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A bibliometric analysis deconstructing research on understanding and managing Industry 4.0

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Abstract

With an overwhelming interest in Industry 4.0 based on published articles for the past couple of years, the topic for this study is Industry 4.0 and a presentation of its concept. The history of this originates from Germany with the three previous industries that lead up to Industry 4.0. The concept is divided between its main components, design principles and trends related to Industry 4.0 to get closer to the demonstration of the gap that is missing in current theory- which is the primary interest for the research question of this study. The gap that is missed, is to find a strategic way to manage the integration of Industry 4.0 technologies and how to handle this integration. Methods that were used in this research bibliometric method to examine and analyse previous existing literature in this field of Industry 4.0 with strategic management as a focus. A structured search on the Web of Science gave access to relevant dataset, which identified the core articles for the research that findings are based upon. Hence, analysing the content led to findings that were presented with a framework, which explains the integration levels of Industry 4.0 and ways to manage each level by strategic purpose. These levels are project management level, process management level, organisation management level and staff management level. At the end of the research, there is a discussion on further research to open further discussion in this field, with this research as a basis. This framework will groundwork the basic understanding of business management regards to organisational change like Industry 4.0 transition. Hence, the aim for the management and the contribution from this study is to make these integration undertake gradually with detailed plans on how to execute ahead, alongside preparing the staff the change they will experience with openness and readiness of Industry 4.0.

Keywords: Bibliometric analysis, Industry 4.0, Technology management, Process management, Management, Strategy

Preface

"A bibliometric analysis deconstructing research on understanding and managing Industry 4.0" is a research paper to finalise the two-year study with a master's thesis within Master of Science in Business Administration (MBA) at Oslo Business School, Oslo Metropolitan University - OsloMet. This thesis is based on the phenomenon of the global trend within industrial technology - Industry 4.0, with its managerial aspect for successful integration into this trend.

Professor Karl Joachim Breunig was the supervisor of this master's thesis from the beginning of the fall semester in 2019, where the discussions of different topics related to master thesis were under assessment. After some research and interest, we rounded the discussion with Industry 4.0 history, technology and issues associated with identifying this phenomenon with simple words for daily business for better understanding of the fundamental structural change that occurred the last decade in this field. In this process, the decision to execute this thesis in the form of the research paper was finalised, rather than carry through a traditional master's thesis research form.

The time I spent for several months of work and gathering it into this final study, represents the most instructive period of the whole five years as a business student. Alongside finishing my journey of the most interesting research till now, both exciting and challenging period at the same time, I want to show my gratitude towards professor Karl Joachin Brenuig for its detailed guidance and support during the whole period.

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1 Introduction

With the massive amount of published articles just in recent years and growing interest in the topic of Industry 4.0, it is still unknown for me the ground understanding of this phenomenon. While doing my brief research on this, I observed the lack of study that explains the basic concepts and its regulation that explains what Industry 4.0 is and how to manage it. With a recent Google Scholar search, I acknowledge the overwhelming amount of published articles within this theme. Only with the keyword “Industry 4.0” there were more than 3 million results, whereby “management” and “strategy” within industry 4.0 studies has a result around 900 000 each- all these since 2016. Looking at this topic from today's global pandemic Covid-19 (Coronavirus) view, it catches my interest even more. Industry 4.0 advanced technologies make it possible for many companies to drive their business as usual in this chaotic global situation. Alongside making room for innovation and new tools to make us survive this pandemic, to make it possible for businesses to feel less fear of facing bankruptcy (Forbes, 2020). Possibilities like how Artificial Intelligent (AI) can foresee an outbreak to minimise or even block the spread of the virus. This technological system can even collect wrong information about Covid-19 that spreads around in social platforms and remove these from availability. Many develop robots that could handle sanitation jobs and perform an online medical examination of the people. The Internet of Things (IoT) for instance was a helpful technology for drones to monitor quarantine and mask-wearing. In contrast, Big data collects real-time data in due course to provide the latest information for scientists, doctors and policymakers to make wise decisions on how to control the pandemic and fight against it. In this present time, technologies like virtual reality, holography and cloud computing have made it even more possible to live fortunate during this pandemic. Such as the option of video calls making it possible to attend any occasion at any time through virtual reality without travelling, and being able to still organise events and conferences through holography, which is a 3D photography. This pandemic has caused social isolation and digital solutions through different applications such as Netflix and Amazon Web services with cloud computing made us feel less isolated (Javaid et al., 2020). The list continues with various technologies that have been helpful during this pandemic that makes us all wonder and admire the era of Industry 4.0 that we exist on.

The recent decade has been a remarkable period for the digital change that has accrued in society. A lot about digital transformation research exists in literature, and it's even discussed in a research about understanding Digital Transformasjon by Vial Gregory with the article "*Understanding digital transformation: A review and a research agenda".* In this article, we get a broad understanding of how digital transformation defines and what it's about, in what content DT executed, and lastly what this technological change will have a role in different firms and organisations. Inspired by this article, we are going to present our research paper with almost similar manners.

Immensely articles about Industry 4.0 also do exist, and we have a lot of researchers who have different perspectives related to Industry 4.0. But what is Industry 4.0? In what content does it live, and does it have any limitation? McKinsey (2015) defines the fourth industrial revolution as: "Digitization of the manufacturing sector, with embedded sensors in virtually all product components and manufacturing equipment, ubiquitous cyber-physical systems, and analysis of all relevant data". The pre-industrial revolutions made Industry 4.0 possible with the breakthrough of a highly-advanced technology creating, among other things, automation. The core idea of Industry 4.0 is to use the emerging information technologies to implement IoT and services so that business processes and engineering processes produce and operate in a flexible, efficient, and greenway with constantly high quality and low cost (Wang et al., 2016). It will also explain how the application of new technology based on cyber-physical systems and the Internet leads to significant improvements and challenges in many areas. The process from integration, customisation and connection, indicates the importance of revolution and transformation through Industry 4.0. We also know many researchers that have broken down different technologies that exist in this field in their research and how they made a framework of the beneficial and challenging side of the industrial sector and the society that has been affected by the last industrial change, which is not the main focus on this study. However, the focus of this research is on the phenomenon Industry 4.0 and understanding the core concept through its main components, design principles and trends which lead us to understand Industry 4.0 as a whole and gain a broad understanding of this phenomenon, so our research question goes by: *"What is Industry 4.0, and how can it be managed?"*

To be able to answer this research question, we choose the bibliometric method to map the literature basis of this field and to characterise the dynamics of each level that contains in Industry 4.0. The source of this bibliographic method is the Web of Science. In the purpose of finding the most relevant articles that could guide us to the research question we started with a structured literature search with different phrases and combination of keyword and lastly determined with following search string *TOPIC: ("Industry 4.0") AND (strat*) OR ("Industry 4.0") AND (management).* This search gave us a total result of 1333 papers for the period of 2015-2020, which is the timeframe all these documents belong to without making any changes to the selection of publication years. Moreover, we excluded irrelevant categories and came down to 443 articles for the bibliometric analysis, where we further through VOSviewer identified 16 highly relevant articles related to strategy and management in the regards of Industry 4.0. I analysed the core articles into the content analysis on the method chapter. Through the 16 core articles, I break down the main elements in managing different technologies and departments that were affected by the integration of advantage Industry 4.0 technologies. The findings on content analysis were furthermore discussed in this paper which then resulted in a framework that presents four different levels of management that builds up level by level to achieve successful transformation. The level starts from *project management* up to *staff management* that exists in Industry 4.0 strategies that are also dependent on each other. This framework can provide a magnificent contribution to discussions related to the strategic management of Industry 4.0 as it delivers a holistic view to the levels that exist to achieve the information that is necessary for integration and operation of such phenomenal trends. Lastly, this research ends with what could be the possibility of further research that can help us understand more of Industry 4.0.

2 Theory

This chapter will present the history of industry 4.0 and its concepts through its main components, design principles and trends related to manufacturing to get closer to the demonstration of the gap that is missing in current theorisation which is the primary interest for our research question.

2.1 Industry 4.0

The transformation of producing products has been modified for the past hundreds of years, where the latest development is digital manufacturing (Marr, 2018). The three previous industrial revolutions focused on the manufacturing sector. They formed the path to the development of Industry 4.0, as it represents the industrial manufacturing systems from manual work towards automation (Rojko, 2017). The revolutions began with the first industrial revolution with mechanisation and mechanical power generation in the 18th Century, which changed and improved quality of life for humans by bringing the first manufacturing processes from manual work. From the second industrial revolution, electrification enabled the industrialisation and mass production; an example is Henry Ford, who is known for mass car production. Then in the 20th century, the third revolution came forward, which was characterised by the digitalisation, where computers were adopted with the introduction to automation. The use of flexible production lines with programmable machines made the production of a variety of products to a whole new level, where the revolution was triggered by the development of Information and Communications Technologies (ICT). Now, the fourth revolution came through by complementing the computers with data and machine learning through smart and autonomous cyber-physical systems (CPS) with decentralised control and advanced connectivity. The Industry 4.0 concept was first introduced in Germany at the Hannover Fair event in 2011, as a part of the High-Tech Strategy 2020 Action Plan. Germany is well known as a global leader in the sector of manufacturing equipment, and for being the most competitive manufacturing industries in the world (Rojko, 2017). The term Industry 4.0 itself means “the smart factory” and characterised by flexibility and efficient use of resources. Industry 4.0 forms an important as it creates a connection of computers and other digital devices with each other, as they communicate without the involvement of human interactions. The digital technology used in Industry 4.0 is termed as highly-advanced since it involves nine main terms or actors; Cyber-Physical Production Systems (CPPS), Artificial intelligence (AI), Autonomous Robots, Internet of Things (IoT), Cloud computing, Augmented Reality, Big Data, Simulation, and Additive manufacturing. The main idea of Industry 4.0 is to exploit the potentials and opportunities of new technologies and concepts like the internet, IoT,

integration of technical and business processes in organisations, digital mapping and visualisation of the real world and smart factories including smart production and products. The core process is digital to physical conversion in a reconfigurable manufacturing system, where Industry 4.0 can transform the manufacturing and industrial sectors in the world to become digitised with built-in sensing devices virtually in all manufacturing components, products and equipment (Tay et al., 2018). The main difference from the previous revolutions, the digital technologies used in Industry 4.0, powers the physical act of development, manufacturing, distribution and performance within one ongoing cycle, called the physical-digital-physical (PDP) loop (Shkabura, 2019). The loop starts with first capturing the information from the physical world to create a digital record of the physical operation and supply network; then machines connect to each other to share information and analyse and visualise the real-time data from multiple sources. Lastly, it generates movement, where they apply algorithms and automation to translate decisions and actions from the digital world into movement in the physical world. Summarised, the real-time information and intelligence flow between physical and digital aspects of the manufacturing process, within this loop.

2.2 Concept

The essence of Industry 4.0 is captured through this connection of digital technologies fostering action in the real world. Industry 4.0 is characterised by four main elements, where the two important ones are horizontal and vertical integration. Horizontal integration is a new generation of global value chain networks. As mentioned above, the PDP loop enables a higher level of transparency. Companies can locate and respond to problems faster, record information from all operations and every aspect of all processes are logged and can be assessed and analysed at any time. The integration refers to acquiring companies to increase market and diversify their product by offering through shares that address the same customer base with different but complementary products or services. In the horizontal integration, the focus is on its activities and around the core competencies and establishes partnerships to build out an end-to-end value chain. The second one is vertical networking and integration, which has a focus on keeping the value in-house. The integration involves acquiring

companies who bring new capabilities to reduce manufacturing costs, secure access to supplies and respond faster to new market opportunities. The vertical networking is based on the digital-to-physical processes for better change from shifting demands, stock levels or unexpected equipment faults. The third element is through-engineering across the entire value chain. As stated in the website *"All the product development and manufacturing activities are integrated and coordinated with the product life cycles. New synergies emerge between product development and production systems"* (Medium.com, 2019). And the last one is acceleration through exponential technologies. The main premise or assumption of Industry 4.0 is to create an increasingly autonomous and highly cognitive ecosystem, which relies on technology such as machine learning, deep learning, advanced robotics and Industrial IoT to further accelerate efficiency. But will it be possible to apply and integrate Industry 4.0 technologies in every process and chain in the new generation of value chain? How will this again affect human relation to work if advanced technologies take charge of the automation in the industrial sector? This lead us to cover the four design principles that exist in the theory of Industry 4.0

Four design principles of Industry 4.0 Mike Boner (2017) presented the four design principles of Industry 4.0 on Viscosity web blog, a research paper written by Hermann et al. The design principles help companies to identify and implement Industry 4.0 scenarios and approaches. The *first design principle* is interoperability, which is a shared platform for devices, people and other entities to communicate by combining the IoT and IoP. Communication between different devices makes this industry create interest alongside wireless communication technology. In addition, the possibilities of the IoT - the connection between sensors, machinery, and many other devices make the tasks that involve monitoring much efficient and effective. Moreover, virtualisation and real-time capability are important as CPS (CyberPhysical Systems) must be able to replicate the real world in a virtual environment and function in real-time to provide live insights about the business operations. The *second design principle*, Information transparency, defines the interconnectivity that approaches different operators for collecting an enormous amount of data and information from every point of the manufacturing process to acknowledge the shortage in different fields so the performance could benefit innovation and improvement. This transparency contributes to using the information to make appropriate decisions for the operators. Also, a convergence of IoT, IoS,

IoP, IIoT should build up the Internet of Everything (IoE) leading to greater transparency of all the stakeholders on the network. The *third design principle* defines the decisions, which is a combination of local and global information which leads to the ability to encourage better decision-making and to increase productivity. CPS should be able to work more independently, which gives a more flexible environment of customised products and problem-solving. The *last design principle*, the technical assistance, defines the assistance systems that are designed for operators that are in need to make knowledgeable decisions to solve urgent problems. Industry 4.0 transformed the role of humans from being an operator that controlled machines, to decision-makers to solve problems. Boner (2017) explained that systems such as interconnection could make it possible to save time. Hence, with the correct use of information transparency, the systems would have the ability to make decentralised decisions. The designs of industry 4.0 will provide much efficiency in the manufacturing process. One of the ways is, for instance, the streaming line where access to helpful data is increased to help with maximizing productivity and reducing the number of resources used. This will make the business decision be better from the aspect of the cost of the material and labour. By using the helpful information to design a better business, the operator will face few rejections from customers and Industry 4.0 will boost productivity and revenue growth. Further, the interaction with customers has impacted efficiency in communication, both directly and indirectly. The operators with the help of information and data can use the technology to respond to customers. Examples of this can be the chat-systems that many operators have developed for customer support on their webpages, alongside telephone systems that were one the only way of telecommunication option for many decades. This unique ability to respond with less amount of time to customers request, and might even be possible to develop custom orders but with less setup time and less complicated systems the principles related technologies. Every process in manufacturing in Industry 4.0 is heading towards an improved process of existing traditional processes and much leaner production to save costs and expenses. Another big impact Industry 4.0 can have on manufacturers is the role of big data and the analytics of it. Many of the decentralised decisions many operators can make are based on modern information and communication technologies like CPS, big data analytics and cloud computing. Analysing information through these technologies helps operators to find and capture early production fails and defects. This way, companies will gain benefits from such technology, and the production will increase with quality. But the

new technology is very advanced processes with the use of complex tools, such as analytics software programs and algorithms to manage the information in a meaningful way. The complexity and outcome of this will be discussed under analysis. In the concern of its newly attention towards Industry 4.0 and with highly advanced technology that exists, are there enough employees that have the knowledge and education in this field to obtain the high quality management?

Four Major Trends Driving Industry 4.0, the transformation in factories and manufacturing is completely changed in Industry 4.0. With advanced technology, including the analytics process of analysing, machine learning, the IoT, cloud computing systems, and components like human-machine are all mixed elements in the manufacturing process (Newman, 2018). These technologies are dependable and cost less, which is a big help in growing applications in this industry. There is no need for big factories to do well in the market, in fact, factories and companies of all sizes have now chance to do well with the opportunities of these technologies created in Industry 4.0. Therefore, with an industry that is still growing and being innovative until the present, it is a must for manufacturers to use digitalisation by using the technologies mentioned above. Hence, four major trends through digitisation driving Industry 4.0 will be presented. The *first major trend* is related to connected consumers and customized experiences. One of the biggest changes between the assets and customers since consumers are now connected to the industry via social networks, customer interactions and data analysis (Newman, 2018). Manufacturers are listening to what consumers need and want, hence embracing the power of next-generation manufacturing to buy it. Before, the cost and the time of customising a million products for a million customers were impossible for companies, but as of now the efficiency to produce customised products through mass customisation and deliver unique products to customers are at a near individual level. The *second major trend* is related to empowered Employees. Beyond connected consumers are connected employees (Newman, 2018). For employees, there is direct access to information they need through new collaboration platforms & tools and devices of their choosing. The trending use of remote working and worldwide use of talent is becoming more normal as a work policy. Technology has given visibility for businesses and manufacturers through the enhancement in ERP (Enterprise Resource Planning), CRM (Customer Relationship Management) and Customer Experience Mapping, where employees can view the entire

supply chain which empowers them to make informed decisions about products and marketing strategies. The *third major trend* is related to optimized production. New technology has made production more efficient, as consumers focus on products and their demand, the production is adjusted dynamically, and insights are accessed in real-time. Business, organisations and manufactures can take advantage of tools like cloud analytics devices now. As machine learning becomes more prominent in manufacturing, the solutions for production speed, product waste or time, lack of inventory, need for equipment for servicing and maintenance can be answered. The *fourth major trend* is related to transformers products. By revolutionizing products, technology can save manufacturers and companies money and time, and bring forth new and improved products. According to Newman (2018), this process is only possible by using the IoT mixed with machine learning capabilities. The productivity will increase by allowing product enhancements and changes quickly, saving time and money. These trends have a major impact on how Industry 4.0 will successfully be captured by different operators. However, in our next segment, interesting dimensions will be discussed. However, will the size of the enterprise have an effect of such integration?

2.3 Digital Transformation Strategy

In contrast to Industry 4.0, it was important to define the concept of digital transformation also in order to separate these two concepts from each other. There are existing many definitions of the term digital transformation (DT) in the literature, yet no common definition (BDI and Roland Berger, 2015). Consequently, a great composed definition was proposed by D. Schallmo, C. A. Williams and L. Boardman (2017) to fill this gap:

> " *The DT framework includes the networking of actors such as businesses and customers across all value-added chain segments (BMWi, 2015, p. 3; Bowersox et al., 2005, 22ff.; Bouee and Schaible, 2015, p. 6), and the application of new technologies (PwC, 2013, p. 9; Westerman et al., 2011, p. 5). As such, DT requires skills that involve the extraction and exchange of data as well as the analysis and conversion of that data into actionable information. This information should be used to calculate and evaluate options, in order to enable decisions and/or initiate activities (BMWi, 2015, p. 3; Bouee and Schaible, 2015, p. 6). In order to increase the performance and*

reach of a company (Westerman et al., 2011, p. 5), DT involves companies, business models, processes, relationships, products, etc. (Bowersox et al., 2005, 22ff.; Mazzone, 2014, p. 8)."

We came across Nwauzu's (2018) article "*Review and comparison of conceptual frameworks on digital business transformation*". This study has great potential and lean understanding of ten frameworks that have been used as a resource for the comparison of conceptual frameworks. The article starts with a brief presentation of the term digitalisation and its background within how this technology is referred to as Industry 4.0. The need for this study was a sense from Nwauzu that there was a lack of agreement for the theoretical framework that has the purpose of the help for the companies to achieve digital business transformation in the organisation. Yet there are many relevant frameworks that have been published till now, but not including the interaction between technology, users and industry. The result of the comparison of those ten frameworks was business and academic literature with keywords related to *digitalisation* and other related words. The comparison was presented as a table at the end of the paper with clarity that pointed out criteria for understanding each framework. Those who had origin from academic literature and roots in the industry publication had nothing much to offer for digital transformation (Nwauzu, 94, 2018).

The comparison was through the ability to evaluate the current state of digital transformation within an organisation, which was in the case of three frameworks: The Six Keys to success, Digital Piano, and Digital Innovation Strategy. Next in the table, it can be observed that the Digital Piano framework has the widest range of coverage with seven areas to transform through digital business transformation (Business Model, Organisation structure, Human resources, Internal processes, IT capabilities, Products/ Services, Stakeholders engagement). One weakness of this result comparison is that none of the ten frameworks provides any detailed approach on how to achieve digital transformation, which could be the most beneficial parameters for our study. Nevertheless, we get eight out of ten frameworks who discuss some critical process that is important on how to transform a digital technology.

The nature of strategy is drastically changed especially in recent years and digital technology is the main reason (Warner and Wäger 2018). To understand exactly why this specific

technology has caused this change in the strategy, it's important to take an insight in digital innovation perspective which originates from information systems (IS) literature (Nambisan et al., 2017; Tilson et al., 2010; Yoo et al., 2010). IS goes under the subject of databases which are systems like software or hardware that assist numerous applications that also includes data management (Sciencedirect.com; Information system Journal 2020). According to Bharadwaj (2013), the IS scholars have been in the last two decades studied the technology of the digital era on firms strategies by describing the effect of the technology on the firm's progress and results (Bharadwaj et al., 2013; Hess et al., 2016; Sambamurthy et al., 2003, Warner and Wager, 2018). For understanding the advantages in the digital industries, strategic leadership has become more necessary for digital transformation in the old and big firms. (Berman, 2012; Fitzgerald et al., 2014; Gray et al., 2013; Hess et al., 2016; Sebastian et al., 2017; Svahn et al., 2017, Warner and Wager, 2018). However, Matt has pointed out that digital transformation stands out from the traditional form of strategy as the result of digital technology has facilitated the speed of change which again has affected the complexity and uncertainty that the firm faces. Sebastian (2017:198) explains the leaders of the biggest companies can both use the existing strategies that run the organisation, but at the same time take advantage of the capabilities within digital technologies. For studying the strategic change in a firm, the dynamic capabilities give a solid "tool" for it. (Barreto, 2010; Peteraf et al., 2013; Schilke et al., 2018, Warner and Wager, 2018).

This set of theory is an eye opener to both separate digital transformation from Industry 4.0 technologies and to understand the ground strategies behind it. Digital transformation has existed throughout the last decades and marks the growth in the digital age from computerising every process, from transformation physical paper into digitalised paper, from internet till now where every device from Industry 4.0 era runs on internet based connection and sensors. However, I still recognize a need to overview the field within the process of integration. Much of the theory above is based on the positive effect of the fourth industrial technologies as a whole, but does not make clear boundaries between every stage that is needed to make this transition level by level. The four major trends (Newman, 2018) that drives Industry 4.0 is a good contribution to this study, but many aspects of the management side are left out in this theory, such as organisation management and staff management. The main elements and design principles that were discussed earlier in the theory chapter, focuses

on the technological integration and its benefits, and less effect on the human work and how it will affect the whole process management. This is the missing link that we observe, which this research paper is aiming to fill by analysing existing literature.

3 Method

Bibliometric analysis was chosen as a method to approach an answer to the research question of this study. Bibliometric analysis is a statistical type of research with books, articles and other publications as resources, to quantify the result of each search team depending on the use of keywords. Veerbek (2002: 181) referred bibliometrics to “The collection, the handling, and the analysis of quantitative bibliographic data, derived from scientific publications". This method is to distinguish the network of each of these teams, regardless of the source's geographical origin. Hence both national and international literature is implemented in the network setting. This review permits to analyse the network between topic areas and also using quantification form to systemise a significant amount of literature (Porter, et al., 2002). The structured literature search was based on the *Web of Science* archive, which is a website related to the university school website and contains mostly papers published within the economy field.

To provide systematic research and review of literature containing the right keywords, it was essential to making use of words like: “Industry 4.0”, management, strat* which then was engaged in the VOSviewer science mapping framework. VOSviewer is a software device which creates maps that are connected between different coloured clusters on a bibliometric network data and distributes a visualised overview to make it advanced in understanding the contexts of that I want to search. Each of the maps introduces each of the items that is analysed (publications, researchers or term). Conducting VOSviewer made me closer to the selection of core articles, which was a combination of different criteria that led me to collect quality content to analyse finally. Hence contributed to the findings of this study.

3.1 Sample

The process of finding the samples is described as a step by step process to understand every stage that was involved in the sample collection. The first stage was to search for content with the assistant of the website Web of Science (WoS), which uncovers academic research with the diversity of many research areas; the data that was needed for this study was collected. After many practices and experimenting on the research, a few keywords were selected to cover the interest area of this research paper. The collection of the data that was used through WOS was based on the following keywords: ("Industry 4.0" AND Strat*) OR ("Industry 4.0" and Management). It was essential to make sure to include "Industry 4.0" in quotation marks. If not, WOS would search for papers related to a random *industry* for itself and articles related to the digital number *4.0* for itself. The quotation marks would help WOS to only search for papers related to *Industry 4.0*. The "star" signed words represents different groups of words; Strat* covers concepts like strategy, strategist, strategic etc, while management covers papers related to management within Industry 4.0. This technique is very useful to make sure for this research to access a wide range of literature and be collective to many research areas and not be limited to literature.

The second stage of this process was to include all years from the WoS publishing criteria. From the early point of publication to recently in the WoS archive to capture the potential developments in this field. The third stage was to only include documents like articles, proceedings paper, review, editorial material, book review and book chapter. These document types would help to access a wide range of paper that is published in this relevant field. This combination resulted in 1 333 papers.

The fourth stage in this process was to include only English as the language of papers published as and in categories: Management, Operations Research Management Science, Business Finance, Business, Economics and Information Science Library Science. These are the categories that focus on the concept of Industry 4.0, management, innovation, technology, Big Data to mention some of the few primary keywords. To be able to reach these categories, another step by step selection was applied, which was based on the numbers of papers that were included in each category. The first step towards the selection of relevant categories was to perform a bibliometric co-occurrence analysis with each category that has more than 100

papers. Threshold 5-7 was used to identify the most relevant keywords within each category. Analysis of the clusters shows whether or not the content on each category is relevant for this research. It means to exclude every category that focuses on technological process and specifications and focus more on the digital change that accorded through Industry 4.0. A further restriction was to make sure to uncover the most influential papers from every category by reading the abstract of the most 30 cited papers, in order not to overlook important content. The combination of these categories resulted in 443 papers altogether, which was downloaded from WoS.

3.2 Analysis

The analysis part of this chapter was divided into three types of analysis that were conducted to make an understanding of the primary connection in this field. For the analysis of 443 papers, the first step was to perform a descriptive analysis to comprehend and understand the development in this field. This analysis was both critical and fundamental to characterize on which regulation operates the "Industry 4.0" research, at the same time having the availability to understand the impact of the research papers collected till now through this method. This way, the history in this field was discovered and a better understanding of the terms throughout the time and across different papers were gaining attention.

The second step was towards the bibliometric analysis of the final research database, to identify the relevant keywords to each of the "Industry 4.0" concepts and also categorise the terms within this field. The discovery through this analysis was to observe the development of keywords clusters and to be able to recognize trendy concepts in this field. This analysis also contributes to the literature review by discovering the most dominant articles by reviewing all 20 most relevant papers selected for the last research database. This will be the last step towards the last analysis on the content. This content analysis will do the research to discover possible conformity and/or contrast in the different concepts in this field. Within this analysis, the relevant papers for this research were selected among all 443 papers down to 16 papers, through the ability on pinpointing the most cited papers and understanding on which regulations are referenced into the final research database.

3.2.1 Descriptive analysis

Descriptive analysis was to mainly understand the development and the growth of the term industry 4.0. One way to observe this was to see the number of quantities that were published within this subject and term within the WoS archive. This way, we could understand the trending status of each year, and at the same time check the potential growth within the publication. With the *Analyze Result* section of the WoS, there was a possibility to analyse the growth in this field throughout the years, along with site other analysis forms that were not relevant for this research. The results of the number of publications through each year was visualised at the end that was used in this paper. More on this is discussed in the next chapter alongside figure 1 and figure 2.

3.2.2 Bibliometric analysis

In this analysis, we implemented all 443 papers, that was the last database search, into the software program VoSViewer, to have a better overview of the main aspects of the papers. This way the identification of each cluster helps a better understanding of the different concepts in this field and also the connection through different colours. See figure 3 and 4. Bibliometric analysis excels through each cluster, which is supposed to have bibliometric similarities based on which method for analysis is used in VosViewer. For this study, three methods were used for analytical purposes: Co-citation, Co-occurrence and Bibliometric Coupling. Co-citation and Co-occurrence are used to analyse the relevance between citations and keywords through the article's abstracts, title and given keywords. The size of the circle each keyword represents illustrates how many times keywords occur, while the distance between two keywords indicated how often these keywords are being used together (Van Eck and Waltman, 2014). Bibliographic coupling was finally used to find the most relevant and influential articles within the final research dataset. This is illustrated through VosViewer map figure 5.

3.2.3 Content analysis

For the selection of the core articles, the abstract of the most cited papers was precisely read and also papers with Industry 4.0 in the title, to cover recently published papers from a total of 443 papers. The result of this selection became 38 articles in total, which was considered

relevant for this research. Papers that focused more on technical and hardware classification didn't make it to the core selection, alongside papers that had irrelevant content beside strategic approach with Industry 4.0. The next step towards this analysis was to implement all dataset from 443 papers into VOSViewer with bibliographic coupling method. The 38 articles that were selected earlier could easily be identified in the VOSViewer map. To be able to get an insight into their bibliometric network, an analysis of the clusters and link to each document was necessary to select articles that were more relevant. The final content ended up with a total of 16 core articles, which will be the premise discussion and conceptualization of this paper.

4 Findings

This chapter will discuss every finding that was discovered through the analysis above and also covering up the core relevant articles that were selected. In addition to that, it will also be a presentation of the bibliometric analysis though VOSViewer maps to visually illustrate the findings.

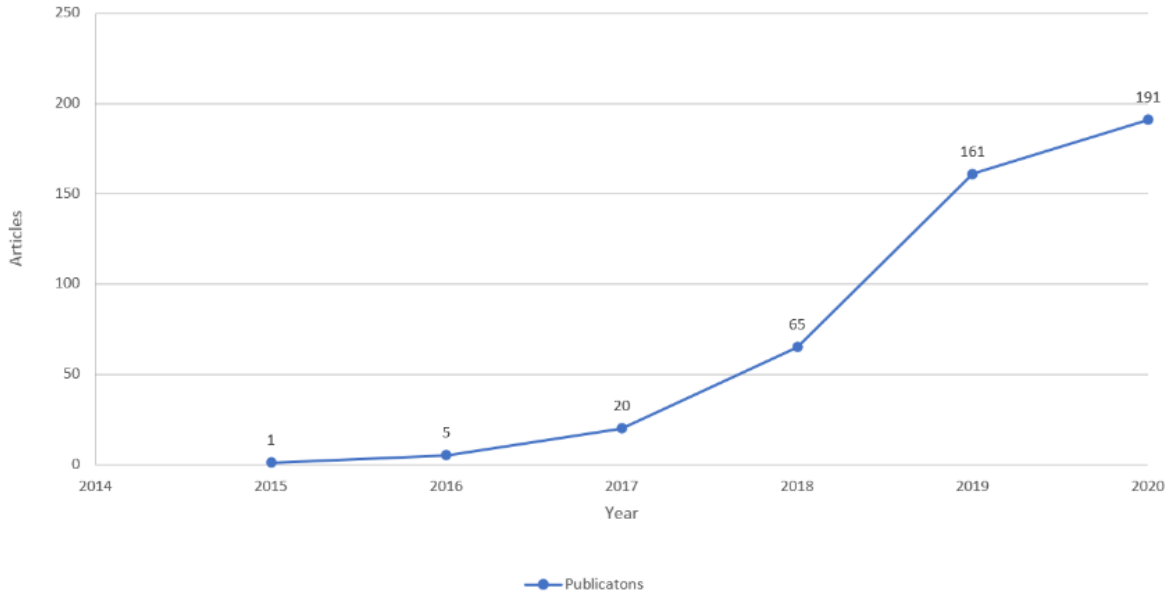
4.1 Findings from the descriptive analysis

The base of descriptive analysis content the 443 papers to look over the development in publications and which categories they belong to. The first discovery was the analytics of the potential growth publication in Industry 4.0 themed papers, which was exponential. This trend has grown dramatically between 2018 and 2020, with the majority of papers within management.

After the final search that collected 443 papers on the Web of Science, we could see the interest in these topics was increasing year by year and it's very much trending right now. With software program Microsoft Office Excel to create an illustration through a dataset that was collected from Web of Science. The first dataset was the 443 publications that were collected at the last search, which was implemented in Excel. The dataset was converted as figure 1, which shows the growth and development in publications from 2015 to 2020. Throughout the graph, it can be observed the immense growth in a publication from 2018 to 2020, which increased by 70 percent. The first publications in 2015 till 2016 had low growth,

as it was a very new subject to research about followed by a sudden increase in 2017 before following the immense interest and growth in this subject after 2018. A quick look at the graph shows that we are at the beginning of this revolution as the first publications within Industry 4.0 that are related to management were out in 2015 according to the Web of Science archive. With only five years of research in this specific field, there is a lot more to study about in the coming years. A reason that can be argued for the defence of the increase in publications is due new business models that have to be developed to maintain the industrial change from previous to current trends, in order to not face bankruptcy. Because this industrial change has not only changed the supply chain management but has also affected consumer behaviour in the digital world. The customers are more involved and connected in the process of their purchased products than earlier, as they're responding to social media trends and also taking a part of the online conversation across the global community which may affect various sizes of companies. In order to keep up with the latest updating regards technology, digital possibilities and to maintain business growth, the increasing interest in managing Industry 4.0 is crucial.

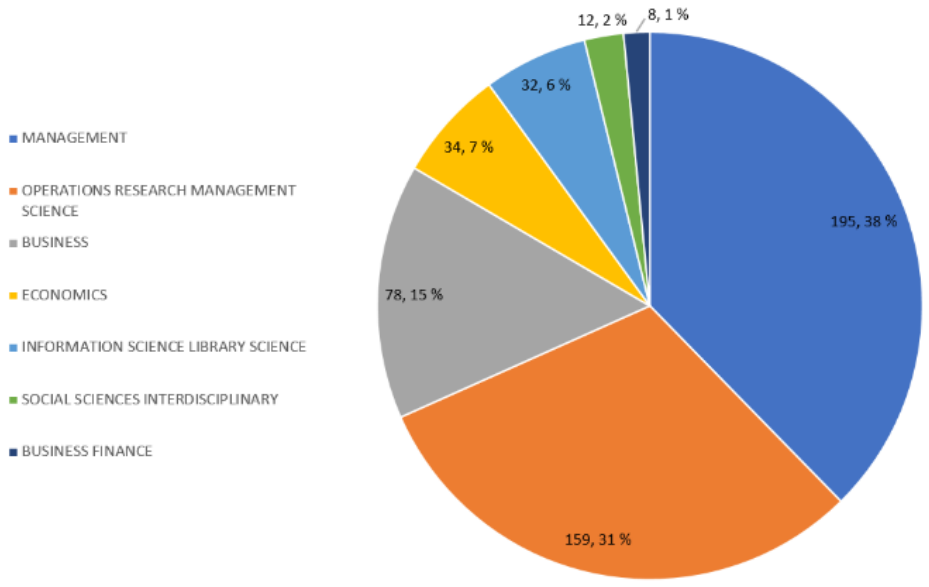
Figure 1: Development in publications from 2015 to 2020 (N=443)



Further finding in this descriptive analysis was the discovery of categories that were identified through these publications. Figure 2 is the visual representation of the respected categories. For the purpose of this analysis categories with around ten or more publications were selected of the total amount of 443 papers. Many of these 443 papers have crossed

many categories than one, which means that the same article might belong to more than just one category. Yet we did not categorize each one of them to one simple category, because the categorisation from the original system does represent an understandable vision of the different dimensions.

Figure 2: Publication visualised through sector graph within each WoS category



"Management" and "Operations Research Management Science" are the two categories with the most publications with 195 and 159 articles which count for 39% and 31% of the database. Almost 80% of the articles within these categories were published between 2018 and 2020 that can be clearly understood from the increasing development in figure 1. While analysing these two categories, we observed that only 35 of the articles were distributed in both "Management" and "Operations Research Management Science". By researching more of the "Management" category after sorting it out after date, it was indicated that the first articles within this category focused on business transformation through technology, supply chain management, review of the IT trends and knowledge/technology resources as a result of digitalisation the impact of industry 4.0 on new business models. The managerial aspect of the Industry 4.0 strategies was very well represented, which is due to its curiosity in managing the impact of this new revolution. "Operations Research Management Science" has a grey zone with "Management" as they both focus on the management aspect of

organisational change as well as technological change that has occurred since Industry 4.0. In this category, it mainly contains articles that focus on operations management, such as supply chain management as well as technical integration into manufacturing.

Categories such as “Business” and “Economics” contain 78 and 34 articles which are 15% and 7% of the articles represented in figure 2. These two categories are mainly based on articles that focus on the effect of Industry 4.0 for new ways of doing business and on the economy such as human resource management that again will impact the organisational culture for many companies. “Information Science Library Science” on the other hand, contains a quantity of 32 articles that focus on technological systems through the management and big data. It discusses systems like information technology, nanotechnologies and cyber-physical systems. While the “Business Finance” category mainly focuses on articles about foreseeing the banking market under the influence of Industry 4.0. By taking a quick look at the eight articles within this category, it is a newly developed area for more room to research, as these articles focus on the strategic approach to the systemic change in both technical and practical sides of a company such as preparing a software program change as well as a change in the organisation structure.

To overview this analysis, 84% of these documents belong to the following categories: *management, operations research management science and business*. One reason for this could be that business and operation management has become a key element in the topic of Industry 4.0, rather than just investing and implementing advanced technologies to expect affirmation on successful business. Documents in these categories have its focus on opportunities that lay within organisational management on transition into technological devices, and challenges that occur during the transition. Hence, the information I need to dive into the analysis further to conceptualise the organisational management during such integration to get better understanding, considering both the opportunities and challenges.

4.2 Findings from the bibliometric analysis

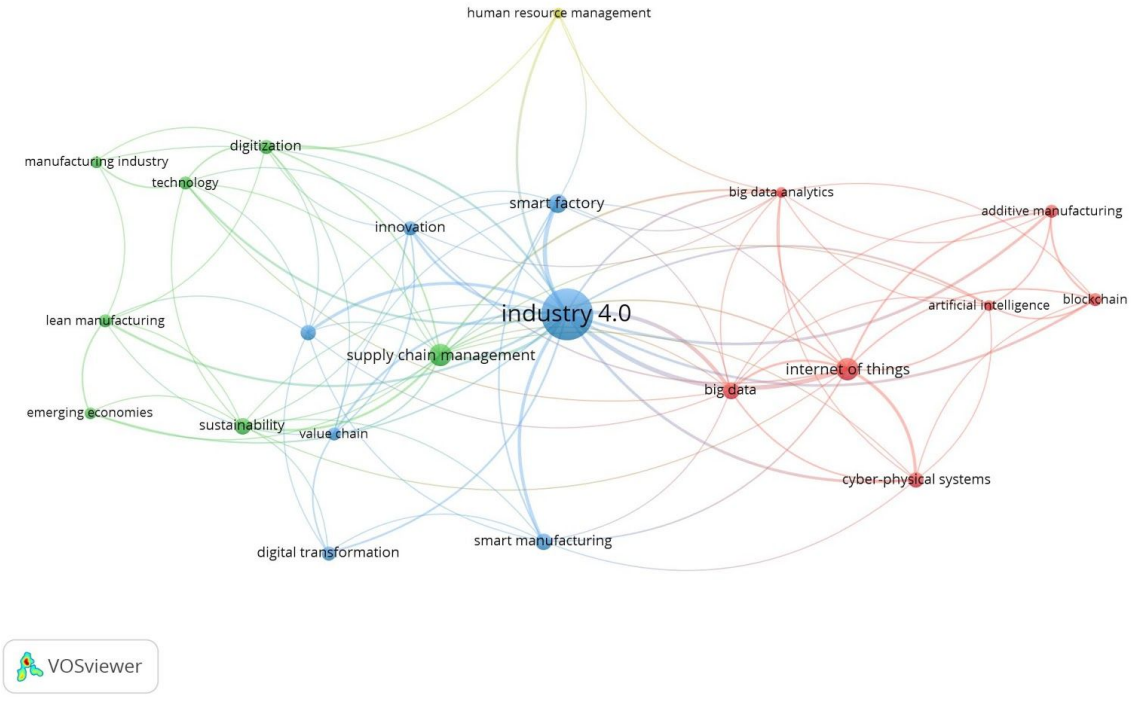
In this chapter, it will present the three following bibliometric analysis: *Co-occurrence and co-citation and bibliographic coupling*. The first findings from the bibliographic method

were through co-occurrence analysis that showed the alliance of frequency of keywords from the samples of 443 papers dataset where Industry 4.0 and management are the heavily weighted keywords from this collection. Next, we have co-citation analysis that is divided into three clusters for industry 4.0, management and supply-chain management, respectively. The findings from the last analysis, which were the bibliometric coupling analysis, are where we come down to our 16 core articles.

4.2.1 Co-occurrence analysis

The purpose of the co-occurrence analysis through VOSViewer is to get an overview of the relevance of the keywords to make incurrence of the contains of the samples collected for research. To make sure the most relevant keywords were included for this analysis, we choose seven as the minimum number of occurrences of a keyword with a significant amount of sample with 443 articles. Another setting that was adjusted in this analysis was to select the full counting method and author keywords as units for the analysis. With these settings and seven of the number of thresholds as five is the minimum link strength, we get down to 21 keywords, which is illustrated in figure 3 through co-occurrence analysis. Before getting the result, we made sure to execute keywords like “industry 4”, “0”, “literature review”, “systematic literature review”, “SMEs”, “internet” and “things” in order to make clear illustration with one keyword representing same topic-rather than “unfinished” keywords.

Figure 3: VoSViewer map visualises co-occurrence analysis using keywords as a unit of analysis



Overall we get three clusters identified with these settings in VoSViewer for this co-occurrence analysis. To review this analysis systematically, it was necessary to make a summary of these keywords with their number of occurrences (OC) and link strength (LS) below on table 1 to organize the findings. The size of the circles that each of the keywords is representing in figure 3 is dependent on link strength. The higher link strength, the bigger size of the circle. In the cluster one, which is the red one, "Industry 4.0" is the most leading keyword, but mentioned earlier that this phenomenon is also called by many the "smart factory" which can be observed from this figure. Cluster two that represent the green network between keywords, the most influential keyword is "Supply Chain Management", followed by "Digital Transformation", "Innovation", "lean manufacturing" and "Technology" that were mentioned earlier in the theory chapter. Then we come over cluster three, the yellow one, that represents keywords related to the technical term of Industry 4.0 such as "Internet of things" and "Big Data". Lastly, we have cluster four, the grey one, with three keywords "Smart manufacturing", "Manufacturing" and "digitalization".

Table 1: *Summary of the bibliometric findings within the co-occurrence analysis*

Cluster 1

Keywords	OC	LS
Industry 4.0	163	118
Smart factory	22	24
Smart Manufacturing	17	17
Digitalization	15	15
Innovation	12	15
Value Chain	10	13
Digital Transformation	13	8

Cluster 2

Keywords	OC	LS
Supply Chain Management	30	27
Sustainability	16	13
Digitization	13	14
Technology	10	13
Lean manufacturing	10	11
Emerging Economics	9	6
Manufacturing Industry	9	5

Cluster 3

Keywords	OC	LS
Internet of things	31	43
Big Data	17	25
Cyber-physical systems	14	20
Additive manufacturing	11	16
Blockchain	10	14
Big Data Analytics	8	16
Artificial Intelligence	8	13

Cluster 4

Keyword	OC	LS
Human Resource Management	8	8

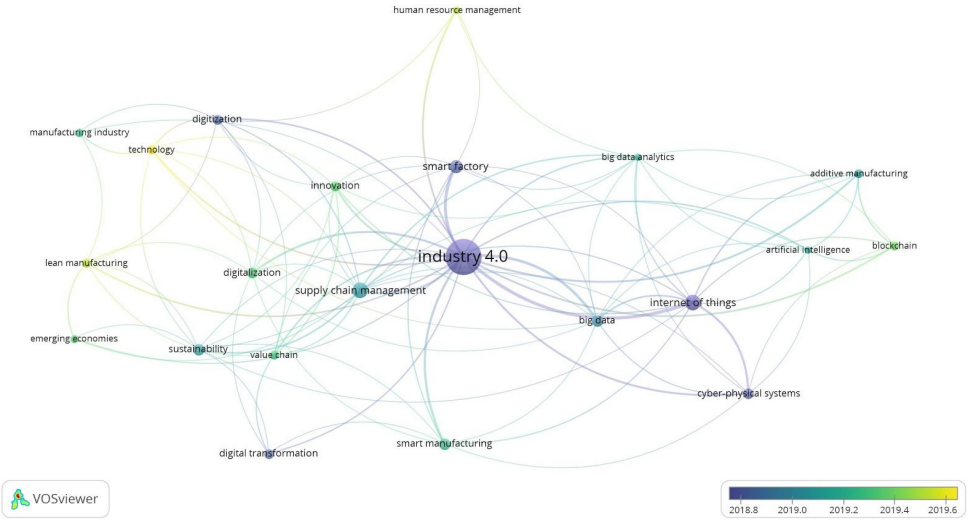
To understand more profound of the importance of the keyword and their relevance, the co-occurrence analysis graph was turned into overlay visualization through VoSViewer,

where the colours change from the previously coded cluster colours into other colours which are representing the average year of each keyword on figure 3 which were included an article that has been published. This overlay visualisation had been illustrated in figure 4. On the bottom to the right of this figure it can be observed grading in a rectangular shape with coded colours of the average year publishing. The lowest average year published is associated with blue; hence the highest average year published is associated with yellow. Based on a dataset that has articles published from between 2015 to 2020, the term "technology" has been the most trendy keyword the last previous years as the average publication year runs to 2019.71. Both the keywords "Digitalization" and "Innovation" have been frequently used in publications with 2019.30 and 2019.33 as the average publication year.

The keyword "Industry 4.0" has an average publication year of 2018.80, that explains that smart manufacturing aspects have drawn attention as digitalisation and innovation has been more than Industry 4.0. What is more interesting about this figure is the keyword "human resource management" has an average year of 2019.50, with yellow links. This can be explained by the increase in the knowledge-driven industry to maintain sustainability, and search for more special capabilities to be able to drive many different aspects that connect to industry 4.0 as mentioned in the theory chapter. The smart factory is another name for Industry 4.0, as industry 4.0 is all about connectivity between machines wireless and contains a lot of sensor systems. The yellow links indicate "human resource management" is frequently used with keywords such as "Industry 4.0", "Smart factory", "Digitization" and "Big Data Analytics". We can observe from the figure below that in the concern of Industry 4.0 "Lean manufacturing" has been more frequently used in published articles, than keywords "Supply Chain Manager" and "Sustainability ". This tells us much about the focus on manufacturing for industrial production that has been researched, more than supply chain which focuses more on the process of value chains form companies and its suppliers for productions of specific products and lastly distribution to possible consumers. This may be because of this industrial change in the current market that many industries reshape its form to more advanced technology to gain more lean manufacturing and move towards smart manufacturing for the benefit of their own. Through this analysis it became clear for the research of this paper that human resources management is indeed a field that needs its attention to maintain sustainability, where less human work might have decreased because of

these advantage technologies mentioned in the theory chapter. This contributes to our research question while reviewing literature regarding staff management.

Figure 4: VoSViewer map visualises co-occurrence analysis as an overlay visualization



4.2.2 Co-citation analysis

The purpose of a co-citation analysis is to get an overview of the network between two or more papers that are cited by the same article. Figure 5 shows an illustration of this visual map converted from VOSviewer, which is based on the 443 datasets collected earlier on method chapter. To get this result in figure 5, we chose the full counting method as well as a cited reference with 31 as the minimum number of citations which gave us 32 references that meet the threshold. The most cited article among this dataset is the 2017 article “Past, present and future of Industry 4.0-a systematic literature review and research agenda proposal” by the corresponding author Liao Yx with 85 citations. With the clear settings in the VOSViewer and this dataset, we got 3 cluster representations in the figure below. Articles that belong to the green cluster are strongly related to managerial related to industry 4.0 themed papers such as supply chain management, sustainability, lean manufacturing. On the other hand, the red cluster contains articles that are related to industry 4.0 technologies such as the Internet of things, cyber-physical systems and Big Data. The blue cluster is a representation of the topics related to the core of this paper theme such as Industry 4.0 and the smart factory. From the co-citation analysis, we have only three articles from these authors that we have selected for

our core articles, as the rest of the authors couldn't contribute to the questions of this research paper. The Ghobakhloo (2018) article "The future of manufacturing industry: A strategic roadmap toward Industry 4.0" from the red cluster in our core articles. From the green cluster, we have Xu (2018) and Fatorachian (2018) article "Industry 4.0: state of the art and future trends" and "A critical investigation of Industry 4.0 in manufacturing: theoretical operationalisation framework" in our core articles. The reason the rest of the articles that are represented through these authors are because they can be irrelevant for this research. As an example, we have Sander, Elangeswaran and Wulfsberg (2016) that discusses their view on managing the technical side of the industrial technologies, while Dalenogare (2018) present a framework of contributions of technologies for industry 4.0 and Frank (2019) brings up emerging of different technologies on companies. The fact that we have only recognised three articles, that even though Industry 4.0 is in its early phase of the revolution, we continuously need strategies that keep us aware of the unknown future trend in order to find sustainability no matter where the companies find themselves in the maturity level.

Figure 5: VosViewer map visualises co-citation analysis using cited authors as a unit of analysis

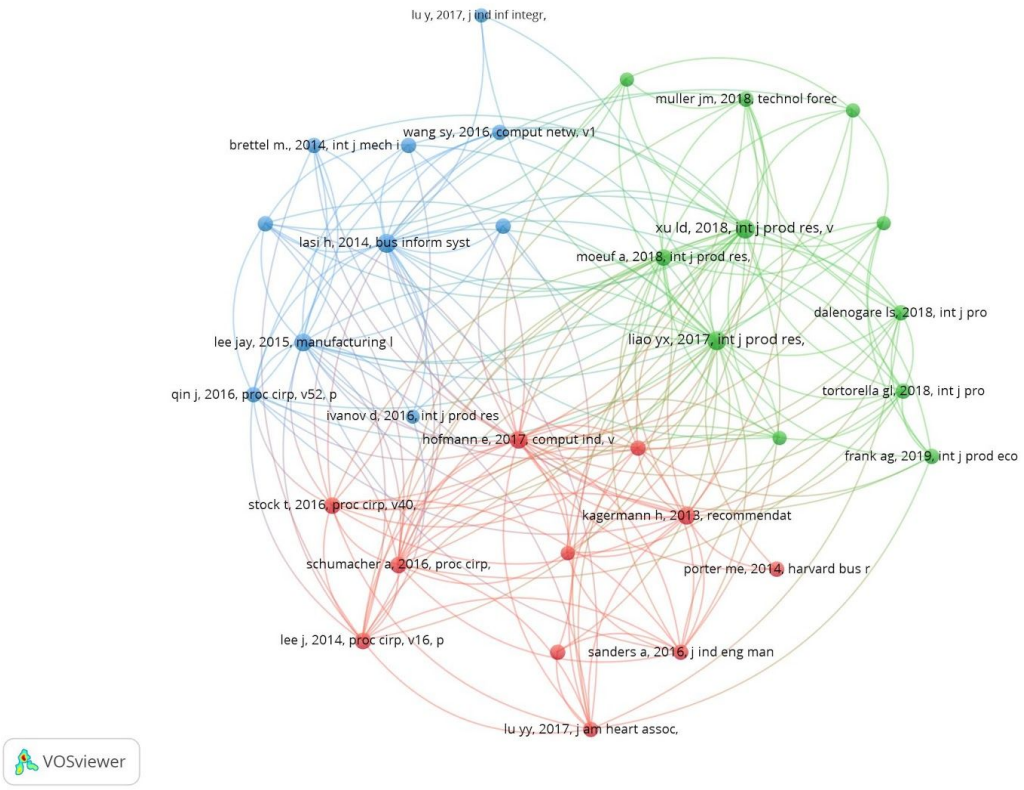


Table 2: *Summary of the bibliometric findings within the co-citation analysis*

Cluster 1		
Authors	**OC**	**LS**
Ghobakhloo M, 2018	41	334
Hoffmann E, 2017	67	476
Kagermann H, 2013	66	353
Kamble SS, 2018	35	277
Lee J, 2014	49	300
Lu YY, 2017	40	301
Porter Me, 2014	38	211
Sanders A, 2016	38	304
Schumacher A, 2016	53	394
Stock T, 2016	49	344
Tranfield D, 2003	37	248

Cluster 2		
Authors	**OC**	**LS**
Delanogare Is, 2018	43	325
Fatorachian H, 2018	34	294
Frank Ag, 2019	44	306
Kusiak A, 2018	32	230
Liao Yx, 2017	85	664
Moeuf A, 2018	49	390
Muller JM, 2018	39	292
Oesterrich TD, 2016	33	275
Tortorella GL, 2018	39	312
Xu Ld, 2018	83	546
Yuin Y, 2018	31	247

Cluster 3		
Authors	**OC**	**LS**
Brettel M, 2014	41	249
Hermann M, 2016	43	274
Ivanov D, 2016	34	247
Lasi H, 2014,	75	453
Lee Jay, 2015	71	415
Lu Y, 2017	31	173
Quin J, 2016	42	309
Roblek V, 2016	39	247
Wang Sy, 2016	40	266
Zhong Ry, 2017	44	262

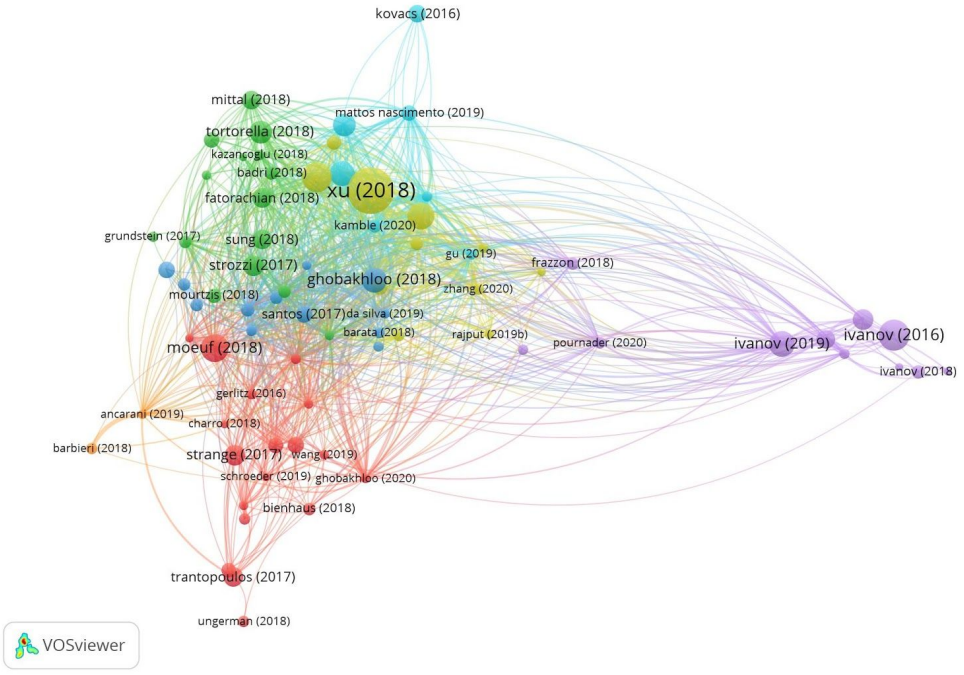
4.2.3 Bibliographic coupling analysis

Figure 6 is a VOSViewer map that illustrates the central clusters and articles. Bibliographic coupling method was the method that was used here, which was the tool for selecting the core articles for this research paper. Each coloured cluster identifies papers and articles that cover the same theme. The red cluster represents articles that cover the performance through knowledge management and strategic business transformation within Industry 4.0 and digitalisation. Much of these articles also discuss the challenges and opportunities of this phenomenon. The green cluster represents articles that cover manufacturing in Industry 4.0 and discusses the operational management perspective. The blue cluster covers articles within the supply chain and also the innovation perspective within Industry 4.0. The yellow cluster represents articles for a better understanding of the implementation of the system within industry 4.0, such as cyber-physical systems and the internet of things. The purple cluster covers supply chain management with a focus on logistics and risk analysis based on industry 4.0. The turquoise colour cluster covers mostly the integration of the architecture and exploring of the Industry 4.0 technologies. The orange cluster represents two articles within back shoring and manufacturing shoring in Industry 4.0.

Analysis from the method chapter, we already come down to 11 core articles earlier in the process, where 4 of these belong to the red and 3 of them to the blue clusters in figure 6. Just like mentioning earlier analysing figure 6, the red and blue cluster contains a good mix of

knowledge management in industry 4.0, supply chain management, and strategic business management related to industry 4.0. Which is the correct literature to search for analysis of the management levels required to develop knowledge that lays on each process towards integration on Industry 4.0. The remaining 4 articles belong to the yellow cluster, since there is a need for articles that can build up to understand the need of implication of the system within Industry 4.0 in order characterize the management of it in purpose of this study. The cluster red only contains 18 articles and after examination, specifically this cluster and analysing the strength links between each article to make occurrences that we had excluded or missed relevant articles. After this step, we come down to include four more articles from cluster red. By going through cluster green and doing the same process, the decision to include 2 articles lastly from cluster green as it will help us to have a content within the operation process management in order to understand build up in this field. The core articles that were selected for this research were from cluster red, green, blue and yellow -which gives us 16 core articles all together.

Figure 6: *VoSViewer map visualises bibliographic coupling method using documents as a unit of analysis*



4.3 Findings from content analysis

On this content analysis, we examine the core articles that we selected till now. By reading and reviewing each article, it was managed to make clear, organised sections of different aspects of management with regards to industry 4.0 technological transformation factor and its effect. We then present the findings with these four levels of management: Project management level, process management level, organisation management level and staff management level.

4.3.1 Project management level

In this level of Industry 4.0, we analysed the researcher's view on project management and its effect on different departments of the business. Just like Charro and Schaefer (2018) argued that to be able to find success in our business proposals, there is a paramount to understand the users' needs. Through cloud systems, it is possible to develop a custom strategy for each customer; hence more personalised product and services are presented. Through this technological system, there is room for getting more "correct" proposals and therefore decreasing cost of production of proposals who wouldn't find its users in the market because big data analytics reveal behavioural patterns, trends and associations (Charro Schaefer, 2018). Also, Kohtamäki et al. (2019) presented very well on his research about the possibilities in the digital age and with the technological equipment of Industry 4.0 era that can develop process and capabilities increased customization efficiency alongside having ability to deliver efficiently. Because of these advanced digital possibilities, we have more efficient ways of resources to be able to find the correct position in the market to achieve new customer goals (Ardolino et al., 2018; Coreynen et al., 2017; Huikkola & Kohtamäki et al., 2018). However, skilled experts within software programming are needed for such advanced analytics to comprehend. Much of the capabilities that are being used for such intentions to make the best business decision is to foresee unexpected marked behavioural to not only be prepared for your own good but also capture new ways of managing a business (Hasselblatt, Huikkola, Kohtamäki, & Nickell, 2018). As from an organisational aspect of implementations of technological software tools, such as a Cloud system has rather been ignored according to Strozzi et al. (2017) on their research. They continue the argument that

the focus is more on production requirement tools and the management aspect of it, such as involving integration on understanding human and artificial agents (Kannengiesser et al. 2015, Kannengiesser and Muller 2013, Zamifirescu et al. 2013). In a study by Slusarczyk (2018) shows a result of a survey that was taken by different companies related to Industry 4.0. They found out many companies treat Industry 4.0 transition more of an opportunity than a threat. In addition to finding out the positive attitude toward new Industry 4 advanced technology, they also found out that the ability to take advantage of these technologies are relatively lower than expected. Moreover, the level of technological solution within Industry 4.0 is software integration and predictive maintenance than autonomous robots for these companies, which means that autonomous robots least liked technological solution (Buchi et al., 2020).

Table 3: Core articles regarding project management level

Author	**Tech Factor**	**Department**	**Effect of Industry 4.0**
Alberto Charro & Dirk Schaefer, 2018	Cloud system Big Data	Product-service system	+ personalized product/service + decreased errors and cost
Marko Kohtamäki, Vinit Parida, Pejvak Oghazi, Heiko Gebauer & Tim Baines, 2019	Cloud system Big Data IoT	Digital servitization	+ increase customization + value creation and capture + efficient delivery
Fernanda Strozzi, Claudia Colicchia, Alessandro Creazza & Carlo Noè, 2017	Cloud systems Artificial intelligence	Knowledge management	- lack of appropriate competence and skilled workforce
Buchi, Giacomo; Cugno, Monica; Castagnoli, Rebecca, 2020	Unknown	Openness to Industry 4.0	+ decreased errors and cost + improved product quality and ability to meet customer needs
Slusarczyk, B., 2018	Software integration, Autonomous robots	Readiness to Industry 4.0	- less prepared

4.3.2 Process management level

Several ways of integration Industry 4.0 technology have been studied and discussed in this research, but a huge part of these technologies is used to implement supply-chain

management in several companies. Ardito et al., (2019) presented a framework of how most of the Industry 4.0 technologies are used in implementing supply chain management. Industrial IoT affects this management in the sense of collecting raw data on in-outbound logistics that emerge solutions that are penetrating and extensive in regard to what kind of data is involved such as the location of the product, time of the production and customer data. The same goes by cloud services which manage all types of data, but the more structured information exists the more it will be helpful for such management to make precise choices regarding the supply chain (Strange & Zucchella, 2017). On the other hand, big data is not directly engaged in managing. In fact, this is where the information through big data analytics emerges into relevant knowledge for it to be used as a strategic step toward better management (Schneider, 2018). Lastly, cybersecurity is used to protect this relevant flow of information data (Nosalska et al., 2019).

Table 4: Core articles regarding process management level

Author	Tech Factor	Department	Effect of Industry 4.0
Roger Strange & Antonella Zucchella, 2017	IoT, Big Data and analytics, robotics, additive manufacturing	Management	+ speed + increased production capacity + process control
Ardito, Lorenzo; Petruzzelli, Antonio Messeni; Panniello, Umberto; et al., 2019	Cloud Computing, Internet of Things, Big Data, Cyber Security	Management	+ improved product quality and ability to meet customer needs
Paul Schneider, 2018	Big Data	Unknown	+ improved product quality and ability to meet customer needs
Nosalska, Katarzyna; Piatek, Zbigniew Michal; Mazurek, Grzegorz; et al., 2019	Cyber Security	Unknown	+ flexibility

4.3.3 Organisation management level

Many researchers have shown their curiosity about industry 4.0 and the effects of different fields within this phenomenon and by explaining through a technological transformation

while making a roadmap towards this industrial change. One of these is the readiness for such transitions. Gunasekaran et al. (2019) discuss his research on human aspects of quality management in the era of Industry 4.0. One thing that stood out was the human issue such as an individual's readiness for change to the implementation of quality management programs. In his research, he reviewed Haffar et al. findings that presented the influence on individuals readiness, where he found two dimensions that may affect the team for successful quality management implementation programs, such as personal benefits and change self-efficacy. Nevertheless, Ghobakhloo and Fathi (2020) discuss the Industry 4.0 transition process by explaining why it has to start with digitizing curtain areas to guarantee a successful transformation. Such as production area, maintenance and quality management operation and other element areas that have a connection to the core business strategy. They also mean to explain that it's almost nearly impossible to achieve full integration of the implementation and data transparency that covers the whole value chain, absolute elimination of functional machines and devices, and lastly the automation of all manufacturing. Hence, it's important to consider areas such as the organisation as a whole, the operational area and lastly the technological and legal openness and readiness for Industry 4.0 transitions for typical manufacturers. However, Ghobakhloo (2018) has earlier on his holistic analysis where he made a roadmap to industry 4.0 transition, he made it clear that strategic management is the first step towards such transformation. He explained three different strategies for this management, and these were short-term, medium-term and long-term strategies that enhanced different types of companies based on their timeline they belonged to. This explains the time-period the company belongs to, as in where it is, where it should be and how it should possibly reach there, based on the pre-set plans on Industry 4.0 (Schumacher et al., 2016). Industry 4.0 and digitization is a difficult and crucial path, but not impossible with the right leadership and management through essential resources (Ghobakhloo, 2018). Hence digital transformation is one of many fields that should be significantly important for leaders and managers that have goals towards Industry 4.0 (Müller et al., 2018; Ustundag and Cevikcan, 2017).

Table 5: Core articles regarding organisation management level

Author	Tech Factor	Department	Effect of Industry 4.0

Gunasekaran, Angappa; Subramanian, Nachiappan; Ngai, Wai Ting Eric, 2019	Automation, IT	Quality Management	+ personal benefits + change self-efficacy
Morteza Ghobakhloo, Masood Fathi 2020	Unknown	Quality Management	+ Continuous improvement across process and operations - Indirect and direct digitization cost
Ghobakhloo, Morteza, 2018	Unknown	Strategic Management	+ Continuous improvement across process and operations

4.3.4 Staff management level

Many research studies revealed that production management through application of Industry 4.0 is strongly related to the production process and to improve flexibility. Many researches have pointed out cloud computing as the tool that has increased the flexibility in production. (Moeuf et al., 2018). However, other Industry 4.0 technologies like Machine learning, big data, collaborative robots are neglected for small-medium enterprises as they are more expensive than cloud computing, which is the main reason why such enterprises are neglecting some industry 4.0 tools or technological devices. Nevertheless, many enterprises of such size lack human resources in the research and development area. Which means they find difficulty in managing technological solutions such as big data analytics, in order to analyze customer behavior for the benefits of the enterprise (Moeuf et al., 2018). Müller (2019) mentioned in his research, while interviewing up to 43 personnel within enterprises that belonged to different sectors related to Industry 4.0, that to have the ability to maintain Industry 4.0 technologies it was required to have special skills within such fields like IT. Which small medium enterprises (SMEs) couldn't easily afford, hence experts within fields like this go to much larger enterprises. Another problem that many of his interviews revealed was the limited workforce on SMEs. It's a challenge for many enterprises of such size to be able to properly train their personnel as their own time of work will be wasted, which causes a delay for the flow of the workplace. This means that larger enterprises have better workforce than small-medium enterprises who have limited workforce. It will be difficult for SME to run the daily business, if the workforce is being trained as. As an example, Horvath and Szabo (2019) explained the heavy dependence on human resources that caused increasing

labour shortages, especially on local human resources. Nevertheless, multinational corporations have better opportunities regarding recruitment as they search for the right recruit globally than small-medium enterprises who have the capacity to locally search for a recruiter. multinational corporations can easily move their production activities to another region if they can't find the correct human resource for the specific position. However, the number of vacancies in fields like artificial intelligence, big data and industry 4.0 is high, while the number of such experts is very low (2019).

Table 6: Core articles regarding staff management level

Author	**Tech factor**	**Department**	**Effect of Industry 4.0**
Alexandre Moeuf, Robert Pellerin, Samir Lamouri, Simon Tamayo-Giraldo & Rodolphe Barbaray, 2018	Cloud computing	Human Resource	+ flexibility - lack of appropriate competence and skilled workforce - longer learning time
Julian Marius Müller, 2019	Internet of things, IT	Human Resource	- increase in cost - lack of appropriate competence and skilled workforce - longer learning time
Horvath, Dora; Szabo, Roland Zs., 2019	Artificial Intelligence, Big data analytics	Human Resources	+ reducing human work + increasing labour shortages + allocating workforce to other areas - lack of appropriate competence and skilled workforce

5 Discussion

Up until this point of this research paper it was collected a dataset of articles that were published under topic Industry 4.0 within relevant categories in favour of this study, and identified core articles that were analysed in under method chapter. In this section of this research it will be discussed about the findings that were discovered, in consideration of the theory chapter and the analyses from the method chapter.

5.1 Project management level

From the project management level it was mentioned how it's important to develop the right strategy for each customer, that caused an increase in personalized and customized product and services which signifies the Industry 4.0 characteristic opportunities. Just like mentioned in the theory chapter that with the horizontal integration networking through the four Industry 4.0 four main elements. By networking the focus on this project management level will position the correct customer and find the market, but also increase market and diversify their products by offering complementary products and services with the same customer base. This is the level where with horizontal integration the focus is on its activities and around core competencies to build out an end-to end value chain with established partnerships. Hence Industry 4.0 integration for any company should plan the transition in more detail and project plan. This contains that on specifying as much as possible in order to acknowledge the characteristics of the work within each phase of the integration in order to organize in the most possible way, and further sideline and as equality important to take consideration in analysing the cost and benefits for each phrase for such integration. Another aspect that we want to look at at this level is from the first design principles in Industry 4.0 that we represented in our theory chapter. As mentioned earlier the first design principle is interoperability, which is a shared platform for devices, people and other entities to communicate by combining the IoT and IoP. Communication between different devices makes this industry create more interest. Alongside wireless communication technology in addition to the possibilities of the IoT, the connection between sensors, machinery, and many other devices make the tasks that involve monitoring much efficient and effective. Moreover, virtualization and real-time capability are important as CPS (CyberPhysical Systems) must be able to replicate the real world in a virtual environment and function in real-time to provide live insights about the business operations.

5.2 Process management level

In the next step toward Industry 4.0 integration we across process management level, and with the existing literature preview in the theory chapter - the main premise or assumption of Industry 4.0 is to create an increasingly autonomous and highly cognitive ecosystem, which relies on technology such as machine learning, deep learning, advanced robotics and

Industrial IoT to further accelerate efficiency. What it was found out through the findings from the content analysis that sufficient maturity level within IT is needed to be ready to integrate into Industry 4.0 for many organisations. Since we are still in the early phase of Industry 4.0 globally with published articles analysed from co-citation earlier, it can be arguable that not all of manufacturers have IIoT production systems that can also handle the whole Industry 4.0 integration throughout the value chain. Which means that for such integration to potential, it needs a throughout plan-setting up ahead of its time, with technological opportunities. Which is why the four design principles are an important part in this level. These principles as mentioned earlier, is to help companies to identify and implement Industry 4.0 scenarios and approaches. The last principle that we represented above focuses on technical assistance, which defines the assistance systems that are designed for operators that are in need to make knowledgeable decisions to solve urgent problems. Industry 4.0 transformed the role of humans from being an operator that controlled machines, to decision-makers to solve problems. In this case it will not only solve urgent problems, but provide much efficiency in the manufacturing process. One of the ways is, for instance, the streaming line where access to helpful data is increased to help with maximizing productivity and reducing the number of resources used. This will make the business decision be better from the aspect of the cost of the material and labour. By using the helpful information to design a better business, the operator will face few rejections from customers and Industry 4.0 will boost productivity and revenue growth. Every process in manufacturing in Industry 4.0 is heading towards an improved process of existing traditional processes and much leaner production to save costs and expenses. In this level of integration it's all about the early preparation which is possible with the information that is collected through big data analytics. Many of the decentralized decisions many operators can make are based on modern information and communication technologies like CPS, big data analytics and cloud computing. Analysing information through these technologies helps operators to find and capture early production fails and defects. Yet, there exist many companies that have difficulty because of lack of skills that manage new technology is very advanced processes with the use of complex tools, such as analytics software programs and algorithms to manage the information in a meaningful way. Which leads us to the next level.

5.3 Organisational management level

As earlier mentioned in this discussion there is a need for a detail oriented plan much ahead of its time for successful integration into Industry 4.0 transition for any organisation. For such a plan each phase must not only consider the technological change that can offer for the maximum value for the customer, but also focus on the economic side of each phase whether or not it's beneficial for the organisation, and the cost of each phase to take place. In order to start with such a plan it is a need to identify the priority of each phase and analyse the functionality for each phase. Another aspect that it's important to know is the information of the employees towards the organisational changes that will occur then the Industry 4.0 transition will happen. The readiness of the employees is extremely important for a successful transition, and planning to hire right skilled people to make this gradual and new transformation within the organisation into more balanced integration right beside employees that worked there earlier. New employees with the right knowledge and skills can be the key to any organisation that has future plans that contains new technological transformation alongside preparing and training other employees for organizational change. Therefore it's important that these changes alliance within each phase of such transition that should be first identified and then managed to operate. The second design principle that was represented in the theory chapter of this research is a definition of such preparation with information transparency, defining the interconnectivity that approaches different operators for collecting an enormous amount of data and information from every point of the manufacturing process to acknowledge the shortage in different fields so the performance could benefit innovation and improvement. This transparency contributes to using the information to make appropriate decisions for the operators. Also, a convergence of IoT, IoS, IoP, IIoT should build up the Internet of Everything (IoE) leading to greater transparency of all the stakeholders on the network. The decentralization principle defines the decisions which are a combination of local and global information which leads to the ability to encourage better decision-making and to increase productivity.

5.4 Staff management level

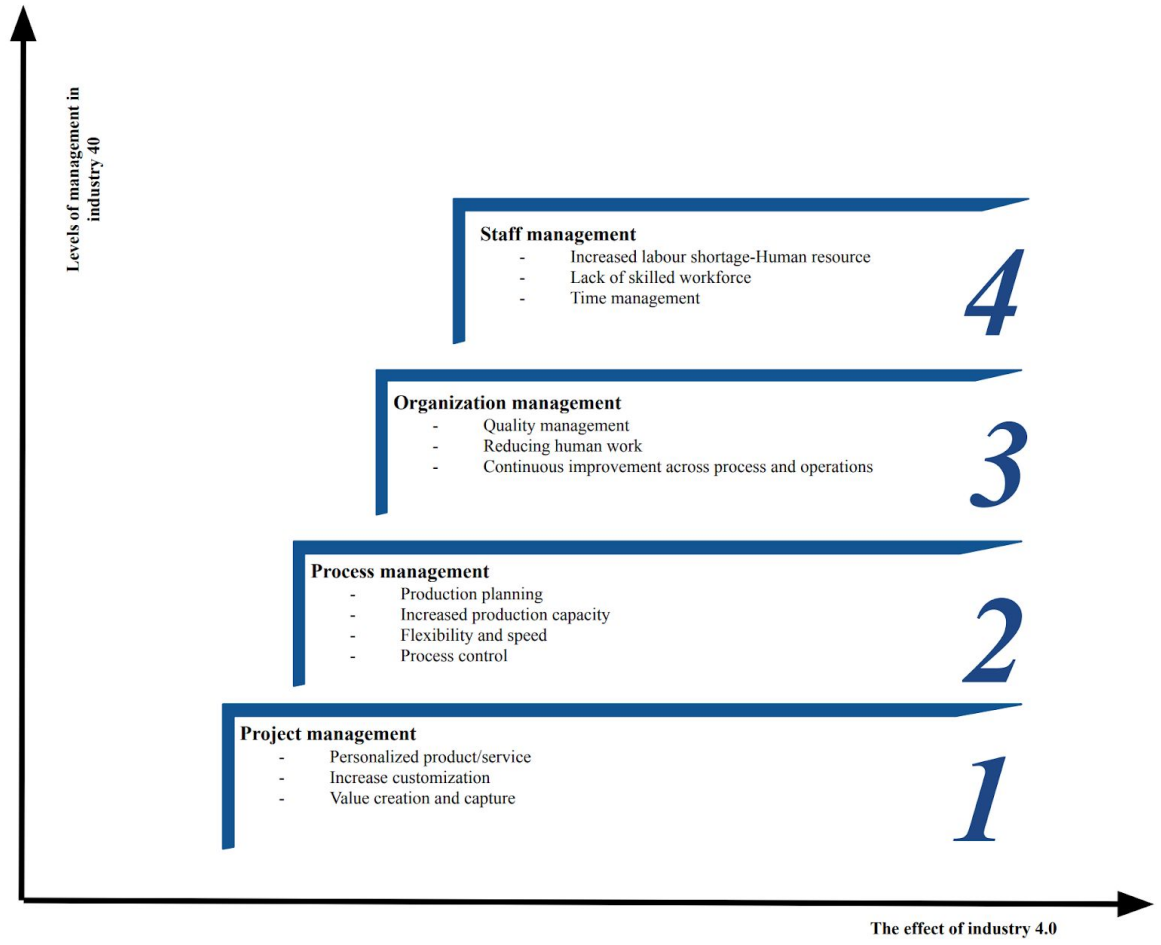
Based on the findings that were identified throughout the research it can't be ignored the fact that there exist many challenges regarding Industry 4.0 that are not focused in this research

paper, such as financial capabilities. The focus has been mainly to the maintenance the integration of the production process and knowledge competencies. However, we got an understanding of how lack of digital culture and training for the skill that is needed to integrate into Industry 4.0 is crucial from this research. This may cause a lack of clear vision from the managers regarding investment in Industry 4.0 technologies with unsure economic benefits. It's not enough to invest only on technologies that make it possible to achieve business goals, but also invest on the training that is needed to manage these technologies with the right skills and knowledge. Throughout analysing the content of the core articles that were identified, it was managed to view Industry 4.0 as an early stage of its development. Which is clearly visualised in the descriptive findings. After all this word phenomenon was first identified in 2011 as mentioned in the theory chapter, and has rapidly grown interest since then with the amount of research papers that has been published according to our descriptive analysis in our finding chapter. Earlier in the theory chapter we mentioned that there is no need for big factories to do well in the market, in fact, factories and companies of all sizes now have a chance to do well with the opportunities of these technologies created in Industry 4.0. However, in terms of staff management level we found out in our findings that small-medium enterprises have difficulties managing time to train new employees in the system. If such enterprises of such size focus on the training, there will be a lack of people who can drive the business as usual. This will cause a dilemma on the investment limitation of staff management.

6 Conceptualization

Taking the analysis of the findings in consideration and the discussion of the content analysis we managed to identify and separate levels within integration of Industry 4.0. The respected levels start with project management level, process management level, organisation management level and staff management level. Even though these levels are separated by each characteristic point of view, they share similarities in regards to technological factors and the effect of Industry 4.0 in general. These levels that were discovered in findings are presented figure 7.

Figure 7: Summary of the effect of the four levels of management for the integration of Industry 4.0



In the bottom line we have the **project management level** that represents the first level of implementation of Industry 4.0 and how to manage it according to our findings. Within this level it was identified to understand user's needs by cloud systems that makes it possible to develop custom strategies for each customer, hence further possibilities for personalized products and services. The technological equipment of Industry 4.0 has not only made it possible to increase customization but also increase the ability of delivery efficiently for satisfaction of the customer, which makes it possible to map the value creation from the Industry 4.0 point of view. However, cloud systems that make project management to have a secure start for the customized business for integrations of Industry 4.0, which was discovered that many managers in this level focus more on production requirement tools than understanding on analytics of user's need. Second level involves **process management** which is mainly focused on supply-chain management because most of the Industry 4.0

technologies are used to implement such management in this process management level. There exist a range of Industry 4.0 technologies in sense of collecting raw data to penetrate the involvement of different relevant data to plan a production, or do structured information analytics to make a better decision to the production such as increasing the capacity. Big data information is rather converted to more advanced analytic to emerge these information into relevant knowledge to do process control. The third level is **organisation management** that involves quality management in the era of Industry 4.0. It was discovered that it is very important to start with digitizing curtain areas already in organisation to guarantee successful transformation toward Industry 4.0 in order to manage such transition. Yet we also discovered that such digitization has an effect on reducing human work. We also identified this level of understanding that it's almost impossible to achieve full integration of the implementation and data transparency that covers the whole value chain, machines and devices which is why it is important with continuous improvement across this process. Our fourth and last level that is presented through figure 7 is the **staff management** where we identified our discovery on how advanced technologies within Industry 4.0 era has caused improvement in efficiency and flexibility, such as cloud computing, machine learning, big data and collaborative robots, even though small-medium enterprises neglect some of these technologies because of their extensive. However, because the lack of human resources in these areas is very less than the development in this area, this causes difficulty to manage such technologies when there are knowledge and special skills which is why it's important to collect data to analyse readiness of such organisational change. Whenever the analysis shows the correct amount of openness and readiness for the integration, the companies won't feel the lack of human resource as it will be covered through the real-time data that employees are willing to fill that gap for the growth of the business.

7 Conclusion

Industry 4.0 is the new industrial revolution of the 21st century, and serves a beneficial attitude towards a global scale. The industry creates an opportunity for manufacturers to make “smarter” products, services and solutions through the advanced technology of Cyber-Physical System, Artificial Intelligence, Cloud Computing, Internet of Things, and many more. Through vertical and horizontal integration along with engineering across the

entire value chain, the result from this implementation is cost reduction, increased work and time efficiency and optimized production along with empowered employees, transformed products and connected consumers & customized experience. From the main components, designs and principles that make up Industry 4.0, there is a connection within each dimension on the fourth industrial revolution through value creation in organizations, technological innovation and knowledge strategy.

The purpose of this research was to outline a map that shows how to execute transformation towards Industry 4.0 for companies regardless of their corporate size, and keys to manage the strategies that suit the integration in order to drive alongside this industrial trend - that changed the whole business model in this early stage of Industry 4.0. To reach the purpose of this research it was used bibliometric analysis based on the structured search that collected literature research paper related to the topic of Industry 4.0 with strategic and management contribution of such topic, which resulted with 1333 documents that were reduced down to 443 papers after choosing the collectively right criteria for this research. By performing descriptive and bibliometric analysis led us to the 16 core articles that we conducted into content analysis. This was further discussed with existing literature from theory and findings from the analysis; Hence served with a framework with four levels that guides the integration. Because our research was mainly focusing on the holistic view of integration of Industry 4.0 we chose not to focus on respective sectors or industries, since it was important to make the framework of the whole concept - with a better understanding of the basis. Moreover, the focus of this research is strategies behind each management that assist such integration without taking the economic and financial perspective of such investments and strategies. We do recognize that there are limitations to our study in terms of place and resource for supervising the search for this study.

7.1 Main contribution

This method of research led to answering the research question as close as possible, and managed to contribute a framework of four different levels where each level surpas each and lead closer to manage a strategic way to perform a successful integration of Industry 4.0 technologies and strategies. The first level is the project management level where the focus is

on the basis level of any organization by analysing the Industry 4.0 characteristic opportunities and emerge it into horizontal networking from the four main elements within Industry 4.0 integration. The next level that was presented in this research was the process management level which is basically about mapping out the integration process through the whole value chain. Supply chain management plays a huge part on this level we found out through our findings and with correct dataset companies can analyse correct ways to conduct their integration of both technological devices and right strategies towards better management of these technological changes. Organisation management level the third level of our framework and explains the strategies on how to analyse through with a long term view, we get a clear picture on how this project will be beneficial for the organisational, and how its going to change the customer satisfaction of Industrial 4.0 transformation. Hence following up with the fourth and last level in the framework we come across staff management level is a strategy that tries to find balance on maintaining the integration of the production process by investing in Industry 4.0 technologies and knowledge competencies to manage these technologies with the right skills and knowledge. However we found out that investing on training doesn't seem a wise choice for small-medium enterprises as their employees are less that it will affect their business negatively if they focus on training new employees. Nevertheless, with detailed plans on the digitized transition in each department and field, much ahead of its time, to fully prepare for the cultural change in the organisation -is possible to fill this gap.

7.2 Practical implications

This industrial change has caused many companies and industries to shift toward this digitized change and keep it up with this trend in order to survive with this global phenomenon. This shift has affected the industrial sector with its industrial technologies like IIoT, cyber physical system, robotics, AI and many more, but also affected the whole value chain from the production to logistics to distribution, to the companies/stores and lastly to the customer. Moreover, the way many businesses handle its process these days, and specially during this pandemic situation with Covid-19, each stage has its Industry 4.0 technology influenced. With our 16 core relevant articles that were identified within this research, we present a framework to understand the levels that exist in the integration of Industry 4.0 and

how to manage it in purpose to serve a contribution within this field and to an groundwork for discussion related to strategic performance within such transformation. With other words, the suggestion based on this research goes by to analyse each stage that is planned into Industry 4.0 transition to fully prepare for the change, in order to make the strategic decisions to perform such technological change - based on the information that alatytics will result. The more openness to this Industry 4.0 integration, the more readiness each stage will experience.

7.3 Limitations

This research is based on topic search that its structurally specific selection of keywords with one specific resource as a dataset, which means that with different search strings and source of dataset we might have different selection of core articles for this research. Moreover, the core articles that we reviewed as existing literature was a result of our content analysis after removing non-english documents, which made limitations to do research that is based on only published in english and ignored other languages in this study, specifically publication within dutch language which is the origin of Industry 4.0 history. In addition, the research is based on empirical evidence surrounded around Industry 4.0 as a topic with existing literature from one source of dataset. However, the framework that was represented in this study is merely a holistic view with holistic approach strategies that those four levels represent in order to achieve a successful integration of Industry 4.0 managements.

7.4 Further research

Further research from this study could be the potential of developing a strategic framework for Industry 4.0 transformation within small-medium enterprises separately, and large and international enterprises for itself in order to collect data on the contrast of each other and comparing with different business sectors or industries. Another view that could bring attention towards Industry 4.0 transition is the financial number. Hence future research in this field could be analysing the numbers of potential business growth before and after Industry 4.0 transformation within companies that have been going through transition and would like to make a framework of companies business goals, investments and what they have achieved after integration.

Reference

Bernard, Marr. 2018. *What is Industry 4.0? Here's A Super Easy Explanation for Anyone.* https://www.forbes.com/sites/bernardmarr/2018/09/02/what-is-industry-4-0-heres-a-super-easy-explanation-for-anyone/#60bf3beb9788

Birkel, Hendrik S., Hartmann, Evi. 2019. *Supply Chain Management.* https://www.emerald.com/insight/content/doi/10.1108/SCM-03-2018-0142/full/html

Bonner, Mike. 2017. *What is Industry 4.0 and What Does it Mean for My Manufacturing?* https://blog.viscosity.com/blog/what-is-industry-4.0-and-what-does-it-mean-for-my-manufacturing

Hislop, Donald. 2018. *Knowledge Management in Organizations: A Critical Introduction.* 4th Edition. England: Oxford University Press.

Javaid, M., et al. (2020). *Industry 4.0 technologies and their applications in fighting COVID-19 pandemic.* Diabetes and Metabolic Syndrome Clinical Research and Reviews 14.

London. PWC, Global Industry 4.0 Survey. 2016. *Industry 4.0: Building the digital enterprise.* https://www.pwc.com/gx/en/industries/industries-4.0/landing-page/industry-4.0-building-your-digital-enterprise-april-2016.pdf

Newman, Daniel. 2018. *Four Digital Transformation Trends Driving Industry 4.0.* https://www.forbes.com/sites/danielnewman/2018/06/12/four-digital-transformation-trends-driving-industry-4-0/#4a66e79604ab

New York. Deloitte, Audit Tax. Consulting. Corporate Finance. 2014. *Industry 4.0. Challenges and solutions for the digital transformation and use of exponential technologies.*

https://www2.deloitte.com/content/dam/Deloitte/ch/Documents/manufacturing/ch-en-manufacturing-industry-4-0-24102014.pdf?fbclid=IwAR042jg506let13ih09K65ATWEiRCFpryRrskL5uWoUJAdJ XPoCndvBd5Ss

New York. Mckinsey&Company, Mckinsey Digital. 2015. *Industry 4.0. How to navigate digitization of the manufacturing sector.*
http://www.forschungsnetzwerk.at/downloadpub/mck_industry_40_report.pdf

New York. Mckinsey&Company, Mckinsey Digital. 2016. *Industry 4.0 after the initial hype. Where manufacturers are finding value and how they can best capture it.*
https://www.mckinsey.com/~/media/mckinsey/business%20functions/mckinsey%20digital/our%20insights/getting%20the%20most%20out%20of%20industry%204%200/mckinsey_industry_40_2016.ashx?fbclid=IwAR0jgRxiFT44wFSG8B57k805-J2Wa1Sj9ciWM8iqG_hH8SBuVwa8xnxmhEc

Nwaiwu, F. (2018). "Review and Comparison of Conceptual Frameworks on Digital Business Transformation." Journal of Competitiveness 10: 86-100.

Rojko, A. (2017). *Industry 4.0 Concept: Background and Overview.* pp. 77-90
https://doi.org/10.3991/ijim.v11i5.7072

Schallmo, D. and C. Williams (2018). Digital Transformation of Business Models-Best Practices, Enablers and Roadmap.

Shkabura, Oleksandr. 2019. *The Main Benefits and Challenges of Industry 4.0 Adoption in Manufacturing.*
https://www.infopulse.com/blog/the-main-benefits-and-challenges-of-industry-4-0-adoption-in-manufacturing/?fbclid=IwAR38qShuY7owIUOwJsOrL4G1ggXTomi6gmMhZyp19m rTleqKcPiDV7lEamg

Sue Newell, Maxine Robertson, Harry Scarbrough and Jacky. 2019. *Managing Knowledge Work and Innovation.* 2nd Edition. England: Palgrave Macmillan.

Taj, S., Aziati, A.H, Chuan, L. T., Ahmad, A. N. A. (2018), *An Overview of Industry 4.9: Definition, Components, and Government Initiatives.* Journal of Advanced Research in Dynamical and Control Systems. 10. 14.

Appendix

1. Abubakar, A. M., et al. (2019). *Knowledge management, decision-making style and organizational performance.* Journal of Innovation & Knowledge 4(2): 104-114.

2. Ardito, L., et al. (2019). *Towards Industry 4.0: Mapping digital technologies for supply chain management-marketing integration.* Business Process Management Journal 25(2): 323-346.

3. Büchi, G., et al. (2020). *Smart factory performance and Industry 4.0.* Technological Forecasting and Social Change 150: 119790.

4. Charro, A. and D. Schaefer (2018). *Cloud Manufacturing as a new type of Product-Service System.* International Journal of Computer Integrated Manufacturing 31(10): 1018-1033.

5. Culot, G., et al. (2020). *Behind the definition of Industry 4.0: Analysis and open questions.* International Journal of Production Economics 226: 107617.

6. Ghobakhloo, M. (2018). *The future of manufacturing industry: a strategic roadmap toward Industry 4.0*. Journal of Manufacturing Technology Management 29(6): 910-936.

7. Ghobakhloo, M. and M. Fathi (2019). *Corporate survival in Industry 4.0 era: the enabling role of lean-digitized manufacturing.* Journal of Manufacturing Technology Management 31(1): 1-30.

8. Horváth, D. and R. Z. Szabó (2019). *Driving forces and barriers of Industry 4.0: Do multinational and small and medium-sized companies have equal opportunities?* Technological Forecasting and Social Change 146: 119-132.

9. Kohtamäki, M., et al. (2019). *Digital servitization business models in ecosystems: A theory of the firm.* Journal of Business Research 104.

10. Moeuf, A., et al. (2018). *The industrial management of SMEs in the era of Industry 4.0.* International Journal of Production Research 56(3): 1118-1136.

11. Müller, J. (2019). *Business model innovation in small-and medium-sized enterprises: Strategies for industry 4.0 providers and users.* Journal of Manufacturing Technology Management.

12. Nosalska, K., et al. (2019). *Industry 4.0: coherent definition framework with technological and organizational interdependencies.* Journal of Manufacturing Technology Management ahead-of-print.

13. Schneider, P. (2018). *Managerial challenges of Industry 4.0: an empirically backed research agenda for a nascent field.* Review of Managerial Science 12.

14. Ślusarczyk, B. (2018). *INDUSTRY 4.0-ARE WE READY?* Polish Journal of Management Studies 17.

15. Strange, R. and A. Zucchella (2017). *Industry 4.0, Global Value Chains and International Business.* Multinational Business Review 25: 00-00.

16. Strozzi, F., et al. (2017). *Literature review on the 'Smart Factory' concept using bibliometric tools.* International Journal of Production Research 55: 1-20.