

TESIS



**Universidad de Jaén**

Facultad de Ciencias  
Sociales y Jurídicas

# **EL PAPEL DE LAS TECNOLOGÍAS DE LA INFORMACIÓN EMERGENTES EN LA FLEXIBILIDAD Y AGILIDAD DE LAS EMPRESAS**

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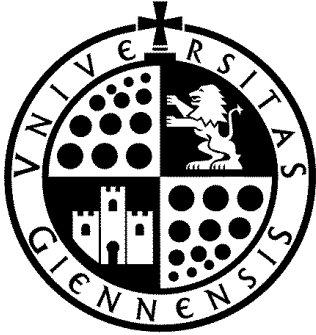
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**UNIVERSIDAD DE JAÉN**

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**FACULTAD DE CIENCIAS SOCIALES Y  
JURÍDICAS**

**DEPARTAMENTO DE ORGANIZACIÓN DE  
EMPRESAS, MARKETING Y SOCIOLOGÍA**

**Doctorado en Organización de Empresas y Gestión de la  
Tecnología**

**EL PAPEL DE LAS TECNOLOGÍAS DE LA  
INFORMACIÓN EMERGENTES EN LA  
FLEXIBILIDAD Y AGILIDAD DE LAS  
EMPRESAS**

**TESIS DOCTORAL**

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*To my family,  
for their love and support.*





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# RESUMEN

La creciente complejidad y volatilidad del entorno en la mayoría de los sectores económicos está obligando a las organizaciones a tomar decisiones estratégicas para enfrentar las amenazas y retos que se plantea en este contexto. Simultáneamente, la irrupción de tecnologías emergentes en el dominio de la Industria 4.0 ofrece a las empresas oportunidades para automatizar y conectar sus procesos, mejorar la visibilidad y el control de sus operaciones, y analizar un mayor volumen de datos para tomar decisiones informadas. Todo ello hace que estas tecnologías faciliten el desarrollo y la mejora de capacidades organizativas, como la flexibilidad y la agilidad, necesarias para responder de manera eficiente a los cambios del entorno, pudiendo generar ventajas competitivas.

El objetivo de esta tesis doctoral es entender cómo las Tecnologías Digitales y de la Información de la Industria 4.0 pueden mejorar las capacidades de flexibilidad y agilidad operativa en las organizaciones. Para lograr este objetivo, en primer lugar se ha analizado, sintetizado y clasificado la investigación existente sobre las Tecnologías Digitales y de la Información de la Industria 4.0 mediante dos revisiones de la literatura. Estas revisiones proporcionan una visión global de lo investigado sobre el tema, identificando diferentes tecnologías y su impacto esperado en las organizaciones. En esta línea, también se ha propuesto una metodología para conducir revisiones de literatura sobre un gran volumen de publicaciones, empleando técnicas de procesamiento del lenguaje natural. Los hallazgos de estos análisis indican que el impacto de las tecnologías muy emergentes sigue siendo en gran medida desconocido, aunque su capacidad para generar una ventaja competitiva puede ser considerable. Es importante destacar que en estos análisis se encuentra que el efecto de cada una de las tecnologías emergentes puede variar considerablemente, justificando así la necesidad de un análisis individualizado. A partir de las revisiones de literatura efectuadas, también se han identificado lagunas y se han propuesto futuras líneas de investigación que deberían cubrirse con nuevas investigaciones.

En la segunda parte de la tesis doctoral se abordan determinadas lagunas de investigación previamente identificadas en la revisión de la literatura y que han podido ser atendidas mediante el desarrollo de una tesis industrial, realizada en colaboración entre la Universidad de Jaén y una empresa multinacional tecnológica. Esta colaboración ha permitido entender y profundizar en las cuestiones de investigación planteadas. En este sentido, se ha investigado la aplicación de la computación de inspiración cuántica para resolver retos complejos en el área de gestión de operaciones en empresas de los sectores de fabricación y logística. Mediante un estudio de casos múltiples, se han analizado casos de éxito utilizando una plataforma digital basada en estas tecnologías, la cual se encuentra en estado operativo, determinando su impacto en la flexibilidad y agilidad operativa. Por otro lado, se ha estudiado cómo tecnologías emergentes de la Industria 4.0 como Cloud Computing, Big Data o Inteligencia Artificial, entre otras, permiten la generación de capacidades específicas y su uso en el desarrollo de nuevos productos innovadores en el sector de la salud. De igual modo, se ha analizado como sucede el proceso de transformación data-driven orientado a la mejora de las capacidades de flexibilidad y agilidad, fundamentado en la adopción de tecnologías Cloud y la evolución de las tecnologías analíticas de datos existentes, en el contexto de la logística de última milla. Para abordar dichos ámbitos se ha aplicado la metodología de Action Research donde el doctorando ha participado directamente en los procesos a investigar permitiendo proponer cambios y adaptaciones en el proceso así como una comprensión más amplia tanto de los cambios acontecidos como de los resultados alcanzados.

Esta tesis doctoral aplicada proporciona valiosas implicaciones gerenciales para organizaciones de diversos sectores y para la administración pública, derivadas de la implicación y participación directa del autor en proyectos desarrollados por la empresa multinacional tecnológica. Esta perspectiva aplicada permite que los hallazgos obtenidos sean de gran interés para empresas y administraciones públicas que busquen optimizar sus capacidades operativas de flexibilidad y agilidad mediante la adopción de tecnologías propias de la Industria 4.0. Asimismo, esta

tesis puede servir como guía orientativa en el proceso de transformación digital de las empresas, especialmente en el sector servicios.

**Palabras claves:** agilidad, capacidades operativas, flexibilidad, industria 4.0, tecnologías emergentes



# ABSTRACT

The increasingly complex and volatile environment in most economic sectors is compelling organizations to make strategic decisions to address the threats and challenges posed by this context. At the same time, the emerging technologies in the Industry 4.0 domain offers companies opportunities to automate and connect their processes, improve the visibility and control of their operations and analyse more data to make informed decisions. These technologies facilitate the development and improvement of organizational capabilities, such as flexibility and agility, needed to respond efficiently to changes in the environment, and can generate competitive advantages.

The aim of this doctoral thesis is to understand how Information and Digital Technologies of Industry 4.0 can improve organizations' operational flexibility and agility capabilities. To achieve this objective, firstly, the existing research on Information and Digital Technologies of Industry 4.0 has been analysed, synthesised and classified by means of two literature reviews. These reviews provide an overview of the research on the subject, identifying different technologies and their expected impacts on organizations. In this line, a methodology has been proposed that uses natural language processing techniques to conduct literature reviews of large volumes of publications. The findings of these analyses indicate that the impact of highly emerging technologies remains largely unknown, although their ability to generate a competitive advantage may be considerable. Importantly, these analyses find that the effect of individual emerging technologies can vary considerably, justifying the need for individualized analysis. The literature reviews have also identified gaps, and future lines of research have been proposed that should be addressed by further research.

The second part of the doctoral thesis examines some research gaps previously identified in the literature review and addressed through the development of an industrial thesis, carried out in collaboration between the University of Jaén and a multinational technology company. This collaboration has made it possible to

understand and explore more deeply the research questions raised. In this sense, the application of quantum-inspired computing to solve complex challenges in the operations management area in companies in the manufacturing and logistics sectors has been investigated. By means of a multiple case study, successful cases have been analysed using a digital platform based on these technologies, which is in an operational state, and its impact on operational flexibility and agility has been identified. This research has also explored how emerging Industry 4.0 technologies such as Cloud Computing, Big Data and Artificial Intelligence, among others, allow the generation of specific capabilities and their use in the development of new innovative products in the health sector. Furthermore, we have analysed how the data-driven transformation process aimed at improving flexibility and agility capabilities, based on the adoption of Cloud technologies and the evolution of existing data analytics technologies, takes place in the context of last-mile logistics. To address these areas, Action Research methodology has been applied, with the PhD student participating directly in the processes to be investigated. This allowed the proposal of changes and adaptations in the process and provided a broader understanding of the changes that occurred and the results achieved.

This applied doctoral thesis offers valuable managerial implications for organizations in various sectors and public administrations, derived from the author's direct involvement and participation in projects developed by the multinational technology company. This applied perspective makes the research findings of great interest for companies and public administrations seeking to optimize their operational flexibility and agility capabilities by adopting Industry 4.0 technologies. This thesis can also serve as a guide to orientate companies' digital transformation processes, especially in the service sector.

**Keywords:** agility, emerging technologies, flexibility, industry 4.0, operational capabilities

# PREFACE

This doctoral thesis is submitted to the University of Jaén as partial fulfilment of the requirements for the degree of Doctor of Philosophy in Economic, Business and Legal Sciences with Industrial mention.

This doctoral work has been performed in the programme of Business Organization and Technology Management at the University of Jaén (Spain), with Prof. Juan Manuel Maqueira Marín as the main supervisor, and Prof. José Moyano Fuentes and Prof. Carlos Alberto Castaño Moraga as co-supervisors.

The PhD student has been employed by Fujitsu and linked to Fujitsu's Data Intelligence Centre of Excellence throughout this doctoral work. During the fieldwork, several applied research projects have been undertaken to advise industrial companies on selected research topics in the doctoral thesis. These companies partially financed the work carried out by the PhD candidate. This has allowed the doctoral thesis to receive the Industrial Mention.

Additionally, the two literature reviews and three case studies included in the doctoral thesis have been partially published by the author in top-level academic journals. These works have already been published or are under minor corrections (see Chapter 1.5 for a detailed list of publications and communications).



# CONTENTS

<b>FUNDING</b>	<b>i</b>
<b>RESUMEN</b>	<b>iii</b>
<b>ABSTRACT</b>	<b>vii</b>
<b>PREFACE</b>	<b>ix</b>
<b>CONTENTS</b>	<b>xi</b>
<b>List of Figures</b>	<b>xv</b>
<b>List of Tables</b>	<b>xvi</b>
<b>List of Acronyms</b>	<b>xvii</b>
<b>1. CHAPTER 1</b>	<b>1</b>
<b>Introduction</b>	<b>1</b>
1.1. Research Background .....	3
1.1.1. Information and Digital Technologies of Industry 4.0 .....	4
1.1.2. Data-driven transformation.....	5
1.1.3. Lean Supply Chain Management .....	6
1.1.4. Operational flexibility and agility capabilities in Operations Management .....	7
1.1.5. The role of emerging technologies in New Product Development.....	8
1.1.6. Precision Medicine .....	9
1.1.7. Quantum-inspired Computing Technology.....	10
1.2. Motivation and research questions.....	11
1.3. Research Methodology.....	17
1.3.1. Systematic Literature Review .....	18
1.3.2. Complementary techniques for literature reviews.....	19
1.3.3. Multiple Case Study.....	23
1.3.4. Action Research .....	25
1.4. Thesis structure .....	27

1.5. List of publications and communications.....	31
1.6. References.....	39
<b>2. CHAPTER 2</b>	<b>55</b>
<b>Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review</b>	<b>55</b>
<b>3. CHAPTER 3</b>	<b>58</b>
<b>Industry 4.0 and Supply Chain. A Systematic Science Mapping analysis</b>	<b>58</b>
<b>4. CHAPTER 4</b>	<b>61</b>
<b>Quantum-inspired computing technology in operations and logistics management</b>	<b>61</b>
<b>5. CHAPTER 5</b>	<b>64</b>
<b>Product development process for a new healthcare service in the Industry 4.0 context: an action research approach</b>	<b>64</b>
<b>6. CHAPTER 6</b>	<b>67</b>
<b>Optimizing last-mile delivery through data-driven transformation: an action research approach</b>	<b>67</b>
<b>7. CHAPTER 7</b>	<b>71</b>
<b>Conclusions</b>	<b>71</b>
7.1. Conclusions.....	73
7.2. Main contributions.....	73
7.2.1. Research Question 1.....	75
7.2.2. Research Question 2.....	76
7.2.3. Research Question 3.....	80
7.2.4. Research Question 4.....	82
7.2.5. Research Question 5.....	83
7.3. Theoretical implications.....	84
7.4. Managerial implications.....	87
7.5. Limitations and future research directions.....	92

7.6. References .....	96
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# List of Figures

## CHAPTER 1

<b>Figure 1.1. Systematic Science Mapping Analysis (SSMA) workflow .....</b>	<b>20</b>
<b>Figure 1.2. Action Research cycle .....</b>	<b>26</b>
<b>Figure 1.3. Thesis structure map .....</b>	<b>28</b>

# List of Tables

**No se encuentran elementos de tabla de ilustraciones.**

# List of Acronyms

<b>AI</b>	Artificial Intelligence
<b>AM</b>	Additive manufacturing
<b>AMT</b>	Advanced Manufacturing Technologies
<b>AR</b>	Action Research
<b>AV</b>	Autonomous Vehicles
<b>AWS</b>	Amazon Web Services
<b>BDA</b>	Big Data Analytics
<b>BIM</b>	Building Information Modeling
<b>CAD</b>	Computer Aided Design
<b>CAE</b>	Computer Aided Engineering
<b>CAM</b>	Computer Aided Manufacturing
<b>CGI</b>	Cancer Genome Interpreter
<b>CIM</b>	Computer Integrated Manufacturing
<b>COB</b>	Crude Oil Blending
<b>CPS</b>	Cyber-Physical System
<b>DA</b>	Digital Annealer
<b>DNA</b>	Deoxyribonucleic Acid
<b>EDI</b>	Electronic Data Interchange
<b>EHR</b>	Electronic Health Records
<b>EPC</b>	Electronic Product Code
<b>ERP</b>	Enterprise Resource Planning
<b>GIS</b>	Geographical Information Systems
<b>GPS</b>	Global Positioning System
<b>HIS</b>	Health Information Systems
<b>HPC</b>	High-Performance Computing
<b>I4.0</b>	Industry 4.0
<b>IDT</b>	Information and Digital Technologies
<b>IoT</b>	Internet of Things
<b>IT</b>	Information Technology

<b>JCI</b>	Journal Citation Indicator
<b>JCR</b>	Journal Citation Reports
<b>JIT</b>	Just in Time
<b>k-NNG</b>	k-nearest neighbours graph
<b>KPIs</b>	Key Performance Indicators
<b>LARG</b>	Lean-Agile-Resilient-Green
<b>LLM</b>	Large Language Model
<b>LM</b>	Lean Management
<b>LSC</b>	Lean Supply Chain
<b>LSCM</b>	Lean Supply Chain Management
<b>NER</b>	Named Entity Recognition
<b>NGS</b>	Next Generation Sequencing
<b>NLP</b>	Natural Language Processing
<b>NPD</b>	New Product Development
<b>OIPT</b>	Organizational Information Processing Theory
<b>OM</b>	Operations Management
<b>PHP</b>	Prefabrication Housing Production
<b>PM</b>	Precision Medicine
<b>PoC</b>	Proof of Concept
<b>QiC</b>	Quantum-inspired Computing
<b>RFID</b>	Radio Frequency Identification
<b>RQ</b>	Research Question
<b>RT</b>	Research Topics
<b>SCM</b>	Supply Chain Management
<b>SJR</b>	SCImago Journal Rank
<b>SLNA</b>	Systematic Literature Network Analysis
<b>SLR</b>	Systematic Literature Review
<b>SMEs</b>	Small and Medium-sized Enterprises
<b>SSMA</b>	Systematic Science Mapping Analysis
<b>TLC</b>	Technology Life Cycle
<b>TRL</b>	Technology Readiness Level
<b>TSD</b>	Technical Specifications Document

**UNCTAD** | United Nations Conference on Trade and Development  
**VMI** | Vendor Management Inventory  
**VR** | Virtual Reality  
**WoS** | Web of Science



# CHAPTER 1

## Introduction





## **1. Introduction**

The increasingly complex and volatile environment in most economic sectors is compelling organizations to make decisions to address the threats and challenges posed by this context. Concurrently, the advent of novel technologies in the domain of Industry 4.0 gives companies the opportunity to automate and connect their processes, improve the visibility and control of their operations, and analyse a greater volume of data. This enables the development of new capabilities in companies, such as flexibility and agility to respond to environmental changes. The objective of this doctoral thesis is to understand how emerging Information and Digital Technologies (IDT) of Industry 4.0 can improve operational flexibility and agility capabilities in organizations.

The following section presents an explanation and justification of the content of the doctoral thesis. To achieve this objective, this chapter is structured into six sections. Firstly, the background provides an overview of the key concepts. Secondly, the motivation for developing the thesis is explained, and the objectives and research questions are stated. The third chapter presents the research methodologies. Next, the overall structure of the thesis is set out and, finally, a complete list of the documents derived from this thesis is provided.

### **1.1. Research Background**

This section presents an overview of the main topics covered in the study. Therefore, it provides explanations of IDT of Industry 4.0, data-driven transformation, Lean Supply Chain Management (LSCM), operational flexibility and agility capabilities in Operations Management (OM), New Product Development (NPD), Precision Medicine (PM) and Quantum-inspired Computing (QiC).

### **1.1.1. Information and Digital Technologies of Industry 4.0**

The term Industry 4.0, also known as the Fourth Industrial Revolution, emerged in 2011 to drive Digital Transformation in the industrial sphere. It promotes an improved customer focus through technology that enables greater interconnectedness between machinery, tools and workers (Kagermann, Wahlster & Helbig, 2013; Núñez-Merino, Maqueira-Marín, Moyano-Fuentes & Martínez-Jurado, 2020). Furthermore, this concept involves enhanced interconnectivity between suppliers, vendors and customers transcending organizational boundaries (Ghobakhloo, 2018; Gilchrist, 2016). Industry 4.0 is based on principles, such as interoperability, virtualisation, decentralization, real-time responsiveness, service orientation and modularity (Hermann, Pentek & Otto, 2016). These principles are supported by various applicable technologies that facilitate their implementation (Núñez-Merino et al., 2020; Diéssica de Oliveira-Dias, Maqueira-Marin, Moyano-Fuentes & Carvalho, 2023).

IDT of Industry 4.0 refers to the application of a set of technologies related to digital transition whose scope extends beyond organizational boundaries and involves intelligent supply chain and connected customers (Ghobakhloo & Azar, 2018; Núñez-Merino et al., 2020; Diéssica de Oliveira-Dias et al., 2023). So, IDT of Industry 4.0 includes the application of mature technologies related to e-commerce tools such as Electronic Data Interchange (EDI); the adoption of Advanced Manufacturing Technologies (AMT) such as Computer Aided Design (CAD), Computer Aided Manufacturing (CAM), Computer Aided Engineering (CAE), and Enterprise Resource Planning (ERP), and the most advanced IDT such as the Internet of Things (IoT), Augmented Reality (AR), Additive Manufacturing (AM), Cloud Computing and Big-Data analytics (Ghobakhloo, 2020; Gilchrist, 2016; Lu, 2017).

The development of Industry 4.0 has been driven by rapid technological advances (Choi, Kumar, Yue & Chan, 2022). Some very emerging technologies such as Artificial Intelligence (AI), Blockchain, 5G/6G technologies and Quantum Computing (Mathauer & Hofmann, 2019; Xu, Lu, Vogel-Heuser & Wang, 2021)

are impacting Industry 4.0 base technologies (Frank, Dalenogare & Ayala, 2019). In this way, IDT of Industry 4.0 comprises a wide range of mature and emerging technologies that are jointly and intensively applied to industry to achieve operational efficacy and efficiency (Doetzer & Pflaum, 2021; Frank et al., 2019; Núñez-Merino et al., 2020). Organizations are interested in using these new technologies, which could improve their operational capabilities at the organizational and supply chain levels (Doetzer & Pflaum, 2021; Núñez-Merino et al., 2020). Advances in IDT of Industry 4.0 have played a key role in information-sharing through intra- and inter-organizational cooperation and communication, which improves an organization's ability to respond to uncertainty (Núñez-Merino, Maqueira-Marín, Moyano-Fuentes & Castaño-Moraga, 2022; Sambamurthy, Bharadwaj & Grover, 2003).

### **1.1.2. Data-driven transformation**

In recent years, Digital Transformation has emerged as a phenomenon of considerable interest to the academic community and professional experts. Digital Transformation is defined as a continuous process of strategic renewal through integrating digital technologies (D. L. Rogers, 2016; Vial, 2019). This process enables the creation of capabilities that transform, update or replace the business model, processes, products, collaborative approach and culture. This results in an improved customer experience and increased value for organizations (Hess, Matt, Benlian & Wiesböck, 2020; Matt, Hess & Benlian, 2015; Warner & Wäger, 2019).

In the field of Digital Transformation, data-driven transformation is the process of using data to drive, catalyse, instruct and guide decision-making in organizations (Gölzer & Fritzsche, 2017). Companies that view information as a strategic resource can gain a competitive advantage and differentiate themselves in the market (D. L. Rogers, 2016).

Business Intelligence and Big Data Analytics tools facilitate the collection, storage, analysis and visualization of data to help companies understand and extract knowledge from their data to guide the decision-making process (Choi, Wallace &

Wang, 2018; Helo & Hao, 2022). This process involves using various Industry 4.0 Technologies, such as IoT, Radio Frequency Identification (RFID), Global Positioning System (GPS) and sensors for data acquisition, as well as the use of Cloud Computing and Big Data infrastructure for storage and processing (Chen et al., 2016).

Advanced data analysis techniques such as machine learning or deep learning are also employed, along with advanced optimization algorithms. Additionally, data visualization tools and technologies are used (G. Wang, Gunasekaran, Ngai & Papadopoulos, 2016). The evolution and application of Business Intelligence and Big Data Analytics enable the development of new capabilities in information processing and provide decision-making tools that can enhance efficiency and operational agility (Park, El Sawy & Fiss, 2017; Schlegel, Birkel & Hartmann, 2021).

### **1.1.3. Lean Supply Chain Management**

Supply Chain Management (SCM) is defined as the strategic coordination and oversight of physical and informational flows within and across organizations. It encompasses internal logistics management and establishing efficient processes with external partners, including suppliers and customers. The objective of SCM is to optimize the above relationships and processes to ensure the timely delivery of goods and services while minimising costs and maximising overall efficiency (Chen & Paulraj, 2004; Kache & Seuring, 2014). In recent years, SCM has been considered a key factor in increasing companies' efficacy and competitiveness (Ataseven & Nair, 2017; Frohlich & Westbrook, 2001). So, a suitable SCM strategy enables improvements to operating results in terms of greater process efficiency, a lower inventory level, higher customer satisfaction, better quality, cost reductions and improved delivery (Christopher & Towill, 2000). In conjunction with the increase in global competitive pressure, this has led to lean principles spreading to the supply chain level to optimize interorganizational processes from the end customer's point of view (Swenseth & Olson, 2016). This has given rise to what is

known as Lean Supply Chain Management (LSCM). LSCM consists of organizations directly linked by upstream and downstream flows of goods, services, finances and information that work together to reduce costs and waste by efficiently and effectively pulling what is required to meet the needs of individual customers (Moyano-Fuentes, Bruque-Cámara & Maqueira-Marín, 2019; Swenseth & Olson, 2016; Vitasek, Manrodt & Abbott, 2005).

#### **1.1.4. Operational flexibility and agility capabilities in Operations Management**

A firm's competitive success depends on its ability to develop operational capabilities that consistently provide high value to the customer (Sansone, Hilletoft & Eriksson, 2017). Operational capabilities have been defined as the specific set of abilities, processes and routines that a firm executes in its OM system and regularly uses to reconfigure its operating resources to solve problems (Roscoe, Cousins & Handfield, 2019; Wu, Melnyk & Flynn, 2010). Operational capabilities can be tangible (physical resources, processes, practices) or intangible (accumulated know-how, skills, expertise) (Roscoe et al., 2019; Saunila, Ukko, Rantala, Nasiri & Rantanen, 2020). These capabilities have long been studied from the perspective of their outcomes (performance), including cost, quality, delivery, speed, agility and flexibility (Jinhui Wu, Melnyk & Swink, 2012; Tan, Kannan, Jayara & Narasimhan, 2004).

The OM literature has defined flexibility and agility as capabilities. The terms are frequently used interchangeably and with similar meanings (Abdelilah, El Korchi & Balambo, 2018; Giachetti, Martinez, Sáenz & Chen, 2003). However, there is also a broad consensus that flexibility and agility are two different elements that enable a firm to obtain competitive advantages by responding to environmental changes effectively (flexibility) and rapidly (agility) (Abdelilah et al., 2018). Flexibility has been defined as the capability to modify a system's operations in response to medium-term changes in the environment (Y. P. Gupta & Goyal, 1989;

Upton, 1994), while agility has been used to refer to an organization's capability to respond to these changes rapidly (Sharifi & Zhang, 1999).

The literature shows that both flexibility and agility are the result of synergies generated by different capabilities (Giachetti et al., 2003; Pérez-Pérez, Serrano-Bedia & López-Fernández, 2016) and that the two concepts are interrelated, with flexibility being the engine that drives agility. So, flexibility is the key to agility, achieved by exploiting synergies between different forms of flexibility in a firm (Abdelilah et al., 2018; Swafford, Ghosh & Murthy, 2008). Some authors state the existence of first- or higher-order capabilities and second- or lower-order capabilities (Schilke, 2014); a firm develops lower-order capabilities from a set of more specific abilities and processes, which are the higher-order capabilities (P. P. Rogers, Ojha & White, 2011; Zhang, Vonderembse & Lim, 2003). In this regard, a body of literature exists that considers flexibility and agility to be interrelated higher-order operational capabilities and that their development and improvement, therefore, depend on other, lower-order capabilities (P. P. Rogers et al., 2011).

### **1.1.5. The role of emerging technologies in New Product Development**

New Product Development (NPD) is a systematic and strategic approach that organizations use to bring new products or services to market (Rochford & Rudelius, 1997). It consists of a series of steps or activities designed to identify, develop and launch products or services to meet customers' needs or preferences (Krishnan & Loch, 2005; Rochford & Rudelius, 1997). The NPD domain is extensive and covers technology strategy, research management and project management (Krishnan & Loch, 2005). The seamless integration of NPD with overarching business strategies is a key aspect of a technology strategy that requires insightful decision-making to align innovation with business objectives (Peng, Heim & Mallick, 2014; W. Song, Cao & Zheng, 2016). Research management aims to foster the development of innovative technologies as yet unlinked to any specific market products (Krishnan & Loch, 2005; W. Song et al., 2016).

In the health sector, NPD is a crucial for driving innovation and enhancing patient outcomes, including quality of life, treatment effectiveness and satisfaction (Denicolai & Previtali, 2020; Ginsburg & Phillips, 2018). Health NPD covers several fields such as pharmaceutical products (Dong & Yang, 2016; Li, Sarpong & Wang, 2022; Lütkemeyer, Heese & Wuttke, 2021), medical devices (Bhamra, Hicks, Small & García-Villarreal, 2022; Lee et al., 2023), digital health solutions (Colloud et al., 2023; Higgins & Madai, 2020; Lee et al., 2023), and healthcare services management (Lyon, Dopp, Brewer, Kientz & Munson, 2020; S. Wang, 2023).

The strategy for developing new healthcare products and services involves leveraging cutting-edge technologies such as AI, Big Data, Cloud Computing, IoT, 3D printing and robotics, among others (Alhayani et al., 2023; M. Gupta, Kumar & Bala, 2023; Tortorella, Fogliatto, Mac Cawley Vergara, Vassolo & Sawhney, 2020). Thanks to these advances, the health sector is experiencing a significant transformation not only in terms of technological solutions but also in the way that medical attention is provided (Love-Koh et al., 2018; Tate et al., 2023): from robots participating in complex medical procedures and better diagnostic techniques to new methods to develop drugs and ground-breaking planning systems to optimize operations (Dai & Tayur, 2020; C. H. Song, 2017; Tortorella et al., 2021). These advances drive improvements in healthcare delivery and patient care while reducing costs and waiting times.

#### **1.1.6. Precision Medicine**

PM is a personalised approach that uses genetic, environmental and lifestyle information to prevent, diagnose and treat disease more effectively. PM uses genomic data to help provide the right treatment to the right patient at the right time (Denicolai & Previtali, 2020; Hopp, Li & Wang, 2018). PM is a medical focus designed to deliver a high value-added service that can improve patient health by specifically and effectively treating patients' unique features. These treatments are intended to identify illnesses a long time before the latter present, and early

intervention minimises the effect of an illness on the patient (Denicolai & Previtali, 2020; Ginsburg & Phillips, 2018; Hopp et al., 2018).

The idea that different patients respond to the same treatment differently is not new (Love-Koh et al., 2018). Knowledge of mutations or genetic variations is essential for PM as it helps to predict a patient's response to a specific treatment and design more effective and personalised therapies (He, Ge & He, 2017; Schmidt & Hildebrandt, 2017). However, to offer patients more personalised, precise and high-quality medical care, healthcare institutions require powerful Industry 4.0 Technologies (Aceto, Persico & Pescapé, 2018; M. Gupta et al., 2023). Furthermore, Digital Transformation in healthcare systems is recognised as a crucial challenge to PM's rollout and success (Denicolai & Previtali, 2020; Gastaldi et al., 2018).

### **1.1.7. Quantum-inspired Computing Technology**

Quantum computing is a computational paradigm that uses the principles of quantum mechanics to perform calculations and solve problems more efficiently than classical computers (Huang, Wu, Fan & Zhu, 2020). Quantum computing offers a vast information processing capacity that eclipses conventional computers (Arute et al., 2019) but its development state has limited its widespread practical application. Quantum computing is still at a very early stage of development and many more hurdles will have to be overcome for it to become accessible to companies (Mohseni et al., 2017). However, in 2017, Fujitsu, a global company in the Information and Communication Technology sector, took a giant leap forward in developing QiC by creating an innovative product called Digital Annealer (DA). DA is the first computing architecture in the world inspired by quantum computing and is capable of making parallel optimization calculations with a speed and accuracy that are impossible with conventional computers (Aramon et al., 2019; Denkena, Schinkel, Pirnay & Wilmsmeier, 2021).

Fast and flexible decision-making and process optimization are essential to guarantee optimal resource allocation and efficient OM. OM efficiency implies

identifying and eliminating wastage, which can increase flexibility to boost operational agility (Enrique et al., 2022; Núñez-Merino et al., 2020; Oliveira-Dias et al., 2022a). Even more rapid and flexible decision-making is needed in manufacturing and logistics, where complexity and uncertainty must be managed in real time. As these issues can be addressed with mathematical models and suitable technology (Olhager, Pashaei & Sternberg, 2015), they can be tackled through advanced optimization techniques (S. Gupta, Modgil, Bhattacharyya & Bose, 2022). However, many combinatorial optimization problems are complex, and solutions are time-consuming. Conventional computers can be used but their solutions are often suboptimal (Gyongyosi & Imre, 2019). Therefore, quantum computing could play a critical role in decision-making and process optimization in OM (S. Gupta et al., 2022; Sarkis, Kouhizadeh & Zhu, 2020).

## **1.2. Motivation and research questions**

Organizations operate in a highly competitive, complex and volatile environment due to Digital Transformation, market globalization and rapid and disruptive change (Belhadi, Mani, Kamble, Khan & Verma, 2024; Lohmer, Bugert & Lasch, 2020). In this context, organizations are pressured to reduce product development cycles, operate with high levels of quality and reduce costs to meet customer requirements (Calatayud et al., 2019; Oliveira-Dias et al., 2022b). Consequently, organizations strive to improve their operational capabilities to meet customer demand more effectively and efficiently (Abdelilah et al., 2018; Srinivasan & Swink, 2018).

Industries are undergoing a significant technology transformation to deliver more customer value that affects all levels and sectors of organizations, extending beyond the boundaries of the enterprise to include the entire supply chain (Ghobakhloo, 2020; Strozzi, Colicchia, Creazza & Noè, 2017). This revolution has been called Industry 4.0. Industry 4.0 relies on interconnectedness, transparency, real-time data and decentralization, with technologies playing a key role (Hermann

et al., 2016). The development of Industry 4.0 has been driven by rapid technological advances (Choi et al., 2022; Letmathe & Rößler, 2022).

In this context, companies are implementing the so-called Industry 4.0 base technologies (Frank et al., 2019; Diéssica de Oliveira-Dias et al., 2023). This can be defined as a set of novel technologies that have attained a higher level of maturity and are the basis for deploying other less mature or emerging technologies. The Industry 4.0 base technologies include Cloud Computing, Big Data and the Internet of Things (Chaudhuri, Vrontis & Chatterjee, 2024; Frank et al., 2019; Diéssica de Oliveira-Dias et al., 2023). Thus, very emerging technologies such as AI, blockchain, 5G/6G technologies and quantum computing (Hofmann, Sternberg, Chen, Pflaum & Prockl, 2019; Xu et al., 2021) are impacting Industry 4.0 base technologies.

Organizations are interested in using these new technologies, as they could improve their operational capabilities at the organizational and supply chain levels (Doetzer & Pflaum, 2021; Overby, Bharadwaj & Sambamurthy, 2006). Although operational flexibility and agility are key capabilities enabled by Industry 4.0 technologies, many organizations find their development challenging (Dalenogare, Benitez, Ayala & Frank, 2018; Frank et al., 2019). These operational capabilities are interrelated, with flexibility being a component of, or an antecedent to agility (Abdelilah et al., 2018; Swafford et al., 2008). Potentially, some emerging technologies can significantly improve the operational flexibility and agility levels achieved to date (Núñez-Merino et al., 2020; Diessica de Oliveira-Dias et al., 2022).

Organizations must evolve their technology infrastructure to achieve high operational flexibility and agility capabilities levels in value chain operations (Hofmann & Rüsçh, 2017; Shahin, Chen, Bouzary & Krishnaiyer, 2020). Leading organizations in their respective markets are using emerging technologies to establish systems that facilitate real-time data and information exchange among manufacturers, suppliers and customers. This enables them to make informed decisions quickly and effectively, which enhances the operational agility of their

own organization and supply chain and gives them a competitive advantage (Frank et al., 2019; Mathauer & Hofmann, 2019; Núñez-Merino et al., 2020).

Generally speaking, academics and managers are unaware that some large organizations are already working in partnership with a QiC technology supplier. They are exploring this technology's capability to provide real-time information to support decision-making in OM aimed at optimizing complex processes such as manufacturing planning, optimal routing of vehicle fleets, inventory management and large-scale supply chain planning, among others. Mohseni et al. (2017, p. 172) state that imminent advances in quantum technologies must be capitalized on, and that this requires that 'the discipline broadens its focus and that scientists work more closely with entrepreneurs' on real applications. So, given QiC's potential to enable organizations to solve highly complex challenges and impact decision-making, process optimization and inefficiency identification and elimination, it is interesting to investigate its possible effects on operational flexibility and agility and the subsequent outcomes. Indeed, the processes involved in manufacturing and logistics are highly complex, with numerous variables and interrelated decisions. In this context, the potential of QiC technology can be significant, as it offers tools to address the inherent complexity of these fields, thereby improving efficiency, accuracy and agility in decision-making.

Industry 4.0 technological advances are also creating new opportunities and applications in healthcare (Aceto et al., 2018; Tortorella et al., 2020). Developing new and innovative technological products can facilitate the implementation of new services in healthcare systems focused on PM. Expectations surrounding this new medical practice have the potential to revolutionize healthcare delivery using patient genomic information (Hopp et al., 2018; Love-Koh et al., 2018). PM aims to optimize healthcare systems by facilitating early diagnosis and individualized treatment, which could significantly increase the agility and efficiency of healthcare systems (Denicolai & Previtali, 2020; C. H. Song, 2017). Although early diagnosis appears to be the immediate objective, a digital platform of this type could improve efficiency and agility in managing other processes related to therapy, prevention, monitoring and active surveillance, as well as in public health and research.

Emerging technologies such as AI, Cloud Computing and Big Data will play crucial roles in achieving this goal (Hopp et al., 2018; Lütkemeyer et al., 2021).

The innovative nature of PM requires further research to identify the tools, technologies and processes needed to make this new paradigm a reality in healthcare systems (Denicolai & Previtali, 2020; Gastaldi et al., 2018). This gap highlights the need to investigate how technology can facilitate the implementation of a new health service and which technological components are essential to optimize the operations of the healthcare workforce. Addressing this research question can provide valuable information on how to use technology to deliver PM services and integrate the principles of operational agility into healthcare. This would enable rapid adaptation to emerging medical advances and support earlier diagnosis and more individualized and effective treatments in line with PM goals.

In contrast, logistics companies experienced a significant increase in turnover during the COVID-19 pandemic, largely attributed to the surge in e-commerce. Logistics service providers are currently investing heavily in digitalization to provide efficient decision-making mechanisms for each business area, accelerate innovation and improve predictive capacity and agility to address a changing environment before their competitors (Cichosz, Wallenburg & Knemeyer, 2020; Su, Fan & Shou, 2020). However, while the push towards digitalization is evident, there remains a gap in understanding how logistics service providers should approach a data-driven transformation process to fully leverage their organizational capacity and flexibility to boost operational agility.

The challenges presented are part of an Industrial Thesis developed within the Collaboration Agreement between the University of Jaén and one of the world's leading technology providers, Fujitsu. This has enabled direct participation in the implementation and use of technologies in the field of Industry 4.0, with the opportunity to observe the achieved results. In this context of collaboration between industry and academia, and to meet the current challenges faced by organizations, a methodology has been employed that has been specially adapted and is useful in these contexts: Action Research (AR). AR facilitates the achievement of

substantive value and transformational organizational outcomes (Coughlan & Coughlan, 2002; Su et al., 2020). It serves as a methodological framework and a dynamic process, bridging practical application and scholarly enquiry.

In this context, this doctoral thesis aims to address these gaps by advancing knowledge on the role of emerging technologies in various sectors and how they can enhance operational flexibility and agility.

Based on the above, this doctoral thesis seeks to answer five specific Research Questions (RQs) and achieve some specific objectives, which are presented below:

**RQ1.** What has been investigated on the relationships between Information and Digital Technologies of Industry 4.0 and the Lean Supply Chain Management and what are the key findings and remaining challenges?

The following specific objectives derive from this question:

**Objective 1.1:** To identify a taxonomy of the current research on Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management.

**Objective 1.2:** To discuss the main findings and propose future research directions based on the identified gaps.

**RQ2.** What is the state of knowledge in the literature on Industry 4.0 and supply chain?

In this case, we seek to achieve the following specific objectives:

**Objective 2.1:** To design and implement a methodology for conducting literature reviews of large volumes of information.

**Objective 2.2:** To identify the topics studied in the articles published on Industry 4.0 and supply chain to date.

**Objective 2.3:** To identify unexplored research fields in the literature on Industry 4.0 and supply chain and suggest directions for future research on this issue.

**RQ3.** What effect does Quantum-inspired Computing technology have on developing operational flexibility and agility capabilities in the manufacturing and logistics sectors?

The following specific objectives derive from this question:

**Objective 3.1:** To explore and disseminate knowledge about Quantum-inspired Computing technology's potential to solve complex challenges faced by the operational agility capability in Industry 4.0 manufacturing and logistics operations.

**Objective 3.2:** To propose a literature review-based framework that identifies a set of operational capabilities enabled by Information and Digital Technology of Industry 4.0 that boost organizational flexibility and agility.

**Objective 3.3:** To propose an exploratory model to explain the relationships between Quantum-inspired Computing technology and the deployment of operational agility capabilities.

**RQ4.** How can Information and Digital Technologies of Industry 4.0 enable the implementation of a new healthcare service?

The following specific objectives that must be achieved to answer this question are:

**Objective 4.1:** To design and develop a new digital product that facilitates the implementation of a Precision Medicine-based healthcare service.

**Objective 4.2:** To incorporate the principles of operational agility in healthcare, enabling swift adaptation to emerging medical insights and supporting early diagnosis and more effective treatments in line with Precision Medicine objectives.

**RQ5.** How should a data-driven transformation process to improve operational capabilities in logistics service providers be addressed?

The specific objectives required to answer this question are:

**Objective 5.1:** To identify a last-mile logistics service provider's key operating processes for a data-driven transformation process.

**Objective 5.2:** To propose a framework for developing a structured process for designing, developing, validating, implementing and continuously improving data analysis tools.

**Objective 5.3:** To identify a set of theoretical and managerial propositions that can be the key to successfully undertaking a data-driven transformation process.

### 1.3. Research Methodology

Research methodology is a systematic framework that researchers use to conduct empirical investigations and contribute to advancing knowledge in a particular field of study. It guides the researcher through the entire research process, including selecting the research design, data collection methods and data analysis techniques. The importance of a rigorous research methodology lies in its capacity to guarantee the dependability, validity and generalizability of study findings. Meticulously detailing the procedures undertaken enhances the replicability of researchers' work, fostering a foundation for subsequent scholars to build upon. A well-crafted methodology also contributes to recognising and addressing potential influencing factors, thereby enhancing the internal and external validity of the research.

This doctoral thesis uses various methods to comprehensively and rigorously achieve the research objectives. Initially, a Systematic Literature Review (SLR) was conducted to assess the current state of knowledge in the study area. Subsequently, the initial phases of SLR have been used with Natural Language Processing (NLP) techniques to design, develop and implement a methodology

suitable for conducting literature reviews with great quantities of articles. This method is called Systematic Science Mapping Analysis (SSMA) and forms part of one of the research objectives. SSMA is described in detail in section 1.3.2. Multiple Case Study methodology was used to investigate specific contexts and gain a thorough understanding of the situations under scrutiny. Finally, AR was employed as a participatory methodology, promoting active collaboration with relevant stakeholders. This approach is a powerful tool for bridging the gap between theory and practice. Integrating these methodologies has significantly enriched the research, ensuring a meticulous analysis and a robust interpretation of the results.

### **1.3.1. Systematic Literature Review**

SLR is a rigorous and structured research methodology employed to comprehensively synthesize existing knowledge in a specific domain (Denyer & Tranfield, 2009; Thomé, Scavarda & Scavarda, 2016; Tranfield, Denyer & Smart, 2003). It involves a systematic and transparent approach to identifying, selecting, evaluating and synthesizing relevant studies to address a defined research question.

The main advantages of this method that can be highlighted are that it guarantees a structured, repeatable and scientific process that enables existing information to be synthesized in a rigorous and objective process (Denyer & Tranfield, 2009; Tranfield et al., 2003). The review process was conducted following the five stages proposed by Denyer and Tranfield (2009):

- (i) *Formulation of the research question(s)*: The first step in an SLR is to define a research question that will guide the entire review process. The research question must delimit the study's scope and purpose. Therefore, the key concepts must be defined clearly.
- (ii) *Identification of studies*: To identify the relevant studies, this stage includes the selection of the databases that will be used for locating the studies and defining the search strings.

- (iii) *Selection and evaluation of studies:* In this stage, researchers should select and adhere to a set of inclusion and exclusion criteria to guarantee the relevance and alignment of the studies with the SLR's research question.
- (iv) *Analysis and synthesis:* The fourth stage involves extracting and storing relevant information about each selected study. The end goal is to link the studies with the topics.
- (v) *Reporting of results and discussion:* The final stage consists of presenting the main findings by reporting descriptive and thematic analyses.

To ensure that the study can be replicated, all the stages of the SLR (including for example, keywords, and inclusion and exclusion criteria) should be reported in detail. Therefore, following the best practices for conducting SLRs (Durach, Kembro & Wieland, 2017; Okoli & Schabram, 2010; Thomé et al., 2016), PRISMA (preferred reporting items for systematic reviews and meta-analysis) flowcharts should be created to illustrate the different phases of the SLR.

### 1.3.2. Complementary techniques for literature reviews

This doctoral thesis proposes a methodological innovation for conducting literature reviews given the enormous volume of scientific production in our field of research. In the proposed SSMA methodology, several methods and techniques are applied sequentially (Núñez-Merino et al., 2022). Figure 1.1 shows the workflow proposed in this methodological approach. Firstly, the initial phases of an SLR are applied to identify, select and evaluate the documents for analysis to respond to the gap to be covered. Then, the selected articles are analysed using NLP techniques (Silge & Robinson, 2017), SciMAT (Cobo, López-Herrera, Herrera-Viedma & Herrera, 2012) and Graphext (Graphext Team, 2021).

When the SLR focus is applied with the first of these methods, the study is substantiated by the rigorous selection of documents for analysis and the guarantee

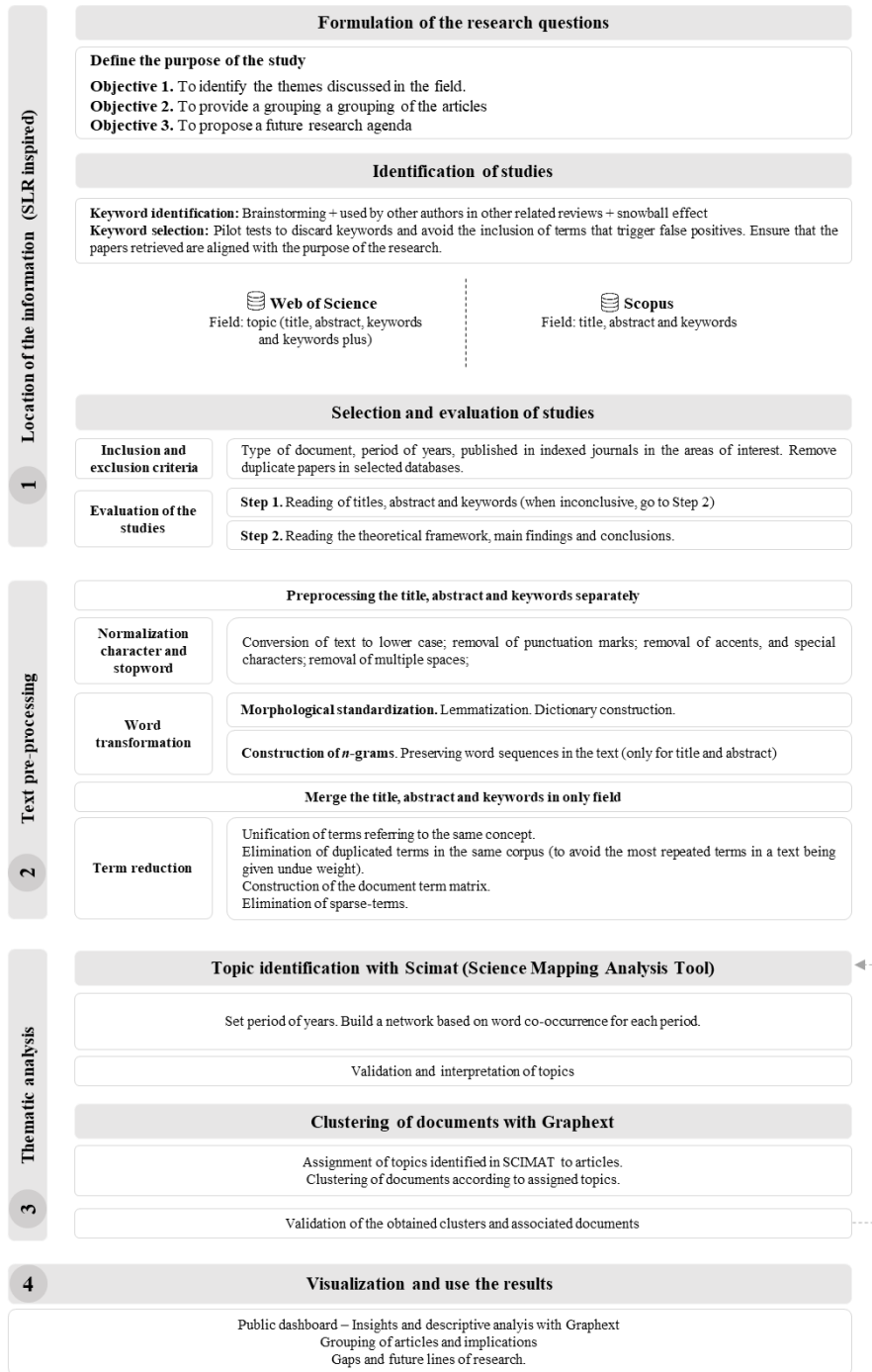
that they have all made a significant contribution to the field of study that the researcher wishes to review and synthesize (Denyer & Tranfield, 2009; Tranfield et al., 2003). Subsequently, NLP techniques are employed to pre-process the article titles, abstracts and keywords and extract new keywords based on this corpus of information. This approach facilitates the standardisation of information, thereby enabling the analysis of data obtained from multiple databases, a limitation of traditional bibliometric techniques and software such as SciMAT.

The proposed methodology uses SciMAT to identify relevant themes based on the co-occurrence of keywords at various time boundaries (Cobo et al., 2012). This approach identifies emerging topics or topics that were only addressed at the beginning of the research time horizon that would otherwise remain unnoticed. Subsequently, all this information is integrated into a single database that is analysed in Graphext. Graphext is a general purpose data science tool (Graphext Team, 2021). It combines various data analytics techniques with a powerful graph-based visualization engine. Graphext software is employed to group articles into clusters that present a similar combination of the topics identified with SciMAT. Combining these techniques and tools makes it possible to analyse large sets of documents without the researcher's subjectivity influencing the obtained results.

Applying this methodology enables the literature to be grouped and research topics and specific research lines to be identified, and also helps determine where future research should go in this sphere. The complete process consists of four steps: (1) location of the information, (2) pre-processing of the text, (3) thematic analysis, (4) visualization and interpretation of the results. Each of these steps is described in detail below.

- (i) *Location of the information:* In this step, the research objectives are formulated based on the SLR. The studies are identified and the

**Figure 1.1. Systematic Science Mapping Analysis (SSMA) workflow**



**Source:** Created by authors

documents are selected and evaluated for inclusion (Denyer & Tranfield, 2009; Tranfield et al., 2003). This stage yields the research contributions that will be considered in subsequent analyses.

- (ii) *Text pre-processing*: This is a fundamental task in NLP and consists of applying changes to the text for the information to be computer-processed using Text Mining techniques (Blei, Ng & Jordan, 2003; Silge & Robinson, 2017). R and Python are suitable tools for this task as they include libraries and functions that facilitate the process. The proposed methodology involves the following steps: (1) normalization, elimination of characters and stopwords (meaningless words) (2) word transformation, and (3) reduction of terms. In this phase, the titles, abstracts and keywords should be processed separately although, after they have been pre-processed separately, they are combined into a single corpus.
- (iii) *Analysis of study topics*: The end goal of this stage is to be able to perform the grouping or clustering of the analysed articles. For this, more traditional bibliographic analysis methods have been used, such as the SciMAT tool (Cobo et al., 2012), which identifies research topics addressed by a set of articles that are part of the review. Other more novel bibliometric analysis techniques have also been used, such as the Graphext tool for dynamic data association (Graphext Team, 2021). This tool has been used to assign the topics detected in the articles. These are then grouped or clustered based on the topic sets assigned to the articles.

This approach produces a network map of embeddings in Graphext constructed from the topics assigned to the documents by creating a k-nearest neighbours' graph (k-NNG). This focus provides a set of clusters formed of articles characterised by presenting a similar combination of topics (the topics that have previously been detected with SciMAT).

- (iv) *Visualization and interpretation of results*: Graphext enables the public sharing of a dashboard on which it is possible to examine the articles in the literature review in depth. Thus, the topics identified in SciMAT and the way that the topics are combined to generate each of the clusters detected in Graphext can be explored in depth. Each of the nodes in the visualization corresponds to a document that can be identified by its reference number. Node size can be defined according to some specific variables, e.g. the number of citations per year.

Some other metadata extracted from the databases are also available in Graphext and can be used singly or in combinations to filter the articles: year, period, authors, journal, database, number of citations and JCR and/or SJR impact index. Graphext also has a keyword search function that can be used to visualize and quantify the words that characterise the set of filtered documents, based on ‘themes by SciMat’, ‘clusters by Graphext’ or any other of the metadata or variables included on the dashboard.

So, the built-in Graphext dashboard enables a detailed examination of the documents and subject areas covered by the set of analysed articles. Along with the knowledge acquired during the initial phases developed in this review, this enables the researcher to identify the gaps and research lines of interest in the area and the identification of future research lines based on the combination of some research themes (previously detected in SciMAT) that have not been jointly analysed in the articles that comprise the review.

### **1.3.3. Multiple Case Study**

The case study method is a qualitative research technique that aims to analyse and understand how business phenomena develop through a detailed and in-depth approach to specific situations (Voss, Tsiriktsis & Frohlich, 2002; Yin, 1994). Multi-case study methodology involves systematically exploring several cases

individually to gain insights into a specific phenomenon in their natural environment (Benbasat, Goldstein & Mead, 1987; Paré, 2004). This approach emphasises the importance of cross-case comparisons to identify commonalities, disparities and emergent themes, thereby promoting a nuanced understanding of the research topic (K. Eisenhardt & Graebner, 2007; Paré, 2004). The methodology involves precise data collection techniques such as interviews, observations and document scrutiny, followed by systematic data analysis methods such as thematic coding or pattern matching (Paré, 2004).

Multi-case study methodology provides researchers with a flexible and comprehensive framework to investigate complex phenomena, allowing them to produce detailed and contextually grounded findings that enhance scientific understanding and theory development (Yin, 1994). The guidelines set out by Voss et al. (2002) were followed, with these guidelines' main steps explained below.

- (i) *Research design:* This stage involves defining the scope of the study, selecting relevant cases, and specifying variables and measures to be examined. Additionally, researchers must match the research purpose with the methodology whether it is exploration, theory building, testing or extension. This approach ensures a robust framework for comprehensive investigation and analysis.
- (ii) *Research sampling:* It is crucial to include multiple case studies to enhance external validity and mitigate bias (Voss et al., 2002). Sampling involves selecting cases representing the phenomenon under study while allowing for diversity and variation. It is widely accepted that the higher the number of cases, the more more robust the results, providing a solid basis for exploration and theory building (Yin, 1994a). Therefore, a range of 6 to 12 cases is considered appropriate.
- (iii) *Data collection:* This stage typically involves gathering information from multiple sources such as interviews, observations, documents and artefacts. Using multiple data sources enhances data reliability and further supports the constructs and propositions (Yin, 1994). Clear

protocols for data collection must be established to ensure consistency and reliability across cases.

- (iv) *Data analysis*: The research conducts an in-depth analysis of each use case (within-case analysis) to understand the phenomenon. Then, a cross-case analysis is performed to fulfil the overall research purpose (Yin, 1994). Eisenhardt (1989) recommends within-case analysis for preliminary theory generation and cross-case analysis for researchers to see beyond their initial impressions and examine evidence through multiple lenses. A cross-case analysis is considered appropriate and more robust as cases can be compared for similarities and differences (K. M. Eisenhardt, 1989).

### **1.3.4. Action Research**

Action research (AR) is a methodology that emphasises collaboration between researchers and practitioners to address real-world problems in specific contexts (Coughlan & Coughlan, 2002). AR enables researchers to participate actively in the process and drives collaboration. It is a technique that diagnoses issues that need to be solved, allows researchers and team members to theorise on how they can be resolved and theory to be applied actively to orientate actions designed to solve the problems identified (Coughlan & Shani, 2014; Coughlan & Coughlan, 2002). AR is especially useful when a flexible iterative approach is required to develop solutions to complex problems (Coughlan & Shani, 2014) and, in this research, plays a crucial role as a link between academia and the industry. AR is a methodological framework, a dynamic process and a bridge between practical application and scholarly inquiry.

Coughlan and Coughlan (2002) made the initial contribution to the field by proposing a comprehensive AR framework consisting of three main steps: an initial phase that focuses on context and objectives, six core steps (three related to data gathering and analysis, and three focused on implementing actions) and, finally, the overarching monitoring of the whole AR cycle. This led to the eight-step cycle

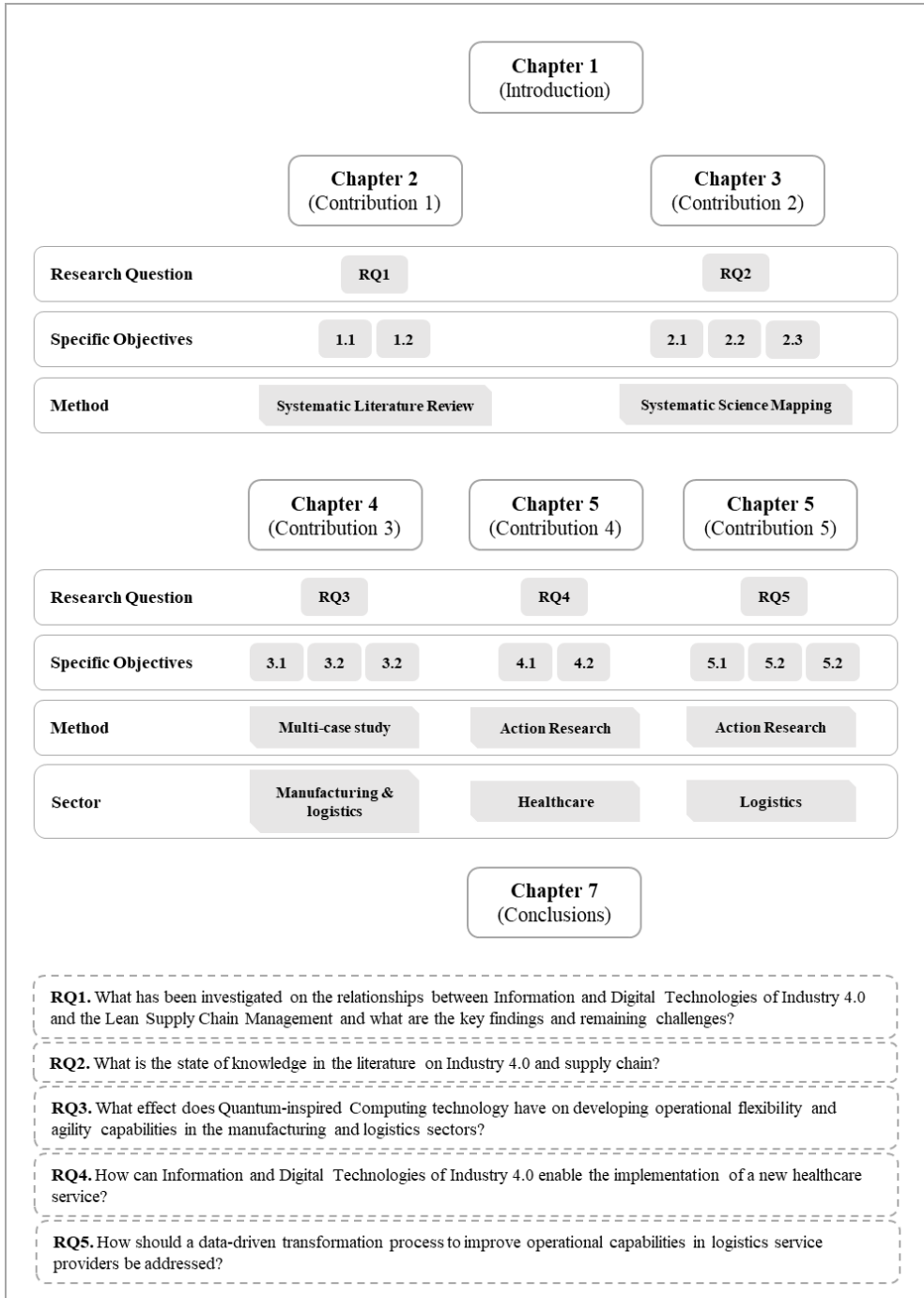


- (v) *Action planning*: The analysis leads to an action plan, a collaborative exercise based on the same data and reasoning. The lead researcher and company top management determine their respective roles and responsibilities. The key questions are: what needs to be changed, in which part of the organization, what type of change is required, what support is needed, and how can commitment be created while minimising resistance to change?
- (vi) *Implementation*: The case company is responsible for implementing the planned action, which involves making the desired changes and following the plans. The client collaborates with relevant key organization members to implement the planned action.
- (vii) *Evaluation*: This step involves reflecting on the action and reviewing the process to provide input for the next planning and action cycle. Evaluation is a crucial aspect of learning from AR, as it prevents actions from continuing and minimises mistakes.
- (viii) *Monitoring*: Throughout the cycles, a meta-step continuously monitors each of the six main steps, identifying their progress, execution and underlying assumptions.

## 1.4. Thesis structure

This doctoral thesis is presented as a compendium of papers and is comprised of seven main chapters. Chapter 1 presents the introductory section, which includes the general research framework followed in this thesis. Chapters 2, 3, 4, 5 and 6 give the original results of the research conducted in this thesis. Finally, Chapter 7 concludes this work with a summary of the research contributions and a presentation of the general implications for theory and practitioners, limitations and future research directions. Figure 1.3 shows how this thesis is structured, including the chapters, research questions, specific objectives, methodologies, theoretical approaches and the relationships between the gaps detected in the chapters.

**Figure 1.3. Thesis structure map**



Source: Created by authors

More specifically, Chapters 2 and 3 of this thesis have contributed to answering the first two research questions (RQ1 and RQ2). Chapter 2 corresponds to the article titled ‘Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management. A Systematic Literature Review’, published in 2020 in the *International Journal of Production Research*. In this paper, an SLR is carried out that focuses on the key aspects and implications of the relationships between IDT of Industry 4.0 and LSCM. This article contributes to the literature by classifying published articles into three lines of research based on the status of the technology in the Technology Life Cycle (TLC) and its use in LSCM contexts. Furthermore, it identifies research gaps and challenges that future research must address. Therefore, in this chapter, SLR adoption enables the research to be classified into research lines according to the degree of consolidation of the various technologies.

The third chapter corresponds to the article ‘Industry 4.0 and Supply Chain. A Systematic Science Mapping Analysis’. This article was published in *Technological Forecasting and Social Change* in 2022. This research complements the second chapter by focusing on the entire set of articles that have been published on the topic of Industry 4.0 technologies and Supply Chain. The approach to SCM in general was motivated by the potential impact of technology on optimizing processes, reducing costs and strengthening operational flexibility and agility capabilities to adapt to the needs of the complex environment. Therefore, given the large volume of published scientific articles, an innovative literature review methodology is designed and implemented in this chapter. This chapter presents a novel literature review technique that integrates the initial phases of SLR, SciMAT and Graphext.

The fourth chapter, titled ‘Quantum-inspired computing technology in operations and logistics management’, corresponds to the article published in *International Journal of Physical Distribution & Logistics Management* in 2024. The chapter addresses the third research question (RQ3) by developing a multi-case study approach to determine the impact of QiC technology on manufacturing and logistics processes. This article is the basis for a framework to identify a set of

operational flexibility and agility capabilities enabled by Industry 4.0 IDT. Study results suggest that QiC technology can potentially harness and boost companies' operational flexibility to enhance operational agility in manufacturing and logistics OM, particularly in the Industry 4.0 context. An exploratory model is proposed to explain the relationships between QiC technology and the deployment of operational agility capabilities.

Chapter five, titled 'Product development process for a new healthcare service in the Industry 4.0 context: an action research approach', corresponds to an article published in *Production Planning & Control* in 2024. This chapter addresses the fourth research question (RQ4) by developing an AR study. AR has been used to identify the needs and orientate the design and development of a technological platform for PM to be applied in healthcare institutions. This methodology can also act as a guide to advance research and make the service a commonplace clinical practice. This research furthers our understanding of how Industry 4.0 technologies generate some specific capabilities that can be used to create other innovative healthcare products, in general, and PM products, in particular.

The sixth chapter, titled 'Optimizing last-mile delivery through data-driven transformation: an action research approach', represents the last contribution of this thesis. The article submitted to *IEE Transactions on Engineering Management* and currently under review covers the fifth research question (RQ5). This chapter delves into how logistics service providers can approach a data-driven transformation process to exploit their organizational capability and flexibility to boost operational agility. This article contributes to the literature by proposing a roadmap for designing, developing and validating data-driven tools to overcome the barrier of cultural change focused on decision-makers. This contribution is of significant importance, as to date there has been a notable absence of research prioritizing the technological component over the human and cultural dimensions in data-driven transformation processes. Furthermore, we present a series of propositions with strategic implications that can contribute to the success of these transformation processes.

## 1.5. List of publications and communications

### List of publications

1. **Title:** Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review

**Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Pedro José Martínez-Jurado (Universidad de Zaragoza)

**Journal (ISSN):** International Journal of Production Research (0020-7543)

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**Status:** published

**Publication date:** August 2020

**ABS Journal Ranking 2021:** 3

**Impact factor Journal Citations Reports (JCR) (2020, year of publication):** 8,6

**Quartile, ranking and JCR category (2020, year of publication):** Q1, 2/84, Operations Research & Management Science

**Impact factor Journal Citation Indicator (JCI):** 1,54

**Number of citations (Web of Science):** 174

**Number of citations (Google Scholar):** 305

**Open Access:** No

**WOS:** 000557216400013

**DOI:** 10.1080/00207543.2020.1743896

**Reference:** Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Martínez-Jurado, P.J. (2020), “Information and digital technologies of

Industry 4.0 and Lean supply chain management: a systematic literature review”, *International Journal of Production Research*, Vol. 58 No. 16, pp. 5034–5061

**Other information of interest:** *In July 2023, this highly cited paper received enough citations to place it in the top 1% of the academic field of Engineering based on a highly cited threshold for the field and publication year (Fuente: Web Of Science). Top-cited International Journal of Production Research papers published within the period 2020-21.*

**2. Title:** Industry 4.0 and supply chain. A Systematic Science Mapping analysis

**Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)

**Journal (ISSN):** Technological Forecasting and Social Change (0040-1625)

**Publisher:** Elsevier

**Status:** published

**Publication date:** June 2022

**ABS Journal Ranking 2021:** 3

**Impact factor Journal Citations Reports (JCR) (2022, year of publication):** 12,0

**Quartile, ranking and JCR category (2022, year of publication):** Q1, 11/154, Business

**Impact factor Journal Citation Indicator (JCI):** 2,47

**Number of citations (Web of Science):** 11

**Number of citations (Google Scholar):** 25

**Open Access:** Yes

**WOS:** 000822688900010

**DOI:** 10.1016/j.techfore.2022.121788

**Reference:** Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2022), “Industry 4.0 and supply chain. A Systematic Science Mapping analysis”, *Technological Forecasting and Social Change*, Vol. 181 No. June, p. 121788.

**Other information of interest:** ...

- 3. Title:** Quantum-inspired computing technology in operations and logistics management.

**Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)

**Journal (ISSN):** International Journal of Physical Distribution & Logistics Management (0960-0035)

**Publisher:** Emerald Publishing Limited

**Status:** published

**Publication date:** February 2024

**ABS Journal Ranking 2021:** 2

**Impact factor Journal Citations Reports (JCR) (2024, year of publication):** 6,7

**Quartile, ranking and JCR category (2020, year of publication):** Q2, 58/227, Management

**Impact factor Journal Citation Indicator (JCI):** 1,41

**Number of citations (Web of Science):** 3

**Number of citations (Google Scholar):** 4

**Open Access:** No

**WOS:** 001155584100001

**DOI:** 10.1108/IJPDLM-02-2023-0065

**Reference:** Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2024), “Quantum-inspired computing technology in operations and logistics management”, *International Journal of Physical Distribution & Logistics Management*, Vol. 54 No. 3, p. 247-274.

**Other information of interest:** *This paper forms part of a special section “IJPDLM's SI from the 6th P&OM World Conference”, guest edited by Christian F. Durach and Leopoldo Gutierrez. The article was selected by the journal to be an open access article during the initial months following its publication. In Altmetrics, it was placed in the first quartile.*

4. **Title:** Product development process for a new healthcare service in the Industry 4.0 context: an action research approach

**Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)

**Journal (ISSN):** Production Planning & Control (0953-7287)

**Publisher:** Taylor & Francis

**Status:** published

**Publication date:** May 2024

**ABS Journal Ranking 2021:** 3

**Impact factor Journal Citations Reports (JCR) (2024, year of publication):** 8,3

**Quartile, ranking and JCR category (2024, year of publication):** Q1, 7/86, Operations Research & Management Science

**Impact factor Journal Citation Indicator (JCI):** 1,15

**Number of citations (Web of Science):** 0

**Number of citations (Google Scholar):** 0

**Open Access:** No

**WOS:** 001214748100001

**DOI:** 10.1080/09537287.2024.2349224

**Reference:** Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2024), “Product development process for a new healthcare service in the Industry 4.0 context: an action research approach”, *Production Planning & Control*, (in press).

**Other information of interest:**

- 5. Title:** Optimizing last-mile delivery through data-driven transformation: an action research approach

**Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)

**Journal (ISSN):** IEEE Transactions on Engineering Management (0018-9391).

**Publisher:** IEEE-Institute of Electrical and Electronics Engineers Inc.

**Status:** under review

**Publication date:** ...

**ABS Journal Ranking 2021:** 3

**Impact factor Journal Citations Reports (JCR) (2024):** 5,8

**Quartile, ranking and JCR category (2024):** Q2, 59/154, Business

**Impact factor Journal Citation Indicator (JCI): 1,17**

**Number of citations (Web of Science): ...**

**Number of citations (Google Scholar): ...**

**Open Access: ...**

**WOS: ...**

**DOI: ...**

**Reference: ...**

**Other information of interest: ...**

### **List of National and International Conference communications:**

Maqueira-Marín, J.M., Moyano-Fuentes, J., Núñez-Cacho Utrilla, P., De Oliveira-Dias, D., García-Buendía, N. and **Núñez-Merino, M.** (2021). “Desarrollo de herramienta innovadora en el Estudio de Casos con fines docentes: Libro de Casos en formato Cómic de Dirección de Operaciones”, *Workshop OMTECH of Acededot 2021*, Granada, Spain (online).

**Núñez-Merino, M.**, Maqueira-Marín, J.M., Moyano-Fuentes, J. and Martínez-Jurado, P.J. (2021). “Industry 4.0 and Lean Supply Chain Management organizational relationships: flexibility and response speed”, *30th International ACEDE Conference*, Cartagena, Spain.

**Núñez-Merino, M.** (2021), “A science mapping approach to analyze the research evolution on Digital Transformation”, *Jornada de Jóvenes Investigadores de la Universidad de Jaén 2021*, Jaén, Spain.

Maqueira-Marín, J.M., Moyano-Fuentes, J., **Núñez-Merino, M.**, De Oliveira-Dias, D., García-Buendía, N. and Nascimento, D.L.M. (2022). “GRAPHEXT, una herramienta de apoyo a las técnicas de revisión de literatura y análisis bibliométrico. Una aplicación en investigación de Dirección de

Operaciones”, *XIII Workshop in Operations Management and Technology - ACEDEDOT OMTech 2022*, Santander, Spain.

**Núñez-Merino, M.**, Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2022), “Industria 4.0 y cadena de suministro. Un enfoque desde la revisión sistemática de la literatura y la minería de texto”, *31st International ACEDE Conference 2022*, Barcelona, Spain.

**Núñez-Merino, M.**, Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2022), “The role of Quantum-Inspired Computing Technology in Firm’ Agility and Flexibility: a Multiple Case Study Research”, *The 6th World Conference on Production and Operations Management P&OM 2022 (2020)*, Osaka, Japan.

**Núñez-Merino, M.**, Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2022), “How are new generation technologies facing complex challenges in the operations management area?”, *VII Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*, Málaga, Spain.

**Núñez-Merino, M.**, García-Buendía, N., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2023), “Proposal of an Artificial Intelligence-based system to driving class debate”, *XIV Workshop in Operations Management and Technology ACEDEDOT OMTech 2023*, Salamanca, Spain.

García-Buendía, N., **Núñez-Merino, M.**, Moyano-Fuentes, J. and Maqueira-Marín, J.M. (2023), “Circular Supply Chain Management: An in-depth systematic exploration of key themes and trends”, *32nd International ACEDE Conference 2023*, Alicante, Spain.

**Núñez-Merino, M.**, Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2024), “Generating flexibility and agility in last mile deliveries through data-driven transformation. An action research perspective”, *33rd International ACEDE Conference 2024, Valencia, Spain*

## **List of conference posters:**

Núñez-Merino, M., Maqueira-Marín, J.M., Moyano-Fuentes, J. and Castaño-Moraga, C.A. (2022). “Quantum-inspired computing technology: use cases for manufacturing and logistics challenges”, Computational and Mathematical Methods in Science and Engineering & International Conference in HPC 2022, Cadiz, Spain.

## **List of courses taught as instructor:**

The course titled “Revisión Sistemática de Literatura”, was held on 25 November 2020 as part of the “*VI Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*”, organised by the Universities of Jaén, Granada, Almería, Málaga and Politécnica de Cartagena, and lasted a total of 1 hour. Jaen, Spain.

The course titled “Revisión de la Literatura, tendencias actuales”, was held on 21 September 2022 as part of the “*VII Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*”, organised by the Programa de Doctorado Interuniversitario en Ciencias Económicas, Empresariales y Jurídicas, and lasted a total of 2,5 hours. Jaén, Spain.

The course titled “Revisión Sistemática de Literatura: tendencias actuales”, was held on 17 November 2022 as part of the “*VII Encuentro Internacional de Especialización para la Investigación en Economía y Empresa*”, organised by the Universities of Jaén, Granada, Almería, Málaga and Politécnica de Cartagena, and lasted a total of 4 hours. Málaga, Spain.

The course titled “Curso aplicado de técnicas de revisión de literatura y análisis bibliométricos: tendencias más actuales y aplicación”, organised by the Instituto de investigación INARBE de la Universidad Pública de Navarra, and lasted a total of 6 hours. Pamplona, Spain.

## Other merits:

Participation as a Member of the Scientific Committee as a reviewer during the “VI Encuentro Internacional de Especialización para la Investigación en Economía y Empresa” held on 25th, 26th, and 27th November 2020. The event was organised by the Universities of Jaén, Granada, Almería, Málaga, and Politécnica de Cartagena.

Reviewer for two articles for the *European Journal of Information Systems* (2022 JCR: 9,5; Quartile: Q1; Category Rank: 27/227 in Management)

Reviewer for one article for the *Artificial Intelligence Review* (2022 JCR: 12; Quartile: Q1; Category Rank: 7/145 in Computer Science, Artificial Intelligence)

## 1.6. References

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# CHAPTER 2

## **Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review**



# CHAPTER 2

## Paper information:

- **Title:** Information and digital technologies of Industry 4.0 and Lean supply chain management: a systematic literature review
- **Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Pedro José Martínez-Jurado (Universidad de Zaragoza)
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# **Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management. A Systematic Literature Review**

## **Abstract**

The purpose of this paper is to provide an overview of the current state of research and the key aspects and implications of the relationships between Information and Digital Technologies (IDT) of Industry 4.0 and Lean Supply Chain Management (LSCM), with the identification of the lines of research developed and an analysis of the main findings. A Systematic Literature Review methodology has been used for the identification, selection, and evaluation of the published research. A set of 78 papers deduced from the most relevant scientific databases, including Web of Science, Scopus, and ABI/Inform, from 1996 to December 2019, has been analyzed and synthesized. The analysis and evaluation of these papers has enabled a new classification of the literature to be offered that identifies four lines of research based on the Life Cycle of Technology: obsolete IDT in LSCM; mature IDT in LSCM; emerging IDT in LSCM; and an Information Systems and IDT general approach in LSCM. The paper goes on to discuss the gaps found in the literature and proposes new opportunities and challenges for future research. A series of implications are presented intended to be useful from not only an academic point-of-view but also from a management focus, including recommendations for industrial managers and policymakers.

**Keywords:** Lean Supply Chain Management, Industry 4.0, Information and Digital Technologies, Systematic Literature Review.

# CHAPTER 3

## Industry 4.0 and Supply Chain. A Systematic Science Mapping analysis



# CHAPTER 3

## Paper information:

- **Title:** Industry 4.0 and supply chain. A Systematic Science Mapping analysis
- **Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)
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# Industry 4.0 and Supply Chain. A Systematic Science Mapping analysis

## Abstract

The purpose of this work is to offer a grouping of the aspects that the literature addresses on Industry 4.0 and its relationship with the supply chain, to contribute an innovative literature review and bibliometric analysis technique, and to detect gaps in the research and how these can be covered in the future. The Industry 4.0 concept originated in manufacturing but has evolved over recent years and extended beyond the limits of the focal company to embrace the entire supply chain. This study applies a variety of techniques sequentially. First, the initial phases of a Systematic Literature Review are applied to identify, select, and evaluate documents for analysis. Subsequently, Artificial Intelligence/Natural Language Processing techniques are applied to identify research topics and group articles. Lastly, bibliometric analysis techniques are applied using an innovative tool that enables dynamic data association. A total of 41 research topics are identified that produce a grouping of 663 articles in 8 clusters. The obtained results are used for an analysis of the extant literature, the detection of gaps, and proposals to guide future research in the Industry 4.0 and supply chain sphere.

**Keywords:** Industry 4.0, Supply chain, Systematic Literature Review, Natural Language Processing, Systematic Science Mapping, Dynamic data association.

# CHAPTER 4

## Quantum-inspired computing technology in operations and logistics management



# CHAPTER 4

## Paper information:

- **Title:** Quantum-inspired computing technology in operations and logistics management.
- **Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)
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- **Open Access:** No
- **DOI:** 10.1108/IJPDLM-02-2023-0065

# Quantum-inspired computing technology in operations and logistics management

## Abstract

**Purpose.** The purpose of this paper is to explore and disseminate knowledge about quantum-inspired computing technology's potential to solve complex challenges faced by the operational agility capability in Industry 4.0 manufacturing and logistics operations.

**Design/methodology/approach.** A multi-case study approach is used to determine the impact of quantum-inspired computing technology in manufacturing and logistics processes from the supplier perspective. A literature review provides the basis for a framework to identify a set of flexibility and agility operational capabilities enabled by Industry 4.0 Information and Digital Technologies. The use cases are analyzed in depth, first individually and then jointly.

**Findings.** Study results suggest that quantum-inspired computing technology has the potential to harness and boost companies' operational flexibility to enhance operational agility in manufacturing and logistics operations management, particularly in the Industry 4.0 context. An exploratory model is proposed to explain the relationships between quantum-inspired computing technology and the deployment of operational agility capabilities.

**Originality.** This study explores the use of quantum-inspired computing technology in Industry 4.0 operations management and contributes to understanding its potential to enable operational agility capability in manufacturing and logistics operations.

**Keywords:** Quantum computing, Logistics, Manufacturing, Flexibility, Agility, Case study, Industry 4.0, Operational capability.

# CHAPTER 5

**Product development process  
for a new healthcare service in  
the Industry 4.0 context: an  
action research approach**



# CHAPTER 5

## Paper information:

- **Title:** Product development process for a new healthcare service in the Industry 4.0 context: an action research approach
- **Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)
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- **Open Access:** No
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# **Product development process for a new healthcare service in the Industry 4.0 context: an action research approach**

## **Abstract**

Precision Medicine (PM) is a personalized approach that uses genetic, environmental, and lifestyle information to prevent, diagnose, and treat disease more effectively. This study aims to explore how Industry 4.0 technologies can enable the development of a new healthcare product, specifically a new PM service. Action Research has been used to identify the needs and orient the design and development of a technological platform that enables PM to be applied in healthcare institutions. This methodology can also act as a guide for advancing research and making the service a regular clinical practice.

This research furthers understanding of how I4.0 technologies enable the generation of specific capabilities and their use to create other innovative healthcare products, in general, and PM products, in particular. Study findings offer practical and governmental implications and can serve as the basis for digital platform design and development to facilitate PM practices in healthcare institutions.

**Keywords:** new product development; healthcare service; industry 4.0; precision medicine; digital platform; action research

# CHAPTER 6

## Optimizing last-mile delivery through data-driven transformation: an action research approach



# CHAPTER 6

## Paper information:

- **Title:** Optimizing last-mile delivery through data-driven transformation: an action research approach
- **Authors and affiliation:** Miguel Núñez-Merino (Universidad de Jaén, Fujitsu), Juan Manuel Maqueira-Marín (Universidad de Jaén), José Moyano-Fuentes (Universidad de Jaén), Carlos Alberto Castaño-Moraga (Fujitsu)
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# **Optimizing last-mile delivery through data-driven transformation: an action research approach**

## **Abstract**

This study is focused on the data-driven transformation process and its impact on flexibility- and agility-related operational capabilities, particularly in the context of last-mile deliveries. Organizational Information Processing Theory underpins this research to understand how the data-driven transformation process improves the stated operational capabilities. Action Research methodology has been used to address the topic under study and, in this particular case, applied to a specific logistics service provider.

The study reveals that data-driven transformation is crucial for exploiting flexibility to improve operating logistics management efficiency and agility capabilities. To overcome one of the main barriers to digital transformation, cultural change, we propose and validate a structured process for the design, development, validation, implementation, and continuous improvement of data-driven tools from the decision-maker perspective. We also put forward a number of propositions with strategic implications for management that, when known by senior management, can contribute to the success of the transformation process.

**Keywords:** action research, agility, data-driven transformation, flexibility, last-mile, logistics.



# CHAPTER 7

## Conclusions





## **7.1. Conclusions**

The objective of this doctoral thesis was to understand how Information and Digital Technologies (IDT) of Industry 4.0 can improve organizations' operational flexibility and agility capabilities. To achieve this objective, this thesis has examined the influence of some emerging technologies in the manufacturing, logistics and healthcare sectors. Accordingly, this study has synthesized and classified research on IDT of Industry 4.0 in organizations through two literature reviews. In light of the research gaps identified in previous studies, this analysis examines the application of technologies across pivotal sectors within organizational contexts. At the empirical level, two qualitative research methodologies have been employed that are consistent with the type of applied industrial thesis presented. These are the case study methodology and Action Research (AR), applied in manufacturing and service sectors where Industry 4.0 technologies play a key role: logistics and healthcare. The objective was to assess the impact of technologies on the organizations' operational flexibility and agility.

## **7.2. Main contributions**

The responses to the five specific research questions and the most relevant conclusions reached in each chapter are summarised below. The main contributions are also summarised in Figure 7.1. The general purpose was to investigate how integrating emerging technologies impacts organizations' operations and what influence they have on two operating capabilities: flexibility and agility. The findings in Chapters 2 and 3 are the basis for this doctoral thesis. To meet the general objective, this research has focused on organizations that operate in different sectors: manufacturing, logistics and healthcare.

**Figure 7.1. Summary of main contributions**

LITERATURE REVIEWS	
<p><i>Chapters 2</i> <b>SYSTEMATIC LITERATURE REVIEW</b></p>	<p><b>RQ:</b> What has been investigated to date on the relationships between IDT of Industry 4.0 and the LSCM and what are the key findings and remaining challenges?</p> <p><b>Contribution:</b> A novel classification of the literature into four research lines based on the Technology Life Cycle (obsolete, mature, emerging and general approach to Information Systems and IDT in LSCM).</p>
<p><i>Chapters 3</i> <b>SYSTEMATIC SCIENCE MAPPING ANALYSIS</b></p>	<p><b>RQ:</b> What is the current state of the extant knowledge in the literature on Industry 4.0 and supply chain?</p> <p><b>Contribution:</b> An innovative methodology that combines SLR and NLP methods to cluster articles according to similar combinations of topics, allowing literature reviews of large numbers of articles while reducing the subjectivity of other bibliometric methods.</p>
EMPIRICAL STUDIES	
<p><i>Chapter 4</i> <b>Quantum Computing</b> Manufacturing and logistics <i>Multi-case study</i></p>	<p><b>RQ:</b> What effect does Quantum-inspired Computing technology on the development of operational flexibility and agility capabilities in the manufacturing and logistics areas?</p> <p><b>Contribution:</b> Explain and disseminates knowledge about quantum-inspired computing technology's potential to solve complex challenges faced by the operational agility capability in Industry 4.0 manufacturing and logistics operations.</p> <p><b>Theoretical implications:</b> Framework to identify a set of flexibility and agility operational capabilities enabled by Industry 4.0 Information and Digital Technologies. Exploratory model is proposed to explain the relationships between quantum-inspired computing technology and the deployment of operational agility capabilities.</p> <p><b>Managerial implications:</b> Quantum-inspired computing technology has the potential to harness and boost companies' operational flexibility to enhance operational agility in manufacturing and logistics operations management, particularly in the Industry 4.0 context.</p>
<p><i>Chapter 5</i> <b>Precision Medicine</b> Healthcare <i>Action Research</i></p>	<p><b>RQ:</b> How can Information and Digital Technologies of Industry 4.0 enable the implementation of a new healthcare service?</p> <p><b>Contribution:</b> Explains how Industry 4.0 technologies enable the generation of specific capabilities for the implementation of a Precision Medicine service.</p> <p><b>Theoretical implications:</b> Discovers, designs and develops a new digital product that integrates different components and technologies to facilitate the adoption of a new health service based on Precision Medicine.</p> <p><b>Managerial implications:</b> Incorporation of principles of operational agility into healthcare, enabling swift adaptation to emerging medical insights and supporting early diagnosis and more effective treatments in line with Precision Medicine objectives.</p>
<p><i>Chapter 6</i> <b>Data-driven transformation</b> Logistics <i>Action Research</i></p>	<p><b>RQ:</b> How should a data-driven transformation process to improve operational capabilities in logistics service providers be addressed?"</p> <p><b>Contribution:</b> Explains how flexibility and agility operational capabilities are improved or developed in the logistics service provider as a consequence of the data-driven approach.</p> <p><b>Theoretical and managerial implications:</b> At the operational level, creation of a roadmap for the design, development and validation of data-driven tools to overcome the barrier of cultural change and focused on decision-makers. At the strategic level, we have formulated a series of propositions that we believe will contribute to the success of these transformation processes.</p>

**Source:** Created by authors

### 7.2.1. Research Question 1

The first research question (RQ1), ‘What has been investigated to date on the relationships between Information and Digital Technologies of Industry 4.0 and Lean Supply Chain Management and what are the key findings and remaining challenges?’ can be answered based on the findings in Chapter 2. Chapter 2 overviews the current research landscape and explores the key aspects and implications of the relationships between IDT of Industry 4.0 and Lean Supply Chain Management (LSCM). This overview includes identifying the research lines developed and analysing the main findings. For this, an SLR methodology was used to identify, select and evaluate published studies. A total of 78 papers were analysed and synthesised. This analysis facilitated a novel classification of the literature into four research lines based on the Technology Life Cycle (TLC): obsolete IDT in LSCM, mature IDT in LSCM, emerging IDT in LSCM and a general approach to Information Systems and IDT in LSCM. Grouping IDT of Industry 4.0 according to its position in the TLC is significant because it incorporates time as a variable and is a valuable tool for decision-making to achieve competitive advantages.

The study findings are both original and novel compared to the existing literature (Buer, Strandhagen & Chan, 2018; Pagliosa, Tortorella & Ferreira, 2021; Pinho & Mendes, 2017; Sony, 2018). Previous SLRs had analysed the interrelationships between Information Technologies in general (Pinho & Mendes, 2017), or IDT of Industry 4.0 in particular (Buer et al., 2018; Pagliosa et al., 2021), and Lean Management (LM) applied on the internal level in a single organization (Buer et al., 2018; Pagliosa et al., 2021; Pinho and Mendes, 2017). In contrast, this is the first SLR to extend the focus to the relationship between IDT of Industry 4.0 and LM at the supply chain level, marking a significant contribution to the field.

This chapter has demonstrated that a significant number of papers have investigated the role of various IDT of Industry 4.0 to facilitate the implementation of Lean practices throughout the supply chain, thereby enhancing their efficiency. The literature analysis revealed the existence of a complementary or synergistic effect between IDT of Industry 4.0 and LSCM that has a significant impact on

supply chain results (for example, some of the many benefits are flexibility, agility, information sharing, coordination, reduced costs, deliveries, and errors, reduced inventory levels, traceability and inventory control, improved service quality and customer satisfaction).

This study shows that the combined impact of IDT of Industry 4.0 and LSCM significantly enhances supply chain flexibility by meeting LM objectives. This conclusion is consistent with previous research on the influence of IDT of Industry 4.0 on SCM (Baryannis, Validi, Dani & Antoniou, 2019; Ben-Daya, Hassini & Bahroun, 2019). Nevertheless, while earlier research only partially addressed the effects of IDT of Industry 4.0 on SCM, this study provides a comprehensive perspective on how the supply chain improves efficiency and flexibility by integrating various IDT of Industry 4.0. In other respects, this study's findings show that emerging IDT have as yet unidentified effects compared to traditional IDT. It is therefore crucial to investigate the impact of highly emerging technologies, whose effects largely remain unknown to companies despite offering a considerable potential for creating competitive advantages in the current context.

This paper adopts a holistic perspective to present the current state and future directions for IDT of Industry 4.0 and LSCM in the digital era. The classification provided in this article gives a vision of the present and situates different IDT of Industry 4.0 that are being applied in LSCM contexts in the TLC, whilst also identifying the digital transformation that they enable.

### **7.2.2. Research Question 2**

The second research question (RQ2), 'What is the current state of the extant knowledge in the literature on Industry 4.0 and supply chain?' can be answered based on the findings in Chapter 3. This Chapter addresses how Industry 4.0, which originated in manufacturing, has evolved and spread beyond individual companies to include the entire supply chain. It offers a full view of the current state of knowledge on Industry 4.0 and the supply chain, identifying gaps and proposing promising ideas for future research.

The focus is notably different from the previous focus centred on a detailed vision as it targets a broad view of a much higher number of articles. This justifies developing this work, as it seeks to offer an exhaustive analysis of everything published on the topic. To obtain this overview, a methodology was developed to enable the treatment and analysis of all the articles published on the subject while avoiding the subjectivity of existing bibliometric techniques.

One of the study's main contributions lies in the proposal of an innovative methodology. Given the extremely large number of publications in this research area and the inherent subjectivity of existing bibliometric techniques, an innovative methodological focus called Systematic Science Mapping Analysis (SSMA) has been proposed. This method applies the preliminary steps of an SLR to formulate the research questions and identify and select only articles that contain pertinent information for addressing these questions in several different bibliographic databases. This is a major advantage over other bibliometric techniques that use the information extracted directly from one scientific database with no additional analysis.

Article titles, abstracts and keywords are subsequently processed together using Natural Language Processing (NLP) techniques to extract some expanded keywords. This procedure contextualises scientific works based on the information contained in these fields. Unlike earlier focuses, which are limited to the exclusive use of the keywords given by the authors and indexed in the database, and which restrict the search to a single database, the proposed methodology overcomes these limitations by broadening the scope of the search and the analysis by combining information extracted from several databases in a format compatible with SciMAT (Cobo, López-Herrera, Herrera-Viedma & Herrera, 2012). SciMAT is open-source software developed for scientific mapping analysis under a longitudinal framework.

In the following step, SciMAT is used to extract the research topics addressed in the literature based on the co-occurrence of words in the article's title, abstract and keywords. Graphext is then used. This general-purpose data-science tool

groups into clusters articles with a similar combination of topics identified by SciMAT. This focus enables the information to be synthesised on two levels. Firstly, broad research topics are identified (clusters detected with Graphext) followed by the specific research topics (topics detected with SciMAT).

This methodological proposal mitigates subjectivity compared to co-citation and bibliographical coupling bibliometric methods. In addition, Graphext provides a public dashboard that enables the researcher to carry out a revision and readers to carry out a deeper analysis based on a broad range of metadata, such as the topics identified with SciMAT, the clusters detected, the journal, the impact factor, the number of citations, the year of publication and the articles' expanded keywords, among others. The above differentiates the proposed methodology from earlier proposals such as Systematic Literature Network Analysis (SLNA) (Strozzi, Colicchia, Creazza & Noè, 2017) based on co-citation and bibliographical coupling techniques. The methodology proposed in this article and its associated advantages, and the careful contextualisation and subsequent selection of search keywords enable the objective analysis, synthesis, and clustering of the extant high-impact scientific production on a research issue.

The proposed methodology identified 41 research topics with 663 articles grouped in 8 clusters, which offered a comprehensive overview of the current knowledge on the interrelationships between Industry 4.0 and supply chain. The topics detected with SciMAT are related to: (1) technologies; (2) some capabilities enabled by technologies at both the supply chain and manufacturing levels; (3) key business processes in supply chain management; (4) sustainability; (5) business sectors; (6) the context in which the supply chains operate; (7) other topics that have been addressed in the literature.

In the technologies group, some topics encompass broad terms such as Information Technologies, Internet & Information Systems and I4.0 technologies in general. Additionally, some specific technologies are discussed, including Additive Manufacturing, Big Data & Analytics, Cloud Computing, Blockchain, the Internet of Things (IoT), Radiofrequency Identification (RFID), Robotics, Cyber-

Physical Systems, Embedded Systems and Multi-agent Systems. Another category of topics pertains to various capabilities enabled by these technologies at both the supply chain and manufacturing levels. These capabilities include information exchange, flexibility and agility, real-time response, quality, coordination, automation, traceability, reconfiguration and variability, security and resilience. A third category focuses on essential business processes in supply chain management, such as procurement, inventory management, transport and delivery management. The fourth category addresses the objective of achieving sustainability in the supply chain, an increasingly important issue for companies. This includes topics such as sustainability, the circular economy, emissions and the sustainable supply chain. The fifth category relates to business sectors such as retail, agri-food and the manufacturing sector. The sixth category deals with the context in which supply chains operate, covering risks, disruptions and the Covid-19 pandemic. Finally, the seventh category encompasses additional topics addressed in the literature, such as smart manufacturing, distributed manufacturing, the digital supply chain, and other aspects such as outcomes, decision-making, data collection, product life cycle and business models.

The articles were grouped into eight main clusters based on the above themes: (1) Integration; (2) Logistics; (3) Smart, additive & distributed manufacturing; (4) Security & Traceability; (5) Sustainability & Circular Economy; (6) Digitalization; (7) Big Data Analytics; (8) Resilience.

In the context of the Fourth Industrial Revolution, one relevant direction for future research focuses on optimising operational flexibility and agility capabilities in the face of technological change. Efficient integration of emerging technologies and adaptation to new digital tools require an integral update of information systems and management. It is essential to investigate how organizations can adopt and use new technologies effectively, maximising their potential to improve operating efficiency and competitiveness. Emerging technologies such as quantum computing have significant potential, although their effects are still not fully known, which presents both a challenge and an opportunity for future research. In addition, developing theoretical and practical roadmaps for digital transformation is crucial

for guiding organizations transitioning from heritage systems to hybrid Cloud systems. This would facilitate a fluid and efficient migration, allowing companies to adapt to technological changes and exploit opportunities to improve their operational capabilities and their market competitiveness. Likewise, IDT of Industry 4.0 offer the possibility of creating new services in sectors such as health, transforming healthcare delivery and improving patient outcomes.

### **7.2.3. Research Question 3**

Based on the main findings in Chapter 4, the third research question (RQ3), ‘What effect does Quantum-inspired Computing technology have on the development of operational flexibility and agility capabilities in the manufacturing and logistics areas?’ can be answered. A multi-case study was conducted in this chapter to determine the impact of Quantum-inspired Computing (QiC) technology in manufacturing and logistics processes. Eight organizations where QiC has been implemented were selected from the manufacturing and logistics sectors. All were large multinational corporations with substantial business volumes that had invested considerable resources in research and innovation. This study covers some of the gaps detected in Chapters 2 and 3 by analysing the role played by Quantum Computing in harnessing and boosting companies' operational flexibility to enhance operational agility in manufacturing and logistics Operations Management (OM).

Research findings contribute to the existing literature by shedding light on and complementing existing knowledge of the relationship between operational flexibility and agility, and specifically focusing on how QiC enhances this connection. The success cases analysed reveal that QiC adoption has facilitated the automation and optimization of decision-making processes in leading car manufacturers, other large manufacturing firms and the logistics sector. This has been achieved by enhancing diverse capabilities that significantly improve operational agility, addressing challenges such as workshop scheduling, production planning and the robot movement optimization in manufacturing. Some other

critical business operation optimization cases have also been studied, including warehouse management, the optimization of parts picking for production lines and distribution logistics management. Consequently, this study explores and supports QiC's ability to overcome very complex real-world challenges in the OM area by optimizing key processes and generating or boosting agility capabilities in organizations.

To respond to the RQ and the objectives set, firstly, the study proposes a framework based on the existing literature on operational capabilities and the impact of IDT of Industry 4.0 on flexibility and agility in which flexibility and agility are considered first- or higher-order operational capabilities developed from second- or lower-order operational capabilities. The empirical analysis focuses on two key OM processes, manufacturing and logistics, and how lower-order capabilities contribute to increasing operational flexibility and agility in these sectors. We have also addressed capabilities that enable flexibility and agility in transversal activities, including some in the areas of logistics and production processes.

The research was designed around this framework of capabilities that enable operational flexibility and agility. The key aspect of the research design to respond to the RQ was the consideration of the elements involved in the mathematical optimization models deployed in the Digital Annealer (DA) QiC technology developed by Fujitsu: the objective function and the constraints. These elements are essential for problem definition and for steering the process towards an optimal solution. The constraints of the problem are delineated by the organization's lower-order flexibility capabilities, while the objective function corresponds to its lower-order agility capabilities.

Applying this research design provided an exploratory model to explain, among other things, the direct impact and implications of some specific IDT of Industry 4.0 for operational flexibility capabilities, and QiC's effect on the exploitation of these operational flexibility capabilities, the elimination of inefficiencies and, ultimately, the improvement in operational agility. This study

demonstrates that enhancing operational agility capabilities through QiC adoption necessitates the pre-existence of certain lower-order operational flexibility capabilities. Thus, it follows that these capabilities need other IDT of Industry 4.0, including robotics, advanced manufacturing technologies, RFID, IoT and business information systems such as ERP, MRP and cloud computing. This finding aligns with the existing literature, which states that an organization must be flexible to become agile (Gligor, Holcomb & Stank, 2013). Nonetheless, our analysis of the cases and the influence of DA on these processes suggests that flexibility alone does not inherently lead to agility. Instead, the capabilities associated with flexibility must be effectively leveraged, a task that QiC can accomplish. Thus, study results suggest that QiC technology can potentially harness and boost companies' operational flexibility to enhance operational agility in manufacturing and logistics OM, especially in the Industry 4.0 context.

#### **7.2.4. Research Question 4**

Chapter 5 answered the fourth research question (RQ4), 'How can Information and Digital Technologies of Industry 4.0 enable the implementation of a new healthcare service?'. This work's general objective was to explore how emerging technologies of Industry 4.0 can support the development of innovative healthcare services such as Precision Medicine (PM). PM is a personalised approach that uses genetic, environmental and lifestyle information to prevent, diagnose and treat disease more effectively. This chapter digs deeper into understanding how Industry 4.0 technologies enable the generation of some specific capabilities and their use in innovative New Product Development (NPD) in the health sector.

An AR-led case study was conducted to address this issue. Results show that creating a new high value-added service in the health area requires a capability set developed by different technologies. This study has set out the process to identify, develop and validate a series of capabilities that, together, can facilitate the development of a new PM-related service.

Developing new technological platforms based on genome studies for health services represents a significant advance in healthcare for PM-related services to be implemented. Despite advances in specific areas such as genome sequencing, storage infrastructure, Big Data analysis and advanced algorithms for genome analysis, robust and efficient tools have still not emerged that offer tangible high value-added benefits in advanced healthcare.

This is one of the first studies to adopt a holistic perspective using AR methodology to combine various components in an integrated PM system. Although the previous literature shows notable advances in genomics and PM, this study contributes to combining multiple tools and techniques in a single platform that makes PM a tangible reality. It also details how to implement this new service using AR, and serves as a reference for health systems interested in benchmarking processes. Study findings can be the basis for designing and developing digital platforms to facilitate PM practices in medical institutions.

#### **7.2.5. Research Question 5**

Based on the main findings in Chapter 6, the fifth research question (RQ5), ‘How should a data-driven transformation process to improve operational capabilities in logistics service providers be addressed’ can be answered. This chapter focuses on how emerging Industry 4.0 technologies such as Cloud Computing and Big Data impact flexibility- and agility-related operational capabilities, particularly in the context of last-mile delivery.

Previously, various researchers have focused on specific aspects of last-mile logistics with several studies proposing roadmaps and maturity models to facilitate the transition towards a data-driven focus by helping companies to align data and strategies. However, previous studies have predominantly concentrated on the technological aspects of data-driven transformation, with relatively limited attention paid to the organizational, human and cultural elements inherent in such processes. These aspects are key to the effective adoption and use of the tools implemented (Zafarzadeh, Wiktorsson & Baalsrud Hauge, 2021).

Precisely, one of the contributions of this chapter is to address the transformation process to overcome the barrier of cultural change. For this, we propose and validate a structured process for the design, development, validation, implementation and continuous improvement of data-driven tools from the decision-maker perspective. We also put forward several propositions with strategic implications for management that, when known by senior management, can contribute to the success of the transformation process.

Furthermore, this chapter shows how integrating Industry 4.0 base technologies has equipped the organization with the required technological capabilities to develop and use tools to automatise tasks and enable real-time basic decision-making. The tangible benefits of this transformation are manifested in greater efficiency and reduced operating costs. These improvements are reflected in service quality and greater agility to meet changing market needs due to the management of available resources and their efficient and flexible exploitation.

### **7.3. Theoretical implications**

Different approaches have been used in this Ph.D. thesis to reveal and understand how emerging IDT of Industry 4.0 can improve operational flexibility and agility capabilities in organizations. At the theoretical level, SLR (Chapter 2) and SSMA (Chapter 3) present a comprehensive overview of the literature in the field, creating the basis for further research developments. By synthesising and analysing the existing knowledge, researchers can easily identify the main topics that have been addressed on the relationship between IDT of Industry 4.0 and operational capabilities.

These publications represent an advance over the prior literature. Our SLR (Chapter 2) proposes a novel classification in the literature by identifying the research line that each of the articles fits into according to the specific technology identified (research subline) and the position that each occupies in the TLC (Kim, 2003; Taylor & Taylor, 2012). TLC shows how technology evolves over time. A generation of technologies comes onto the market, grows and matures, and finally

falls into decline and is replaced by the following generation of technologies (Kim, 2003). The impact of highly emerging technologies remains largely unknown, even though their ability to provide a significant competitive advantage is considerable. It is important to highlight that the effect of these emerging technologies can vary considerably. Therefore, the need to focus on analysing the individual effects of these emerging technologies is justified.

In Chapter 3, one of this study's main contributions is the proposal of an innovative methodology that obtains an all-encompassing image of research developed on a topic. The proposed method combines traditional methodologies such as SLR with cutting-edge techniques for processing natural language and visualization with knowledge graphs. This methodological proposal enables literature reviews of large volumes of information and diminishes the subjectivity inherent in traditional methodologies while improving the interpretability of results over existing bibliometric methods. As a result of applying the proposed method, this chapter contributes a grouping of articles in clusters characterised by the research topics on the interrelationships between Industry 4.0 and the supply chain. The topics identified include different technologies, multiple capabilities enabled by technology, key supply chain management business processes, various facets of sustainability and the context in which supply chains operate.

Furthermore, in the empirical studies (Chapters 4, 5 and 6), qualitative methodologies have been used to understand how some emerging Industry 4.0 technologies, implemented in diverse sectors such as manufacturing, logistics and health, use data to improve decision-making processes to develop flexibility and agility capabilities. These technologies enable organizations to optimally exploit their resources and capabilities by using their flexibility better, gaining efficiency, and improving agility and customer response capability.

Specifically, this doctoral thesis analyses the role of Quantum Computing in exploiting and boosting companies' operating flexibility to improve agility in Operations Management (OM) (Chapter 4). Quantum Computing adoption is an emerging topic with deep implications for industry and society, in general, and for

OM, in particular. As far as the authors know, this is the first exploratory study to investigate QiC's potential for solving problems in the OM area and enabling organizations to develop capabilities that improve operational agility in manufacturing and logistics processes. The research was designed around the proposal of a framework based on the existing literature on operating capabilities and the impact of IDT of Industry 4.0 on flexibility and agility. Our vision focuses on two key OM processes, manufacturing and logistics, and how lower-order capabilities contribute to increasing operational flexibility and agility in these processes. Research findings contribute to the existing literature by shedding some light on the relationship between operational flexibility and agility (Dubey, Gunasekaran & Childe, 2019; Swafford, Ghosh & Murthy, 2008; Yang, Ling & Zhang, 2013), and specifically focus on how QiC improves this connection. The success cases analysed show that QiC adoption has enabled the automatisisation and optimization of decision-making in some of the main car manufacturers, other large manufacturing companies and the logistics sector.

This doctoral thesis also examines how technologies of Industry 4.0 generate capabilities that enable the creation of New Product Development-based health services in the healthcare sector, specifically concerning PM (Chapter 5). This AR-guided case study has demonstrated a process for identifying, developing and validating a series of necessary capabilities generated by technology. Together, these capabilities enable advances towards the development of a new PM-related service with more agile and precise clinical attention for diagnosis and treatment personalisation.

This is one of the first studies to adopt an integral perspective in developing a new health service (Pulley et al., 2012; Tate et al., 2023). The scientific community and various organizations have made significant advances in genomics in the past decade, leading to the development of methods, tools and products. Although these elements do not allow PM adoption individually (Denny & Collins, 2021; Gastaldi et al., 2018), their integration has led to a technological platform combining different technologies such as Cloud Computing, Artificial Intelligence (AI) and Big Data, which enables PM to be practiced. The publication associated

with this Chapter is one of the first to shed light on how different components can be combined to create a workflow on an integrated platform developed with functional objectives to make the adoption of PM-associated practices viable.

Chapter 6 examines the data-driven transformation process founded on cloud technology adoption and the evolution of already-existing analytical technologies in a last-mile logistics service provider from the AR perspective. Previous studies have investigated the adoption of key technologies to optimize specific aspects of last-mile logistics (Chu, Zhang, Bai & Chen, 2023; Ghosh, Kuiper, Mahes & Maragno, 2023; Pegado-Bardayo, Lorenzo-Espejo, Muñuzuri & Aparicio-Ruiz, 2023; G. Xu, Qiu, Fang, Kou & Yu, 2019; Z. Xu, Ni, Liu, Wang & Li, 2024). In addition, several works have also proposed roadmaps and maturity models to facilitate the transition to a data-based focus, helping companies align their data with their strategies (Gökalp & Martinez, 2022; Kayabay, Gökalp, Gökalp, Erhan Eren & Koçyiğit, 2022; Kırmızı & Kocaoglu, 2022; Pora, Gerdri, Thawesaengkulthai & Triukose, 2022).

Our research makes a differential contribution by addressing one of the most relevant barriers in digital transformation processes: a cultural change roadmap is proposed for designing, developing and implementing data-driven tools from the decision-maker perspective. This Chapter stresses the value of augmented operating capabilities derived from the organization's adoption of a data-driven focus. The research shows that data-driven tools improve decision-making processes, allowing a more efficient use of organizations' flexibility and resources. This increases efficiency and quality, reduces costs and enables more agile responses to customer needs, especially in last-mile logistics.

## **7.4. Managerial implications**

This doctoral thesis with a mention in industry provides valuable management implications for organizations in various sectors and public administrations deduced by the thesis author's involvement and direct participation in projects developed by a tech consultancy. These have given rise to the thesis's empirical

Chapters. This applied perspective makes the findings very interesting for companies and public administrations seeking to optimize their flexibility and agility operational capabilities by adopting technologies of Industry 4.0. This doctoral thesis can also guide companies' digital transformation processes, in the services sector, especially.

The research has been focused on the adoption process of emerging technologies that enable data to be used for operational decision-making in companies aimed at optimizing the use of their resources flexibly and efficiently by making the right decisions. These technologies allow companies to analyse and use data in real time, which improves their efficiency significantly, which is a capability for adapting to environmental changes and optimizing internal processes and, thus, improving the response capability and operational agility.

Chapters 2 and 3 have explored the extant literature on technologies of Industry 4.0 in a general way. These Chapters have proposed a classification of existing technologies and analysed different key aspects for organizations in the current context. This classification can be a useful strategy tool for senior management as they can use it to deduce the role and impact of emerging technologies from existing research. As per the future research lines presented in these Chapters, senior management can act on a range of IDT to boost their digital transformation in the quest for advantages over their competitors. They can also identify the technologies that would be most useful for the specific goals of the transformation, the deployment or improvement of capabilities that they wish to obtain. Specifically, Chapter 2 provides a novel classification according to the TLC of IDT of Industry 4.0, which is an interesting strategy tool for assisting senior management in pursuing competitive advantages in decision-making on the use of some specific IDT.

Lastly, we are left in no doubt about the crucial role that the Public Sector can play in facilitating digital transformation. The lack of governmental policy has been identified as one of the main barriers to Industry 4.0 adoption. In this sense, the main barriers and weaknesses identified by this research could be used as a

reference for technology and policy forecasts as they need to be overcome and a roadmap needs to be devised to transition to Industry 4.0. Therefore, this research could act as a reference for policymakers.

Prior studies (Barata, Rupino Da Cunha & Stal, 2018; Hughes, Dwivedi, Rana, Williams & Raghavan, 2022; Smit, Kreutzer, Moeller & Carlberg., 2016) emphasised management's lack of digital knowledge, training and awareness of IDT of I4.0 and their potential benefits, the investment capacity, cybersecurity issues and legal conditions, amongst other relevant inhibitors and/or barriers. Consequently, regional, national and supranational government policies can play a crucial role by supporting and funding research, coordinating digital transformation initiatives in relevant sectors, developing platforms for sharing best practices and lessons learned, raising awareness of the challenges and opportunities, supporting the development of regulations, facilitating the access of SMEs to financing and promoting multidisciplinary consortia. Regarding emerging technologies, it is essential to establish demonstrators and evangelization centres that apply these technologies to the company, and finance Proofs of Concept and prototypes based on these technologies' in-company use.

This doctoral thesis has analysed different practical applications of QiC in large, leading organizations in their respective sectors and provided empirical evidence of their benefits and, thus, boosted their adoption on the company level (Chapter 4). Findings show that when a company is using QiC to improve its operational agility, it must first guarantee that its productive systems and processes have the required flexibility capabilities as, without them, it will be impossible to improve its agility. This research reveals QiC's potential for making the right decisions that enable an organization to exploit its resources and flexibility efficiently and thus improve its agility. Thanks to quantum computing's processing capability, multiple variables and scenarios can be analysed practically in real time. This allows organizations using quantum computing to make decisions rapidly and precisely, eliminate inefficiencies and optimize their systems' flexibility, which results in greater agility. This improved agility facilitates better adaptation to

market demands, which could translate into a reduction in operating costs by shortening manufacturing or delivery times.

This research shows that whatever their size and their available resources, organizations that wish to set out on the digital transformation path or that have already done so need the cooperation of other agents. This need is even greater in the case of very emerging technologies, including QiC. Along with tech providers, studies of success cases are determinants of emerging and disruptive technology adoption (Maqueira-Marín, Bruque-Cámara & Minguela-Rata, 2017). Our study shows that quantum computing is a very promising technology with the potential to achieve competitive advantages in various sectors based on the use of emerging technologies. Some large, pioneering companies, motivated by the new trends in operations designed to provide a quick customer response and the required flexibility to address customer needs are already making great strides in their experiments thanks to this technology's enormous potential.

This doctoral thesis also addresses the process of new high value-added services in the health area thanks to the use of emerging technologies, applied, in this specific case, to PM (Chapter 5). The process of designing, developing and implementing a new product based on emerging technologies that advances PM adoption in normal clinical practice in Spain is described in detail. Unlike the prior literature, this study provides a specific roadmap for implementing this innovative service, for which the AR technique was used. To date, both the academic community and various organizations have achieved notable advances in genomics and PM over the past decade and this has led to the development of several methods, tools and products that have been independently analysed (Denny & Collins, 2021; Gastaldi et al., 2018). However, the main practical implication of this study lies in the convergence of multiple previously researched technological tools and techniques in an integrated platform that makes it viable that PM will come to fruition as a tangible reality.

This study's implications can be essential for health systems seeking to adopt similar services as they enable benchmarking with the standards established herein.

In addition, this research can potentially encourage institutions specialising in genomics, the scientific community, tech providers, and government bodies to make efforts and investments to further develop and integrate this new paradigm into the delivery of innovative services in the health area.

Implementing PM in Spain requires a combination of political, educational and infrastructure strategies. Developing training for health professionals is crucial in this field. Moreover, research and development must be invested in to explore new PM technologies and focuses, with collaborations between academic institutions, industry and hospitals. Clear policies and regulations are needed to enable PM adoption, including quality standards and security for genetic tests and other related services. Our research also emphasises the importance of interoperability between the Spanish autonomous communities' EHRs. Achieving perfect interoperability is essential for the blanket adoption of PM practices and collaboration between healthcare providers. This requirement must be addressed for all the potential of PM initiatives to be exploited in Spain.

The study also highlights other critical areas that demand more attention. For example, health systems have no established procedures for implementing new-generation sequencing (NGS) in clinical settings, and significant inefficiencies exist in the management, storage, access to and updating of patients' and citizens' genomic information. Current tools and methods for curating genomic data in the secondary analysis phase also need to be improved as the results of current commercial tools may prove inadequate for more precise and exhaustive analyses. Generative AI and Large Language Models (LLMs) offer an interesting opportunity to improve the mentioned tool's capabilities.

Lastly, this doctoral thesis focuses on the data-driven transformation process based on technologies such as Cloud Computing and Big Data Analytics in a last-mile logistics service provider from the AR perspective (Chapter 6). However, on a more general level, findings can be as relevant and applicable to organizations in other sectors immersed in similar transformation processes. Firstly, we propose a roadmap focused on decision-makers for designing, developing and validating data-

driven tools to overcome the cultural change barrier. This is a pertinent contribution as, to date, there has been a gap in the existing research, which has prioritised the technological component and paid less attention to the human and cultural dimensions of data-driven transformation processes. We have also set out a series of propositions with strategic implications that could contribute to the success of these transformation processes.

Secondly, we have highlighted the value of the operational capabilities that are improved or developed in the logistics service provider by the data-driven focus. By showing how the data-driven transformation exploits flexibility to improve efficiency and agility in logistics management, we also offer a practical framework for senior management in this area. Taken as a whole, this study offers valuable insights and tools that can be applied to enhance data-driven transformation process management and last-mile logistics results thanks to the improvement and/or development of flexibility- and agility-related operational capabilities in the context of intense technology use.

## **7.5. Limitations and future research directions**

Although this doctoral thesis yields a range of insightful advances for literature and practice, this study has some limitations that must be acknowledged.

Firstly, literature review studies (Chapters 2 and 3) have some inherent limitations. For example, search chain and inclusion and exclusion criteria selection could result in some publications being excluded. Notwithstanding, this can be considered a minor limitation as three relevant databases (WoS, Scopus and ABI Inform) were used to identify the documents (Durach, Kembro & Wieland, 2017; Thomé, Scavarda & Scavarda, 2016). In addition, the keywords included in the search chains were carefully selected by several researchers considering the prior literature. Another specific limitation of SLR (Chapter 2) lies in the subjectivity of the literature classification. However, a group of researchers was involved in all the SLR steps to reduce the impact of this limitation (Thomé et al., 2016). This limitation was overcome using the SSMA methodology used in this doctoral thesis.

It must also be mentioned that some emerging technologies that have become more relevant recently have not been addressed in the literature reviewed (e.g. quantum computing). Therefore, we recommend that future studies cover these new developments and their impacts on operational capabilities. Furthermore, although some of the gaps indicated in Chapters 2 and 3 have been covered by empirical studies, others have yet to be explored.

Secondly, some limitations can also be highlighted regarding the empirical studies (Chapters 4, 5 and 6). The implications of Chapter 4 are based on case studies. But it should not be forgotten that this is exploratory research that contributes to and disseminates knowledge of how QiC impacts OM by leveraging flexibility to develop agility capability. So, as QiC is a very emerging technology, the study's exploratory nature can be considered a minor limitation. However, this research has a major limitation: the bias caused by it being based solely on information provided by the tech provider. This prevents a full understanding of the technology implementation's limitations and outcomes. Another relevant limitation of this research is that it only presents the positive side of the technology. Notwithstanding, it is important to restate that this research is exploratory and that its purpose is to demonstrate the potential of a very emerging technology (QiC) for OM, which would enable its dissemination and adoption by other companies. Lastly, the studied use cases may represent only a fraction of the range of issues that QiC has been able to solve, as our study only analyses the impact of DA and other providers of this type of technology also exist in the market.

As QiC is a nascent technology and knowledge in the area is only just emerging, many challenges still need to be addressed. The academic and business worlds must collaborate in this technology's future development and application. The objectives of Quantum computing and areas for future research centre on various key aspects. Firstly, the importance has been highlighted of exploring new areas to apply quantum computing and case studies in OM, and of identifying challenges and opportunities for optimizing current algorithms and developing new ones. Another point of interest is understanding the drivers and barriers to organizations adopting quantum computing. As with any new technology, it is

crucial to identify and disseminate knowledge of the factors that facilitate or prevent its adoption, as senior managers will be able to address these aspects to drive a safer and more controlled adoption. The exploration of possible quantum computing adoptions in conjunction with mature technologies such as 5G is also proposed, particularly for creating digital twins to support smart and collaborative manufacturing operations. Combining these technologies can potentially generate new technological concepts, with implications for flexibility, adaptability, agility and performance. We also highlight the need to address the challenges of integrating quantum computing into companies' current technological infrastructure and processes. This implies identifying the requirements and techniques for integrating quantum computing with other mature technologies used in production to facilitate its adoption and effective use. Lastly, the importance of challenges to management associated with quantum computing adoption and the relationship between humans and machines in the context of Industry 5.0 have been highlighted. The arrival of new emerging technologies is expected to redefine roles and dynamics in industry. A detailed analysis is, therefore, required of the changes in management and human interaction with these technologies to orientate future research.

Regarding the research presented in Chapter 5, despite the Proof of Concept to discover, design, develop and validate that a prototype is successful, the project scope was limited to the Spanish context and a small number of DNA samples. Also, priority was given to confirming that the information flows and the various processes all worked and were appropriate for the goals of the service. Specifically, only a limited number of hospitals and professionals participated in the study. Although this could constrain the applicability of the results, this is a minor limitation if we consider the significant novelty that a new high value-added service contributes to an extremely new and changing field such as genomics. Also, the Proof of Concept was developed over only a few months, making it difficult to capture the long-term effects.

Despite these limitations, the AR focus provided valuable information and the opportunity for our findings to form the basis for a transformative change in

healthcare institutions by offering more personalised and efficient medical attention. In addition, as the PM paradigm evolves, questions and challenges will arise that require further research and exploration. Given these limitations, we believe that further studies are required to complement the present research. Future research on PM should explore health systems in countries where private organizations predominate over public institutions, and in societies with different cultural contexts. This will help us understand how these factors influence the implementation and effectiveness of PM outside the Spanish context. The processes and information flows studied should also be validated by a greater number of experts, and complementary AR cycles should be undertaken focused on improving and developing the current technological platform.

Lastly, Chapter 6 on data-driven transformation in a last-mile logistics service provider has several limitations to consider when interpreting the results and planning future research. Our research was focused on developing use cases and data analysis projects to provide workers in logistics sector companies with tools that improve operating efficiency and decision-making. Further, the study was undertaken over a specific period, which limits the capability to assess the impact of the data-driven focus implementation in the organization over the long term.

Future research is recommended to validate the structured process for the design, development, validation, putting into production and continuous improvement of data-driven tools from the decision-maker perspective proposed in this study in other organizations in the same sector and other sectors. Another possible future research line is the need for longitudinal studies to assess the long-term impact of this implementation and consider how disruptive factors or events can influence the outcomes. In the future, it might also be interesting to evaluate how other highly disruptive emerging technologies such as AI, 5G and Quantum Computing might impact the transformation process to benefit the development of new operational capabilities.

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