1997; Jayaram et al., 2008; Nawanir et al., 2013). However, it remains interesting how these conditions interact with each other to generate ROA. These issues are discussed in the truth table analysis.

4.3 Truth table analysis: description of emerged configurations

The second analysis carried out in this thesis is the truth table analysis. With these calculations, it is possible to create the different configurations of conditions that are sufficient to lead to the outcome. This is the most characteristic analysis of QCA. Furthermore, the configurations found make it possible to describe how the elements investigated by the survey interact with each other.

The analysis was carried out using the software fsQCA 3.0. The software automatically proposes the configurations and the respective coverage and consistency values. Thanks to these two measures, only the most significant configurations can be selected.

In this thesis, the possible configurations of just in time, proactive behaviour, job autonomy and the presence of ERP, MES and RFID were analysed. However, no single truth table analysis was performed by including all selected conditions. It was decided to conduct several analyses in order to better explore the effects of the technologies within the various configurations.

All the analyses carried out considered aspects of operational excellence and behavioural practices. These are fundamental elements within the industry 5.0 paradigm. For this reason, just in time, proactive behaviour, and job autonomy were considered fundamental criteria in all analyses. The technology aspect is also fundamental to the industry 5.0 paradigm. However, it is a very variable aspect. Depending on the sector a company has different technological needs, while operational excellence and behavioural practices are common to all sectors. Therefore, the implementation elements of ERP, MES and RFID were not considered in all analyses. Several cases were created in which the possible interactions between all and some of these 3 digital technologies were analysed.

Thus, the analyses were carried out considering 6 cases. Each case considers a different set of causal conditions. Below are all the cases that were analysed, described by their component conditions.

- CASE 1 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), and ERP.
- CASE 2 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), and MES.
- CASE 3 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), ERP, and MES.
- CASE 4 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), and RFID.
- CASE 5 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), ERP, and RFID.
- CASE 6 - It considers Just in Time (JIT), proactive behaviour (PB), job autonomy (JA), ERP, MES, and RFID.

It should be noted that none of the cases individually exceeds the limit of 6 conditions imposed by the sample size.

In this section, all condition configurations generated for each individual case will be reported and discussed. Each resulting solution is represented by a graph. In the graph, each column represents a configuration. In the configuration, each condition is associated with symbols. Black circles indicate presence, i.e. the condition must be present for the configuration to be sufficient to generate the outcome. The crossed-out circle, on the other hand, denotes the necessary absence of the condition. In the end, if nothing is indicated, the presence or absence of the condition is irrelevant to the configuration. Moreover, each symbol may be large or small. If the symbol is large the associated condition is a core condition, if not, it is a peripheral condition.

4.3.1 Configurations of just in time, behavioural practices, ERP and MES.

The description of the configurations that emerged from the comparative analysis is divided into two groups. In one, cases concerning the use of ERP and MES are discussed, in the second, cases that also consider the use of RFID technologies. In this section, the cases of configurations considering ERP and MES are discussed.

The first case analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), job autonomy (JA) and ERP.

Case 1

	High ROA	
JIT	⊗	●
PB	●	
JA	⊗	●
ERP		●
Consistency	0,9432	0,8165
Raw coverage	0,3855	0,4000
Overall solution consistency	0,8636	
Overall solution coverage	0,8260	

Figure 6 - Configurations of JIT, PB, JA and ERP

Case 1 generates two configurations. Each of them is sufficient to generate a high ROA, i.e. an ROA above the industry average.

The first configuration (first column) is characterised by the presence of proactive behaviour together with the absence of both just in time and job autonomy. The presence of ERP is indifferent. The second configuration (second column) is characterised by the indifference of the presence of proactive behaviour together with the presence of both just in time and job autonomy. The presence of ERP is required in this configuration.

From this first solution, some links emerge. They will be recurrent in all the analyses carried out. Firstly, it appears that just in time and job autonomy tend to be present or absent at the same time. That is, when the presence of JIT is necessary then the presence of job autonomy is also necessary. Symmetrically, the necessary absence of one occurs together with the necessary absence of the other. Just in Time and job autonomy seem to have a close connection with each other. It appears that these two conditions move in pairs.

Proactive behaviour tends to be the opposite of the pair of JIT and JA. In fact, it is only present in the configuration in which JIT and JA are absent. In the second configuration, the absence of proactive behaviour is not necessary. Hence, it does not move in a completely opposite direction to just in time. In any case in the second configuration, proactive behaviour plays a neutral role. From this it seems to emerge that Just in Time practices require high job autonomy but not necessarily proactive behaviour. Although in no case does proactive behaviour have a negative link to ROA. Therefore this condition is not a condition to be avoided regardless. These links are recurrent in all the cases analysed, which empirically validates their significance. For this reason, sections 4.4.1 and 4.4.2 goes into detail on the possible reasons for these links.

As far as ERP is concerned, the two configurations show that they are never negatively related to outcome. Therefore, the adoption of this technology never seems to be something negative per se in terms of performance. Furthermore, it seems that ERP tends to move in the same direction as the pair of just in time and job autonomy.

Continuing with the description of the cases, the second analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), job autonomy (JA) and MES.

Case 2

	High ROA	
JIT	⊗	●
PB	●	
JA	⊗	●
MES		●
Consistency	0,9432	0,8961
Raw coverage	0,3855	0,4000
Overall solution consistency	0,9223	
Overall solution coverage	0,8260	

Figure 7 - Configurations of JIT, PB, JA and MES

Case 2 also generates two configurations sufficient to generate a high ROA. The two configurations repeat the same pattern as in case 1. Just in Time, proactive behaviour and job

autonomy have the same comportment as in case 1. The MES also never has a negative link to the outcome. Furthermore, MES tends to occur together with just in time and job autonomy.
Thus, it appears from this case that ERP and MES seem to have almost equal behaviour at the configurational level. This is not surprising as both are software aimed at facilitating business management. The two software are extremely similar in terms of strategic goals and usage. Moreover, MES is often a component of ERP, so it is natural that the behaviour of these two technologies is extremely similar.
Finally, case 2 stands out from all the cases analysed in that it is the one with the highest values in terms of overall solution coverage and consistency. This makes the connections presented so far also the most statistically significant.
In conclusion to this section, case 3 is presented. It analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), job autonomy (JA) and both ERP and MES.

Case 3

	High ROA	
JIT	⊗	●
PB	●	
JA	⊗	●
ERP	⬤	⬤
MES	⬤	⬤
Consistency	0,9215	0,9019
Raw coverage	0,2724	0,4000
Overall solution consistency	0,9245	
Overall solution coverage	0,8173	

Figure 8 - Configurations of JIT, PB, JA, ERP and MES

Case 3 also generates two configurations sufficient to generate a high ROA. They confirm all the trends that emerged from case 1 and case 2. The main change relates to the conditions regarding digital technologies. For the first time, the analysis shows the presence of core conditions. Both ERP and MES must necessarily be present in all configurations found. ERP and MES considered individually were configurational neutral when only the presence of proactive behaviour was required. While when they are considered together, even in this configuration, their presence becomes necessary.

It can be deduced that ERP and MES together always have a positive connection with the presence of high ROA. This suggests that the full implementation of management software tends to generate good ROA, independent of the other elements. However, neither of these conditions is necessary to lead to the outcome.

The fact that in the configuration with the presence of proactive behaviour and the absence of JIT and JA, the presence of ERP and MES becomes necessary only if both are present, suggests that the full implementation of this type of software has a strong impact on ROA. That is to say, the implementation of an ERP that does not consider production-specific aspects, i.e. that is not linked to an MES, is not able to generate the same effects as a full implemented ERP.

4.3.2 Configurations of just in time, behavioural practices, RFID, ERP and MES.

This section analyses all cases where, in addition to just in time, proactive behaviour, and job autonomy is considered RFID. Both cases with RFID alone and cases with all technologies analysed in this thesis, i.e. RFID, ERP and MES, are taken into account. This section describes cases 4, 5 and 6.

Case 4 analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), and RFID.

Case 4

	High ROA		
JIT	⊗		⊗
PB		●	●
JA	●	●	⊗
RFID	⊗	⊗	●
Consistency	0,7239	0,9147	0,9432
Raw coverage	0,4028	0,3420	0,3855
Overall solution consistency		0,8236	
Overall solution coverage		0,8260	

Figure 9 - Configurations of JIT, PB, JA and RFID

Case 4 generates the solution with the most differences compared to all other solutions. Indeed, this is the only case in which the solution generates 3 configurations sufficient to lead to a high ROA. However, some behaviours of the conditions are confirmed.

Proactive behaviour also in this solution never has a negative link to ROA. This reinforces the idea that proactive behaviour is never an unfavourable condition in terms of financial performance. Another confirmation is the tendency of proactive behaviour not to occur together with just in time. It seems that the just in time technique requires operators to implement specific behaviours that hardly give room for proactivity.

As far as job autonomy is concerned, the solution only partially confirms the tendency of it to occur together with just in time. In the third configuration (third column) both conditions must necessarily be absent. However, in the second configuration the presence of job autonomy leads to the outcome independently of the implementation of just in time. Finally, in the first configuration job autonomy is necessarily present and just in time is necessarily absent. It should be noted that this solution is the one with the lowest consistency values. Moreover, of all the analyses it is the only one with these trends. This might suggest that these links are less representative. However, it can be inferred that the relationship between just in time and proactive behaviour is strong and requires the presence of only one of the two in order to generate the outcome. While the relationship between just in time and job autonomy is less strong, so it is possible that in some cases the outcome is achieved even without the necessary presence of both just in time and job autonomy.

Case 4 introduces a new technological condition: RFID. From this solution, it appears to have an inverse behaviour to job autonomy. In no efficient configuration are both necessarily present. On the contrary, the presence of one requires the absence of the other. There is a very clear link between the use of this digital technology and the need for low job autonomy. This link is present in all cases that consider RFID, so it is considered empirically validated. For this reason, in section 4.4.4 we elaborate on the possible reasons why, in companies with above-average financial performance in the sector, the presence of a good implementation of advanced logistics technology corresponds to a low job autonomy.

Continuing with the discussion of the truth table analyses carried out on the 6 designed cases, the discussion moves on to the cases that jointly consider the presence of management software (ERP and/or MES) and RFID.

Case 5 analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), ERP and RFID.

Case 5

	High ROA	
JIT	⊗	●
PB	●	
JA	⊗	●
ERP		●
RFID	●	⊗
Consistency	0,9432	0,8165
Raw coverage	0,3855	0,4000
Overall solution consistency	0,8796	
Overall solution coverage	0,8260	

Figure 10 - Configurations of JIT, PB, JA, ERP and RFID

Case 5 generates 2 configurations sufficient to lead to a high ROA, just like the cases discussed in section 4.3.1.

This solution has no aspects that are not present in other solutions already discussed. Thus, these configurations confirm the links between the conditions that have already been highlighted above. If RFID is not considered, the solution is identical to case 1. Just in time and job autonomy tend to move in the same direction, while proactive behaviour tends to be present when just in time is absent. ERP is more efficient at the outcome level when job autonomy is also present.

The RFID part, which is new compared to case 1, is also a confirmation. In fact, RFID shows a strong opposite tendency to job autonomy. A performing configuration necessarily always has either the presence of one and the absence of the other or vice versa. In no case is either condition indifferent.

This RFID trend is also fully confirmed in case 6. It analyses the possible configurations and interactions between just in time (JIT), proactive behaviour (PB), ERP, MES and RFID. This analysis is the most comprehensive as it is the only one that simultaneously considers all the conditions selected for this study. Thus, the solution generated by this analysis provides a general idea of all possible interactions between configurations to generate efficient configurations.

Case 6

	High ROA	
JIT	⊗	●
PB	●	
JA	⊗	●
ERP	⬤	⬤
MES	⬤	⬤
RFID	●	⊗
Consistency	0,9215	0,9019
Raw coverage	0,2724	0,4000
Overall solution consistency	0,9245	
Overall solution coverage	0,8173	

Figure 11 - Configurations of JIT, PB, JA, ERP, MES and RFID

This case also generates 2 configurations sufficient to lead to a high ROA. The solution presented fully confirms all the trends seen in all the previous cases. It can be regarded as a summary in which all trends are present. If RFID is not considered, it is identical to case 3. Thus, the presence of just in time, proactive behaviour and job autonomy follow the patterns already highlighted. Also, in this case ERP and MES are core conditions. This underlines the fact that a comprehensive management software is definitely an element that helps companies increase their financial performance, regardless of all the other conditions observed. Finally, the behaviour of RFID is also a confirmation of those already observed, as even in this solution its necessary presence is always concomitant with the necessary absence of job autonomy. Thus, ERP and MES technologies have the opposite behaviour to RFID. The former are efficient in environments with high autonomy, while RFID is not.

4.4 Discussion of trends emerging from the truth table analysis

In this thesis, after selecting the conditions to be investigated, six cases were created. A truth table analysis was done for each case separately. The solutions found have been reported in previous section.

Comparative qualitative analysis is usually used to construct a single solution. However, having 6 solutions available, all with very high levels of consistency and coverage, it is also possible to describe and search for any similarities between the different cases. Thanks to this cross-case analysis, it emerges that certain characteristics of the conditions are general and present in all solutions. Qualitative comparative analysis allows to describe such results without being able to measure their complex significance. However, even just by describing them, interesting relationships emerge.

From the analyses carried out in this thesis, several recurring patterns emerged. They are worthy of further investigation. In this section, they will be dealt with in detail one at a time.

4.4.1 A complex combination: the integration of just in time and proactive behaviour

Solutions emerged from all the case studies suggest that proactive behaviour is a characteristic that does not fit well with the implementation of just in time.

It should be specified that in no configuration found does proactive behaviour have to be absent in order to lead to a high ROA. This means that having employees who feel free to express their opinion and suggest improvements is never a negative element. This first result validates the importance of putting the human being at the centre of the company's attention. It validates the relevance of the human centricity pillar reiterated in the Industry 5.0 definition. Moreover, even scholars suggest that proactive employee behaviour generates a structural value that enables greater organisational effectiveness (Frohman, 1997; Bateman & Crant, 1999).

However, this attitude of workers seems to not combine well with the implementation of just in time practices. In almost all the configurations created, when high proactive behaviour is required, the absence of just in time is necessary.

To better understand why these two conditions struggle to be compatible, it is important to recall what was investigated by the survey. Regarding proactive behaviour, the propensity of employees to independently propose process improvements and/or to develop and make creative changes to the production process was investigated. Thus, proactive behaviour in this study is intended as the attitude of employees to be part of the strategic design of processes. It is also intended as a tendency of operators to have a high level of creativity.

Just in time was investigated as a managerial practice used to align production with market demand. This strategy increases efficiency and reduces costs through the reduction of waste. In order to make this possible, the pull system is implemented. In practice, it is a set of techniques and rules that allow production to be activated only when there is demand from downstream stages, and raw materials to be reordered only when they are needed. The survey verified the adoption of the pull system and also of some tools related to it, such as kanban tags and andon boards. In the philosophy of lean management, all these operational techniques aim to create a set of shared rules to standardise production. The standard is fundamental because it equalises the level of efficiency of a process regardless of any factor. In lean management, there is a belief that the standardised process is the one best suited to be scientifically analysed for improvement. The standard is the basis of continuous improvement, kaizen in Japanese. Without standards, it is not possible to develop sufficiently structured improvement. Therefore, in just in time it is essential that shared rules and defined production standards are observed.

In the literature, the effects of just in time integration have already been studied. In particular, it appears that it leads to a reduction in the variability of tasks assigned to operators (Adler, 1993; Adler & Borys, 1996). This is the effect of the standardisation imposed by the lean technique. In general, it appears that lean management has negative effects on employee outcomes. Its implementation leads to an increase in psychological strain. In particular, an increase in job anxiety and job depression occurs after the implementation of lean management (Parker, 2003). Thus, the literature suggests that the implementation of lean management leads to a reduction in well-being. Since proactive behaviour is a positive component of corporate well-being (Cangiano et al., 2018), the results emerging from the analysis are in line with the existing literature.

On the one hand, there is just in time, characterised by standards and rules. For its effective implementation, it is essential that workers comply with the established rules. This leads to a reduction in well-being and an increase in demotivation and perceived job depression. On the other hand, there is proactive behaviour that promotes corporate well-being, in which workers are free to make creative changes to the process or its parts. As the literature suggests, it is natural that these two conditions struggle to be compatible because they are in direct logical opposition.

Moreover, too proactive behaviour can lead to confusion and inefficiency in plant adopting just in time. Acting freely can mean acting beyond the rules, thus not following the lean technique. This makes it inefficient.
In contrast, lean management is also based on the concept of continuous improvement (kaizen). Proactive behaviour is an extremely useful characteristic in order to suggest and implement process development (Parker, 1998). However, in just in time, even the suggestion of such improvements must be done according to rules and timing. In this way, the proposal can be analysed and implemented in the appropriate way. Therefore, although proactive behaviour is useful for the development of lean processes, it is important that, in a company adopting just in time, it is moderated and regulated.
In conclusion, proactive behaviour is a condition that every company should aim to develop internally. It makes it possible to develop processes and in particular it is very useful at strategic and decision-making levels, where it is a key resource for creatively solving complex problems (Crant & Bateman, 2000). However, at the operational level, proactive behaviour is not compatible with the implementation of just in time. The latter is a technique that can lead to high performance, but at the same time has negative effects on employee outcomes. Therefore, for the correct implementation of this technique, the attitude towards proactive behaviour should be limited and regulated.

4.4.2 The role of job autonomy in the implementation of just in time

Another important relationship that emerged from the joint analysis of all cases. It is the one between just in time and job autonomy. In all efficient configurations identified by the QCA if just in time is necessarily present then job autonomy is also necessarily present. The relationship is symmetrical in that the necessary absence of one corresponds to the necessary absence of the other. It emerges that an efficient implementation of just in time requires the presence of a high level of autonomy. However, proactive behaviour is never necessary in these configurations. Academics suggest that job autonomy is an antecedent of proactive behaviour (Parker et al., 2006) therefore both conditions would be expected to be present simultaneously. However, this is not verified by the analyses carried out in this thesis.
In order to delve into this finding, it is appropriate to recall what is meant by job autonomy in this thesis. The survey items on job autonomy refer to the most classical definition of the construct. In this sense, job autonomy constitutes the extent to which a worker is free to decide

the order of the tasks assigned to him/her and also the most appropriate way in which to perform them (Hackman & Oldham, 1980). A company with a high job autonomy score is one in which operators have the freedom to organise tasks within their role. The objectives and tasks are set by management, but the individual operator has discretion in how they are carried out.

On the contrary, in the studies of Parker et al. (2006) job autonomy is defined in a dimension of coordination of people. It is not individual as in Hackman and Oldham's version, but collective. It considers an autonomy extended beyond the individual and involving the management of one's colleagues. Thus, it is plausible that by focusing only on the autonomy to decide on the sequence of assigned tasks and to choose suitable tools, job autonomy is present also in environments where proactive behaviour is limited. This is the case of just in time implementation emerged from the qualitative comparative analysis.

Defining job autonomy as an individual dimension of freedom over the worker's operational tasks, as it is done in this thesis, it logically appears that job autonomy is incompatible with an efficient implementation of just in time. In fact, as pointed out in section 4.4.1, just in time, and lean management practices in general, are characterised by the presence of precise standards and rules. This seems in logical opposition to the autonomous decision-making of the worker. Moreover, job autonomy and proactive behaviour promote corporate welfare (Warr, 1999; Cangiano et al., 2018). Therefore, since in the early stages of lean production initiatives, negative consequences in employee well-being emerge (Parker, 2003), it is reasonable to assume that job autonomy is also not compatible with just in time. However, the results emerged from the QCA show the opposite. In order to understand this evidence, the relevant literature is analysed below.

Early studies concerning the interaction between JIT and job autonomy confirm the logical assumptions that workers are unlikely to perceive high job autonomy when implementing rules and standards. However, these studies do not directly explore the relationship between the two conditions. In them, the aim was to validate the importance of allowing worker autonomy in order to increase performance. This construct is extensively validated. Subsequently, among the practices to increase autonomy emerges the creation of buffers. This solution was found to be particularly effective in increasing the perceived autonomy of workers. By creating buffers of different types of products, the worker can decide for himself which product to work on. He can also choose the same product several times as he can contribute to building the buffer (Runcie, 1980). This allows managers to manage demand uncertainty. Buffers act as a safety buffer for sudden peaks in demand (Galbraith, 1973). What has just been described perfectly represents the traditional production logic that is opposite to the pull system. Lean management, through the implementation of the pull system and kanban tags, aims to reduce stock creation. One of the key elements of the lean philosophy is the reduction of waste (Muda in Japanese). This is why traditional studies considered job autonomy and just in time to be incompatible. However, more recent studies reveal that they are perfectly compatible. Taking a closer look at autonomy aspects, it appears that an efficient implementation of JIT requires high levels of autonomy. In a plant where a pull system is applied, production is based on actual market demands. This implies that the production mix is flexible. This is one of the main advantages of lean management. Managing this flexible mix is the responsibility of the operators. They have to follow the rules and standards, but they have the freedom to choose what type of product to do so on. The pull system usually creates a different product mix every day. The mix is set as a daily target, so within the day each operator can decide how to work independently. The perceived individual autonomy increases greatly when the operator can decide on which product to apply established rules. In addition, just in time also increases collective autonomy, since while setting standards and rules, it opens the possibility for all operators to suggest improvements. On a collective level, the individual feels that he or she has taken part in the management decision of the entire process. This increases the perception of autonomy (Klein, 1991).

To support Klein's findings on the increase in the perception of individual autonomy, I will give an example from a first-hand experience. Before writing this thesis, I worked as a business consultant. In particular, I worked with a company specialising in operations and lean management. During this time, I participated in a project in which a client company wanted to implement the pull system. In this process, many lean management techniques were implemented and, in the end, standards were created. They made it possible to cope with the high variability in their market demand. In practice, the department was connected with the downstream department via the MES. In this way, the operator was informed in real time of the required production mix. The standards created served as a guide for the operator in selecting the product to be run. In fact, it is not possible to define a priori a standard mix to be repeated periodically. The most appropriate product to produce was different at any given time. The work of implementing lean techniques led to classifying products with colours. Then rules were created. Based on the last colour, they allowed a maximum of two new colours to be identified. The operator had to choose one of the two colours. This represented the product to be produced next. These rules technically did not allow much autonomy for the workers. They are obliged to always produce one of the products resulting from the algorithm on which the colour classification was based. However, the workers perceived the choice between the two colours

as very relevant. Several times the workers came directly to me and said that they felt they had too much autonomy. Some were afraid of the responsibility of their choice. Their perception was that it was no longer the head of the department telling them what to do, but they could choose. They had a daily target and according to it they could choose the colours to produce. So, their perceived autonomy was very high. At the same time, the rules within the department had increased a lot, but this did not change the perception of the workers. On the contrary, they were happy to have rules as they intended them as a support to their choices. For them, in each instant, the process depended on their free choices. This example is not statistically valid, but I think it is useful to understand how an effective implementation of the pull system and just in time coexists perfectly with an increase in the perception of job autonomy.
At this point, the main studies published are in opposition to each other. On the one hand, Klein 1991) argues for the compatibility of just in time and job autonomy. In this view, JIT rules are perceived as operational decision support. On the other hand, Parker (2003) points out that companies show a reduction in job autonomy in the periods following the implementation of lean management. The literature is divided in judging the effect of these managerial practices on job autonomy. In this context, de Treville and Antonakis (2006) provide clarity. They point out that the implementation of lean management does not always have the same effect on employee outcomes. Lean management techniques do not directly influence employee outcomes such as well-being, motivation and job depression. Their effect is mediated by other characteristics such as job autonomy and skill utilisation. Thus, lean management influences work characteristics (including job autonomy) and then these characteristics influence the employee outcome. This is the mediational framework proposed by Parker (2003). De Treville and Antonakis (2006) use it to emphasise the importance of considering the effects of lean management at a holistic and configurational level. Indeed, it acts on work characteristics but is not the only element that acts on them. The work characteristics themselves also interact with each other. The complex result of all these elements generates the employee outcome. Thus, operational excellence practices do not have a direct positive or negative effect on employee well-being. Just as the perception of job autonomy can be either high or low. It all depends on the context and the configuration of conditions present. In general, it turns out that there are different types of lean implementations and different configurations, and many of these are actually compatible with high levels of job autonomy. The cases with the most negative effects on employee well-being are those involving excessive leanness. If there is too much reduction in skill variety, work facilitation and responsible autonomy then overall job autonomy is more likely to be reduced. In all other cases, the implementation of practices such as just in time tend

to reduce job autonomy, but many organisational factors can coexist that override this tendency. In particular, it emerges that human resources management plays a key role in directing the effect of organisational contingencies. Experiment with advanced simulation systems show that when human resources management practices are implemented within the company, then perceived job autonomy is high in the presence of just in time (Rodriguez et al., 2015). The human resources management practices considered are the same as those initially analysed in the survey used for this thesis. Therefore, in companies that implement a good feedback system, that have a well-defined career development and that have a measured incentive system employees are more likely to perceive high job autonomy.

In conclusion, the relationship between just in time, job autonomy and proactive behaviour is not uniquely identifiable. JIT tends to negatively influence the perception of job autonomy. However, the latter is influenced by various organisational aspects such as human resources management and organisational culture. Thus, the effects of the implementation of lean management techniques on job autonomy depend on the entire configuration of conditions with which one decides to implement the techniques. In the specific configurations studied in this study it emerges that job autonomy is always high in the presence of just in time.

4.4.3 ERP and MES: Technologies that foster job autonomy

From the solutions found through the QCA, it emerged a number of features related to the technologies considered. In particular, all solutions confirm that ERP and MES assume the same behaviour when configured with the other conditions studied. The implementations of ERP and MES, at the configurational level, appears to be identical. Both contribute equally to the generation of the outcome. Indeed, the two systems are extremely similar. Very often the MES is integrated within an ERP system. Therefore, it is reasonable to consider the two systems as part of a single technology. Considering them together, there also emerge interesting findings.

Firstly, only when both ERP and MES are present do they become core conditions. Thus, they have a strong relationship with the generation of a ROA above the industry average. This is true only if the system implementation is advanced and therefore considers both systems.

The literature has often studied the positive effects of implementing a complete ERP system. It is now well established that it can contribute to business efficiency through the redesign of business processes and the implementation of new detection and communication systems between and within functions. (Soja, 2005; Brazel & Dang, 2008; Ahmed & Ayman, 2011).

Secondly, considering ERP and MES individually, from the analysis it emerges that when they are necessarily present to create a sufficient configuration to lead to the outcome, job autonomy is also necessarily present. At the absence or indifference of high job autonomy, the presence of ERP and/or MES is indifferent. Thus, these systems never have a negative link to performance. This reaffirms the high effectiveness of these technologies. Furthermore, a link between ERP systems and high job autonomy emerges.

In the literature, there are studies investigating this relationship. From these, a plausible interpretation can be deduced. The implementation of ERP and MES technologies involves the disruption of business processes. Very often they must be remapped and redesigned. The implementation of these technologies brings with it a major business shock. Process redesign also affects the activities of employees. It changes the way they perform their activities and changes the way employees interact with each other and with the company (Davenport et al., 1996; Liang et al., 2007). The impact of this upheaval also affects the way employees perceive the company. Studies show that perceived job autonomy is often high following this shock (DeLone & McLean 2003). Process redesign requires that the different business functions be brought into communication. This leads to a greater connection of each function. This connection enables more information to be communicated to employees and they in turn can communicate this information to the rest of the company. The perception that has emerged from studies is that the employee no longer works for his or her job but sees his or her work as part of the company's overall operations. This increases the feeling of individual responsibility. Each worker perceives the impact of his or her work on all the functions to which it is linked. Moreover, this constant connection requires one to adapt to the needs of the entire company. Therefore, the worker often has to make decisions in relation to the data obtained. These decisions increase the sense of job autonomy (Davis, 2004; Venkatesh, 2010; Wickramasinghe & Karunasekara, 2012). The perception of autonomy increases when the worker must interface with the needs of the entire plant and has to make operational decisions based on these.

4.4.4 Negative effect of RFID implementation on job autonomy

The last noteworthy element that emerges from the analysis concerns RFID technology. All cases show that in configurations where the presence of RFID systems is necessary to create a configuration sufficient for the generation of high ROA, the absence of high job autonomy is also necessary. This relationship is symmetrical, so the presence of job autonomy corresponds to the necessary absence of RFID. Thus, it emerges that RFID and high job autonomy are never compatible in order to create a high-performance configuration.

It is important to emphasise that RFID technology is not always linked to outcome generation. In none of the cases that emerged is it indifferent. This is the first difference with ERP and MES. While they are generally always an investment that generates a positive effect on performance, the implementation of RFID does not always have a positive effect. This effect depends on the context. In particular, its implementation has an impact on the perception of job autonomy.

RFID is an information tracking system that allows to implement advanced logistic systems. Thanks to this technology, it is possible to monitor the status, quantity, and location of different items within the plant and within the entire supply chain. These benefits are achieved by scanning and reading the code on the RFID tags. There are various ways to do this that depend on the type of RFID used. However, this technology requires modifying the production process by adding some necessary steps for monitoring RFID tags. These are dictated solely by the technology and not by specific company or process needs. This potentially creates rules to be followed within the processes to perform the tasks (Hossain & Quaddus 2015; Shi & Yan 2016). Operators are obliged to perform certain actions for the implementation of RFID to be efficient. Thus, the implementation of this technology brings with it an increase in rules in the workplace. The increase in rules tends to correspond with a decrease in the perception of job autonomy (Hall, 1987; Schonbergerger, 1986). As seen in section 4.4.2 Just in Time entailed an exception because these rules are created in common with the operators and they are perceived as supporting the choices to be made in the workplace (Klein, 1991). However, this is not the case for RFID because the rules are dictated solely by the technological features of tags. Therefore, the perception of the operator may be that he or she is simply asked to perform certain tasks without his or her opinion being considered. This is undoubtedly a factor limiting job autonomy.

In conclusion, as it emerged from QCA, RFID technologies decrease the perception of job autonomy. Thus, in efficient configurations, if RFID technology is implanted, high job autonomy will not be achieved, and vice versa.

CONCLUSIONS

Industry 5.0 is a new concept still in its early stages of development. The production model it aims to build is not yet widespread in the Italian firm. However, the principles behind this new industrial revolution are spreading throughout society. Sustainability and human centricity stand out among them. Therefore, some practices that are already being adopted by companies today can contribute to the development of smart factories embracing Industry 5.0. By analysing some of these practices, in this thesis, it has been identified specific behaviours and managerial practices that can help manufacturing companies to move closer to Industry 5.0 model while remaining efficient in terms of ROA. The elements analysed in this study concern operational excellence, digital technologies, and behavioural practices.

Operational excellence practices are chosen because the literature suggests them as managerial practices that foster the development of the human centricity principle (Mladineo et al., 2021). Moreover, these techniques are based on the principle of waste reduction. Therefore, operational excellence practices make production processes more in line also with the principle of sustainability. To analyse operational excellence practices, the focus was on just in time, which is the most comprehensive and widespread lean management approach. Similarly, with regard to behavioural practices, elements that are indicators of the spread of the principle of human centricity were selected. These are proactive behaviour and job autonomy. Both are enablers of corporate well-being (Warr, 1999; Cangiano et al., 2018). Thus, a company that promotes the development of these conditions is committed to the principle of human-centricity as it places the workers and their well-being at the centre of business decisions. Finally, digital technologies were considered. The technological aspect is the main theme when dealing with industrial revolutions and changes in production models. Therefore, this thesis considered how new technologies can foster the implementation and development of Industry 5.0 model. In particular, the most developed technologies in the sample were chosen. These are ERP, MES and RFID.

By considering all these elements through a qualitative comparative analysis, some configurations of conditions sufficient to generate a ROA index above the industry average were created. In this way, it is possible to provide a holistic view of the conditions that enable Industry 5.0 approach. The present analysis revealed that none of the conditions analysed is necessary to generate a high ROA. Thus, studying the direct correlation between a condition and organizational financial performance is not sufficient. It is necessary to study the effects of a condition on the entire set of conditions and outcomes. The configurational approach is the best way to obtain this information.

In support of the value of configurational analysis, the results of this study are reported, particularly those related to just in time implementation. The adoption of this managerial practice in some cases is an enabler of behavioural practices that enable well-being while in other cases it is an inhibitor of such behaviours. Both job autonomy and proactive behaviour are enablers of well-being. However, the adoption of just in time management practices does not have the same effect on both. The results show that just in time is an enabler of job autonomy, whereas it is rather incompatible with environments with high proactive behaviour. This occurs because just in time, and lean management practices in general, do not directly influence employee outcomes such as the perception of well-being. Lean management practices do influence work characteristics (task variability, effective autonomy, and skills utilization) and these act as mediators in generating employee outcome (Parker, 2003). Work characteristics depend not only on the type of production model implemented but also on all organisational contingencies (de Treville & Antonakis, 2006). Human resource management practices and organisational culture play a fundamental role in defining work characteristics. Therefore, considering the effect of lean management alone is complex, as well as ineffective.

The studies and findings of this analysis suggest that lean management negatively affects work characteristics by reducing task variability. However, it is possible to mitigate these effects through all conditions that influence work characteristics. In this way, it is possible to implement lean and increase the perception of job autonomy (de Treville & Antonakis, 2006).

From the configurations of just in time, job autonomy, proactive behaviour, ERP, MES, and RFID studied in the sample companies, it emerges that just in time reduces task variability and limits employee proactivity. Just in time also standardises and regulates suggestions for improvements. However, the implementation of this practice allows each process step to be linked to the others, which requires workers to decide which products are most appropriate to produce to be in line with the production requirements of the entire plant. Having to make these decisions on a daily basis increases the perception of job autonomy (Klein, 1991).

Furthermore, with regard to the technological aspect studied in this analysis, it emerges that the implementation of integrated systems such as ERP and MES are often accompanied by high levels of perceived job autonomy. Workers interfacing with such software have a greater understanding of the links between the various business functions and processes (Davenport et al., 1996). With this understanding, they have to make decisions to carry out their tasks. Thus, they perceive a high level of job autonomy (Klein, 1991). Furthermore, ERP and MES software

are generally helpful in improving company performance (Soja, 2005; Brazel & Dang, 2008). Especially if they are adopted together. That is, a company that implements a complete ERP system tends to perform better than others that do not. On the contrary, the implementation of RFID systems has a tenuously negative effect on the perception of job autonomy. This technology requires the inclusion of procedures necessary for its proper functioning (Shi & Yan 2016). These procedures reduce task variability and thus negatively affect work characteristics such as job autonomy.

In conclusion, what are the configurations of operational excellence, digital technologies and behavioural practices that lead to superior performance?

In general, proactive behaviour and adoption of an ERP system integrated with the MES are conditions that lead to high performance. Regardless of the other conditions, these elements are always positively related to the outcome. However, it is not possible to answer uniquely for all companies. Performance depends on the entire set of conditions in the organisational environment. From the conditions analysed here, it emerges that just in time leads to ROAs above the industry average when it is implemented in such a way that the operator perceives the connection of a phase to the entire process. In this way, the worker is required to make operational decisions, which, despite being guided by the standards imposed by just in time, tend to enhance the perception of job autonomy. However, by imposing standards and rules, proactive behaviour is restricted. Furthermore, the imposition of rules and tasks that do not derive from process requirements, but are aimed at making a technology work properly, reduces the perception of job autonomy. This is the case with the implementation of RFID. The perception of autonomy increases when the worker has to interface with the needs of the entire plant and has to make operational decisions based on these. This can be facilitated by redesigning production processes and by integrating them within an integrated management system. For this reason, the implementation of ERP and MES software is often associated with high levels of job autonomy.

The answer of this thesis to the research question depends on the entire configuration of conditions in the organisational environment and not just the conditions analysed in this thesis. Therefore, to better understand which sets of conditions are the best performing to develop Industry 5.0 approach, we need to expand this analysis. In the future, it would be useful to consider a larger sample of companies. In this way, the interaction between a larger number of conditions can be studied. Among these, it is interesting to investigate how human resources management practices mitigate the effect of lean management on work characteristics. Furthermore, it is interesting to verify the effect of even other operational excellence practices and managerial practices in general. Finally, expanding the sample considered, it would be interesting to select companies with strong technological development. In this way, it is possible to verify the effect of advanced technologies such as 3D printing, advanced simulation, and artificial intelligence.

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