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Doctoral Thesis

Collaborative Robotics in Industry 5.0.

Carried out for the purpose of obtaining Dr.-Studium der techn. Wissenschaften Maschinenbau. Submitted at TU Wien, Faculty of Mechanical and Industrial Engineering, by

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ETHICAL DECLARATION

I, **Mary Doyle-Kent** hereby declare

1. that I am the sole author of the Collaborative Robotics in Industry 5.0 thesis of 306 pages, bound, and that I have not used any source or tool other than those references or any other illicit aid or tool, and

2. that I have not prior to this date submitted a doctorate thesis as an examination paper in any form in Austria or abroad.

Vienna, date 12.02.2021

………………………………
Signature

DEDICATION

I wish to dedicate this thesis to my husband Aidan, and my sons, Darragh, Niall and Pierce.

“If you are striving to be equal to your destiny and worthy of the possibilities that sleep in the clay of your heart, then you should be regularly reaching new horizons.”

John O’Donohue

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I would like to take this opportunity to thank my family Aidan, Darragh, Niall and Pierce who have accompanied me on this road of many twists and turns. Their patience and understanding have made this life's chapter possible.

Thank you most sincerely to my supervisor em.o.Univ.Prof. Dr.techn.Dr.h.c.mult. Peter Kopacek who continues to inspire students from diverse backgrounds over generations.

A special thank you to my mother and late father who believed in me all these years, and, as a child, gave me the gift of independence.

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Finally, to my long list of friends. Marie Coleman who was by my side helping to look after our special son Pierce over the last few years. To Patricia Ryan and John Lawlor, friends from my undergraduate engineering student days and whose generous listening ears I often engage with. To my 'Book-Club Lady' friends who never cease to encourage me and made me laugh all the way to the final chapter.

The global pandemic of Covid-19 has been an enormous challenge to humankind. To me it has brought an opportunity to focus on this thesis with little interruption. We have moved into more of a digital world due to this formidable global threat to humanity. Let us now look forward to rekindling the human connection, albeit in collaboration with digital and automation.

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Abstract

This research investigates how, in a new age of manufacturing, robotics and humans can work together seamlessly. Collaborative robots (Cobots) and their operators (Coboters) are the future of an agile, flexible, environmentally friendly, safe, and efficient working environment. Little work has been outlined to date in the literature describing this relationship, hence there is a unique opportunity to make an academic contribution to this field.

In this thesis, a history of manufacturing has been recounted from the age of the invention of the steam engine right through to our modern day. The advantages and disadvantages of automation, in its many forms, have been discussed. An analysis of how the human worker, in the past, has been forgotten, undervalued, and even made redundant as technology evolved, has been described. By remembering lessons learned from the past, future improvements can be suggested.

It is important that we value the input of humans to enable future generations to be part of Industry 5.0 at all levels. Bringing the ingenuity of humans back into the factories of the future will be the key to improving manufacturing in this new era. Educating our youth and re-educating our more mature citizens will be the key.

The inclusion of diverse populations in the engineering and technology workplace is also important and this thesis looks at the absence of women engineers in Ireland. It also asks the questions why is this important, and how can this diversity be harnessed in the future?

The Irish manufacturing industry is a relatively novice one when it comes to automation and robotics and has evolved since the 1960’s when American multinational manufacturing companies started to establish plants in Ireland. This brings associated challenges in terms of education of the technical workforce. It is widely accepted that every country needs to be forward thinking to remain competitive in manufacturing, and some European countries have the advantage of a rich history in automation and robotics.

This thesis investigates the status of Irish manufacturing companies with regards to collaborative technology. It has a mixed methodology drawing together ideas and theories from the current body of literature and then gathering primary original data from

a case study with collaborative robot specialists and a follow-on survey to collect data from a wider cohort involved in manufacturing.

It is hoped that this research is informative for both industrialists and educators. It aims at gathering a body of knowledge that will contribute to the understanding of automation and human centred systems in manufacturing in Ireland. In addition, this research aims to outline a methodology that can help the introduction of human centred systems into modern manufacturing companies in a manner that will focus on adding value. It is acknowledged that each type of industry has its own specific drivers and priorities, but it is based on common goals that are fundamental to all. Enabling technical managers, professionals, and students, in a step-by-step manner, to achieve this goal is the genesis of this research. The methodology is founded on solid principles and informed by industrial opinion.

Chapter 1. Introduction to Industry 5.0

1.1 Research background

Human beings have inhabited this planet for around 200,000 years. Since the 1760's considerable changes in technology have reinvented how we live, work and play. The lives we live now are quite different to our grandparents' lives. The virtual world is often the substitute for the real or physical world. This is evident in how we communicate, how we educate and even how we design and manufacture products.

Technology also brings challenges. By living virtual lives, we no longer understand or appreciate nature. This leads us to make poor decisions, the destruction of our planet being the most obvious. It is reported by the group World Wildlife that *"runaway consumption has declined global wildlife, triggered by mass extinction and exhausted Earth's capacity to accommodate humanity's expanding appetite."* In the past four decades alone, we have succeeded in reducing the wide animal population by 66%. *"Climate change and plastic pollution are also significant and growing threats. But wildlife is not just a "nice to have" for humans, the report warns, with human food, health and medicines all relying on natural resources. All human economic activity ultimately depends on nature, the report said, with globally natural resources estimated to provide services worth $125 trillion a year."* (RTE, 2018). Without significant intervention in the near future, planet earth will no longer be viable for human life.

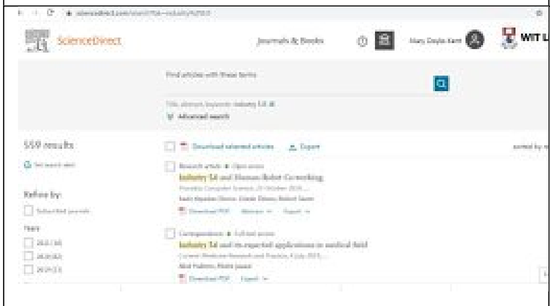
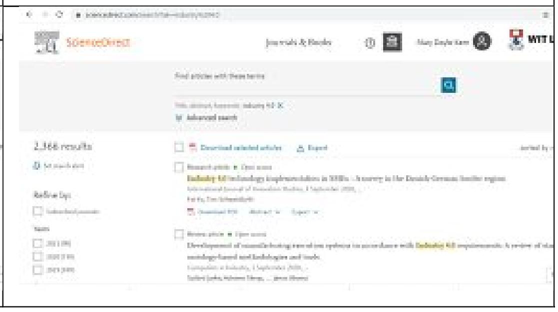
The revolutionary inventions of steam power and electrification have provided opportunities for designing machines that were stronger, faster, more precise, and more efficient than humans. Mass production, automation and digitalisation have completely transformed the world of manufacturing. More recent cyber physical systems facilitate remote design of products and their manufacture. Industry has the possibility of replacing the human completely by the latest trends where robots, artificial intelligence and internet of things are the norm. The fourth industrial revolution is transforming modern industry and most nations are accelerating towards this world of high performance with little understanding of the consequences for the human workforce and nature itself. Natural resources are being wasted in a time of mass production of unwanted, throwaway products.

With the advent of these highly sophisticated manufacturing plants, human input is being made redundant. Human creativity is no longer valued, and there is little room for these ‘underperforming beings’ in such a high-tech environment. Highly intelligent robots bring excellent efficiency, repeatability to manufacturing and can work twenty-four hours per day. The human factor is being removed from day-to-day decision making. Human skills and know-how seem to be no longer required on the factory floor with robots and automated specialised machines. Skills no longer used are at risk of being lost to future generations.

Historically, over the past couple of centuries, manufacturing, and how we make things, has radically evolved. We have moved from local craft-based manufacturing to industrial automation, mass production and globalisation. The importance of the machine and the human in manufacturing has changed and evolved, both taking the lead at different times in history. Up until recently it was difficult to imagine the synchronisation of the human and machine on a factory floor but with the latest evolution in automation this is now a reality: humans and robots can now work side by side, complementing each other’s abilities.

In this research, the ‘post-fourth industrial revolution’, otherwise known as Industry 5.0, was studied. It was established that there was a lack of academic papers in this area. This can be seen in Table 1 which shows that only 559 articles on Industry 5.0 were available on the Science Direct Database whereas 2,366 were available on Industry 5.0 on 19.12.2020.

Table 1 The availability of literature on Industry 4.0 and 5.0 using Science Direct on 19.12.2020.

Industry 5.0 advanced search in database Science Direct on 19.12.2020. 559 articles.	Industry 4.0 advanced search in database Science Direct on 19.12.2020. 2,366 articles.
	

The main source of information available was found on internet blogs and websites. Published books point out the potential risks associated with Industry 4.0 but do not offer any vision of what will happen after the robots, artificial intelligence and the Internet of Things displace the human in manufacturing.

In the Literature Review in this thesis, the historical journey that brought us to this technological juncture was reviewed. It also projects into the future in an attempt to understand how humans can be reintegrated into the manufacturing industry. Humans, given the opportunity, can bring their ingenuity, creativity, valuable skills, and ethics into an environment which is increasingly being controlled by artificial intelligence and robots. It establishes why human intervention is necessary in the decision-making process and how collaboration between 'man and machine' will be essential going forward, outlining how advanced technology should be used as a platform, and not a replacement for humans.

The fifth industrial revolution will be based on this concept of human centred systems, bringing the best of automation and the best of humans together, to optimise production. An interesting and important evolution in manufacturing is collaborative robots, or Cobots, working in harmony with human operators, or Coboters. Cobots of various formats have been in existence for over 30 years now, the most basic were hand guided machines. They are designed specifically for interaction with humans and the evolution of modern technology has facilitated a revolution is this area. There are many different types of Cobots commercially available from several different manufacturers worldwide at this point in time.

The modern manufacturing environment will require both robots and humans to collaborate and work together harmoniously, each bringing their positive attributes to the table. Anecdotal evidence suggests that industrialists are finding it more and more difficult to find the appropriate staff for this high-tech working environment. When staff are hired and trained, a significant investment is made. It is a high priority of companies to keep the staff long term. Favourable working conditions and an opportunity in career development are essential to keeping staff engaged and motivated. Opportunities are now opening up in the field of automation using collaborative robots and Coboters.

Since March 2020, the world has been plunged into a global pandemic due to the highly contagious and dangerous Covid-19 virus. This has resulted in working remotely for millions and for those who are required to work on site, social distancing is a health and safety requirement together with following individual national health guidelines. In terms of manufacturing, Cobots offer a social distancing solution. They can take the place of a human and collaborate safely on a manufacturing line. This solution has far-reaching advantages in the pandemic and is gathering interest and attention in Ireland.

There are many obvious advantages of Cobots and Coboters working together in a modern plant; health and safety improvements, increase in quality and repeatability of the product, improvements in working conditions, flexibility, low cost of the Cobot and excellent return on investment are just of them. A high number of multinational companies are already using this technology to improve competitiveness but the challenge going forward is to engage and entice small to medium size companies. How can these smaller companies invest in collaborative automation if they cannot see the opportunities either strategically, financially, technically or in terms of how to improve their workers job satisfaction? Is there a way of empowering management to see the opportunities on a case-by-case basis?

This research focuses on Irish manufacturing industry as a case study. This is because the researcher is Irish, living in Ireland, and working as a lecturer in a third level Institute. Some of the questions put forward in this research are: what are the main drivers and roadblocks to evolving this industry into a human-centred, collaborative, high-tech manufacturing environment? How can education play a role in upskilling the current employees of these firms? How can future engineering graduates obtain the required skills to integrate collaborative robotics in an ever-changing highly technical manufacturing environment?

1.2 Research Objectives

This thesis focuses on the adoption of collaborative robotics in Irish manufacturing companies. The study used a mixed methodology. Firstly, an in-depth Literature Review was undertaken to gather the secondary data. Secondly, primary data was gathered in the form of a two-step approach by undertaking case studies and then constructing a questionnaire which was distributed to technologists working in the manufacturing industry. As the research unfolded over a number of years, a series of academic papers were written by the author and presented at the International Federation of Automatic Control (IFAC) and the International Symposium of Production Research (ISPR) conferences, and, subsequently published. These papers have been included in the appendices. Publishing throughout the research aided the researcher by having the work peer reviewed by experts in the field, throughout the process of writing.

By both looking back into the history of previous industrial revolutions and at current technologies either available or emerging, and, by critiquing the roles that humans have played in all these scenarios, several research questions emerged on the future of manufacturing. This was the subject of a published academic paper in ISPR 2019. (Doyle Kent, M., Kopacek, P., 2019).

Social scientists bring an understanding of work and its importance to humans. This was considered in this research along with the evolution of work throughout the decades. Organisational culture, workplace values, vision, priorities, and leadership norms were looked at and an understanding of safety in the modern manufacturing workplace was considered. The education of engineers, technicians and operators was considered in two publications co-authored by the author. (Kent, M.D., et al., 2018) and (Costello, O., et al., 2019 (a) and (b))

Researchers have, over many decades, understood the critical role that humans play in the modern manufacturing engineering workplace, alongside automation and technology. An important element of this research was to investigate and understand this body of thought. Professor Mike Cooley has made contributions on human centred systems in manufacturing, and his work, together with others, was reviewed.

Consideration of the social and ethical aspects of automation was investigated in an academic paper. Its main goal was to look at 'state-of-the-art' and future development trends in this field. Special emphasis was given to new approaches required for advanced robots and automation, including the evolution of educational and legal requirements. This material was published in an academic paper in ISPR in 2020. (Doyle Kent, M., Kopacek, P., 2020 (b)).

Another discussion in this research is how to include a more diverse community into the modern manufacturing plant and one way of doing this is to bring more minorities into engineering. A niche area is to bring more women into the engineering community in Ireland. Part of the Literature Review looks at the lack of women in engineering in Ireland and how to remedy this into the future. (Kent, M.D., et al., 2019) (Kent, M.D., et al., 2020) and (Bula, I., et al., 2020)

The author proposes a set of guiding principles which are based on the work of several well-known academics in this area. These include Jesuthasan and Boudreau who look at reinvention work by introducing high value to the human-automation relationship in the workplace, Mumford who is a renowned author in human system designs and Cooley who is renowned for his work in the area of socially useful human centred manufacturing.

These guiding principles were published in an academic paper in the ISPR 2020 conference in Turkey (Doyle Kent, M.; Kopacek, P., 2020 (a)).

1.3 Research hypothesis and questions

An hypothesis was formulated to help the researcher establish a focus. This was then broken down into four research questions. The hypothesis and questions were established after an initial Literature Review of state-of-the-art Industry 4.0 and 5.0. They are as follows:

Hypothesis Industry 5.0 will be a symbiosis of the technological advances of Industry 4.0 and a highly skilled creative workforce to create a human-centred workplace which generates personalised high-value and high-quality products.

Question 1.0 What would an Industry 5.0 conceptual framework look like?

Question 2.0 Can collaborative technology play a role by enabling humans and robots working together in Industry 5.0?

Question 3.0 Can a set of guiding principles be developed to aid with the introduction of human centred automation in modern manufacturing companies?

Question 4.0 In Industry 5.0 can a highly skilled creative workforce be established to work in a human centred workplace, which generates personalised high-value and high-quality products?

Primary data was gathered using a mixed model approach starting with case studies in the manufacturing industry in Republic of Ireland. Specialists in collaborative technology were consulted initially to gain an understanding of this state-of-the-art technology. And finally, a comprehensive survey was developed to collect data around the industries' experiences of collaborative technology.

1.4 Academic scholarship

Globally we are currently in the fourth industrial revolution or Industry 4.0. This term was introduced in Germany. There are thousands of academic papers and studies on Industry 4.0 including the specialist areas of internet of things, IoT, Big Data Analytics 3D printing, Advanced (autonomous) Robotics, Smart Sensors, Augmented Reality, Cloud Computing, Energy Storage, AI or Machine Learning, Nanotechnology, Human Machine Interfaces, Mobile Devices and Cyber Security (Hallward-Driemeier et al., 2017).

Looking forward to the fifth industrial revolution, there is extraordinarily little literature available because it is effectively looking into the future. This research focuses on human-centred automation in manufacturing. In terms of academic scholarship, it has developed a conceptual framework to encompass the main elements of Industry 5.0. The aim of this framework was to illustrate that multiple factors need to be considered in an Industry 5.0 human centred systems approach. These factors are intertwined and influence the adoption of the overall system.

Industry 5.0 will be highly automated but there is a risk that the human will become redundant unless they can upskill to the high technical level necessary to interact with this automation. Education is critical so this research looked at how humans can be upskilled in this ever-changing dynamic environment.

One important subset of robotics emerging now is collaborative robotics. Their operators can work side by side these robots and can hand over the repetitive, difficult jobs to them. Human work, as a result, has changed and the work has higher value and is less physically demanding, as well as being safer. This research looked at the human robotics interface, the relationship between the collaborative robot and operator and evaluated what the drivers for implementation are.

The design of socio-technical system is complex. Another aspect of this research was to find a protocol to assist small to medium firms with the transition to automated and semi-automated systems. The focus was to redesign the work by optimising the human element, in line with the company's strategic values. One key finding was that to be successful this new system had to take the human needs seriously and make them central to the system design in Industry 5.0.

1.5 Theoretical Proposition

A theory has been defined as *"A set of interrelated constructs (concepts), definitions, and propositions that present a systematic view of phenomena by specifying relations among variables, with the purpose of explaining and predicting phenomena."* (Kerlinger and Lee, 2000: 9). A significant part of any doctoral research is an understanding of the theoretical relevance of the work undertaken.

"Ontology is the study of being, that is, the nature of existence and what constitutes reality. So, for example, for positivists the world is independent of our knowledge of it – it exists 'out there', while for relativists and others there are multiple realities and ways of accessing them." (Gray, 2018) In addition to understanding, Gray describes epistemology as *"what it means to know."* As Easterby-Smith et al. (2008) point out, having an epistemological perspective is important for the following reasons:

- In terms of research design, it clarifies problems. What is the structure of the research and what evidence is being collected?
- How is the aforementioned research going to be interpreted?
- Understanding the research philosophy helps understand what design will and will not work.

The ideology in this research is pragmatism. According to Rorty, pragmatism is true only if it generates practical consequences for society. Hence, pragmatists focus not on whether a proposition fits a particular ontology, but whether it suits a purpose and is capable of creating action (Rorty, 1998).

A belief, according to Gray, is true if it facilitates improvements in living standards, technology, democracy and so on. Kelemen and Rumens in 2012 state that the ideology of pragmatism has struggled to maintain its influence beyond the first three decades of the twentieth century but since the 1970s, according to Onwuegbuzie, it has regained some of its popularity. This is seen to be because of the insights it has given into research undertaken in the area of management and organisations.

Pragmatism is seen by some to provide an epistemological justification for mixing approaches and methods (Onwuegbuzie et al., 2009). While in pragmatist research, research paradigms can remain separate, they can also be mixed or combined into another research design. Hence, pragmatism views the mixing of quantitative and qualitative data in a single study not only as legitimate, but in some cases necessary. (Gray, 2018)

In summary, a pragmatist approach is taken in this research study because it generates positive outcomes for society, and this is the most important objective of this study.

1.6 Chapter 1 Summary

This introductory chapter brings together the research background, research objectives, hypothesis, and questions. The background to the research describes how technology has transformed how we live on planet earth, and how industrial revolutions have played a significant role in this. Not all the changes and transformations are positive. It is noted that automation has had the effect of radically changing the role of the human in industry.

Often the all-important skills of the human have been made redundant due to this technology. In the past decade, innovations in collaborative technology mean that there is now potential for a new industrial revolution, Industry 5.0, to emerge. Here, humans and Cobots will work side by side in a mutually beneficial manner, building on the foundations of Industry 4.0. There is very little written in the literature on Industry 5.0 at the moment.

This research focuses on Irish manufacturing industry as a case study and a mixed methodology approach is used. During the course of this study, seven academic papers were written to present concepts and ideas to the research community for peer review.

A research hypothesis was established, and this gave rise to four research questions. The final elements of this chapter are the description of academic scholarship of this work and the theoretical proposition. The academic scholarship looked at the important debates around Industry 5.0. A pragmatic approach is taken in this research as the overarching objective is to generate positive outcomes for society.

Chapter 2. Vision of Industry 5.0 and the state-of-the-art Model.

2.1 Introduction to the new Technology

The personalisation of products and services is now a reality. Our cities have become more connected and smarter. All around us the division of work between machines and humans is changing and is continually being redefined. Everyday examples of technology transforming how we live our lives are to be found routinely, for example, in the areas of buildings, manufacturing, transportation, healthcare, logistics and many other industries. This is the world of Industry 4.0. There is considerable interest in these new and emerging digital connected technologies globally, and a vast amount of literature is becoming available on how to use these new technologies to improve quality of life as well as optimising the use of key resources.

In June 2017, the European Commission held a conference to look at how to leverage these new technologies across multiple areas, including digital manufacturing, agriculture, smart healthcare, energy, and smart homes and connected and automated driving. It is clear from Figure 1 that platforms necessary to support these digital technologies need to be designed and piloted so that they are standardised, interconnected and can work on a global level.

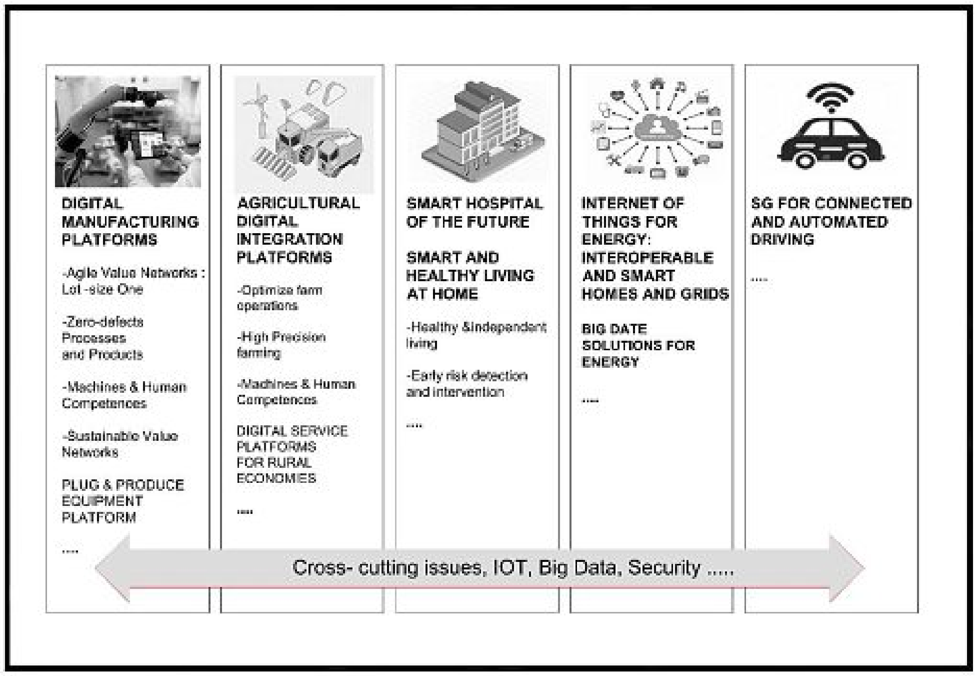


Figure 1 Adapted from the European Commission Topics pan-European platform-building and piloting. (Lemke, M., et al., 2017)

"Plug and produce platforms" are critical. From Figure 1 each area has its own critical requirements, but they are connected by the common denominators of the internet of things (IoT), big data, cyber security, and artificial intelligence. In terms of the digital manufacturing, the key topics which emerged from the conference were:

- agile value networks: lot size one
- zero defects processes and products
- machine and human competencies
- sustainable value networks

The term Industry 4.0 (or in German Industrie 4.0 or I4.0) is widely used but not well defined. The result of this is that it is difficult for both industry and academia to implement this new technology into manufacturing, both on a theoretical and practical level. Nonetheless, Industry 4.0 is widely seen as an important route to strengthening global competitiveness at a national level, and improving profitability, at a corporate level. Both are enabled by production or manufacturing optimisation at a company level.

2.1.1 Industry 4.0. worldwide priorities

In October 2019, the German Research Council published a paper titled "Key themes of Industrie 4.0". In its opening paragraph, Hirsch-Kreinsen et al. stated that *"by making Industrie 4.0 a reality, digitalisation is enabling a fourth industrial revolution. This root-and-branch change in terms of new technologies, patterns of work and corporate organisation, business and revenue models, value networks right up to dynamic digital ecosystems has the potential to have all-encompassing social impact which is, as yet, difficult to grasp in its entirety. The use of cyber-physical systems (CPS) and their tight interconnectedness underlie this transformation."* (Hirsch-Kreinsen, 2019)

He continues to state that *"supply, manufacture, maintenance, delivery and customer service can all be interlinked and convert rigid value chains into highly flexible value networks. Industrie 4.0 here describes a new stage in production and in the organisation and control of the entire value chain over a product's life cycle. For example, smart products can actively direct the production process. Devices autonomously initiate actions and define the next working steps. Sophisticated analysis of the data generated as a consequence combined with Artificial Intelligence (AI) means that processes can be analysed and optimised in real time. Criteria are, for example, costs, availability, or consumption of resources. There is also new potential for designing and implementing* *innovative business models."* This interesting definition gives an insight into how products are conceived and manufactured using Industry 4.0.

Worldwide, the focus of Industry 4.0 in different countries varies greatly, and countries are at various levels of 'readiness', that is, ready to implement I4.0 technologies into manufacturing plants.

Germany is recognised as the world leader of these technologies and is focusing now on integrating information, communication, and manufacturing technologies in smart, self-organising factories. The focus for Germany's drive is to excel in smart factories and smart manufacturing. Several major companies behind this drive include Siemens, Bosch and ThyssenKrupp and ABB robots.

In contrast, in the USA, and increasingly in China, the focus is on smart products, internet platforms and the new business models that are based on these technologies.

According to a report published by a consortium in Germany titled "Industrie 4.0 International Benchmark, Options for the Future and Recommendations for Manufacturing Research", Gausemeier et al. state that the USA are focusing on the business side and on the implementation of intelligent technologies. This development has been called the Industrial Internet of Things. This is driven by pragmatic advantages and value for the customer and is enabled by Silicon Valley. Radical innovation, due to existing competences and the available innovation systems in the field of data-driven services, is pushing digital products into the physical world. Since 2011, the ambition in the USA was to become a leader in manufacturing again after years of outsourcing, primarily to Asia and other South American countries. Cisco, General Electric, IBM, Intel and AT&T are some of the companies leading the way.

The focus of Europe, and, in particular, Germany, is on the implementation of strategic concepts. With a strong technical foundation, the challenge in Europe is to balance the opportunities of digitalisation in industrial value creation with the needs of a human-centric world of employment. Europe sees I4.0 as a socio-technological challenge. Reclaiming industrial competitiveness is critical in manufacturing as well as the preservation of sustainable careers.

The German “High-Tech-Strategy” or the French “La Nouvelle France Industrielle” are examples for corresponding European initiatives, as are, “Made Difference” in Belgium and “Fabbrica del Futuro” in Italy.

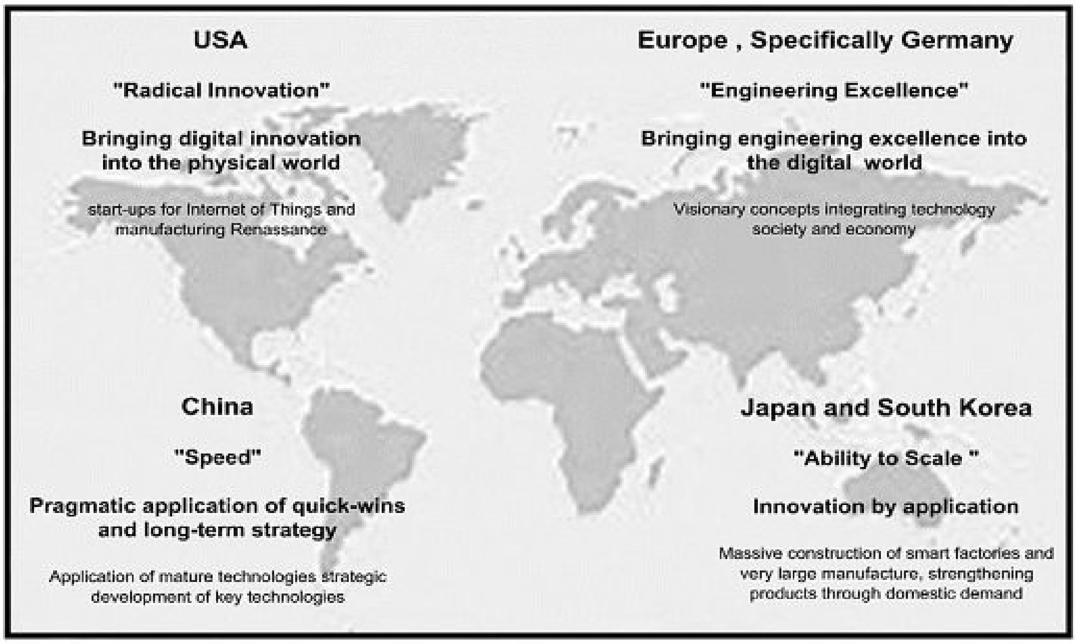


Figure 2 Adapted from current focuses of selected countries and regions in the context of Industrie 4.0 (Gausemeier et al., 2016)

Japan and South Korea have different goals. They are working on establishing strong local engineering corporations as “networked manufacturing systems”, in the first place internally, in their individual countries. When these are established, smart manufacturing will move into vast economies of scale and their governments are supporting this initiative. Japan's focus is on artificial intelligence and robotics. Japan aspires to address its problem of an aging population with I4.0, and it is a rapidly occurring problem for this country. Companies such as Mitsubishi, Fujitsu, Panasonic, Toyota, and Canon are playing a major role. Programmes supporting the construction of 10,000 smart factories in Korea are underway and this, in turn, will facilitate the planned economies of scale for the smart technologies’ implementation.

China's goal is to become a leading nation in manufacturing with indigenous innovations and total self-sufficiency. Its focus is very much on the smart factory, smart manufacturing, sensors, and robots. In China, the low level of automation is slowing down the implementation of I4.0. *“Catching up to global competitors in key technologies of advanced manufacturing is part of a national strategy. The overarching goal of all Chinese activities is maintaining the global leadership role in manufacturing and associated jobs, whilst at the same time, raising the standard of living to the level of other* *industrialised countries."* (Gausemeier et al., 2016). Consortiums and programs are being formed, such *as "Made in China 2020-2025"* which is a smart industry innovation alliance that brought together Stasun, Shenyang Blue Silver, Shanghai STEP and Shenyang Machine Tool.

2.2 Industry 4.0 and Smart Manufacturing

2.2.1 Definition

One on-line source refers to smart manufacturing (the fourth industrial revolution or Industry 4.0) as a manufacturing environment where systems are fully integrated and collaborative. It responds in real time to changing demands, which are driven by customers' requirements. It extends to the supply chain network from customer, to supplier, to factory floor. It is an information intensive manufacturing environment. This connected environment consists of data, people, processes, services, systems, and the Internet of Things (IoT) enabled industrial assets. Information is critical, its generation, its leverage, and the utilisation of this actionable information, enables smart industry, its ecosystems of industrial innovation and collaboration, to thrive. (I-Scoop.eu, 2019)

2.2.2 Elements of I4.0

Before the hyper-connectivity of systems, manufacturing systems often operated in a standalone manner. Machines and people used paper, manual and semi-automated systems to run machines with little or no feedback and optimisation. The fact that Industry 4.0 machines are connected to the IoT means that all the data that is being generated by connected sensors can be captured, processed, and used to optimise processes and plants. This data can be retained and used to benchmark best practice.

This new smart way of manufacturing is enabled by increasing levels of automation, cyber physical systems, digital twins, and the intensive use of data analytics. It is driven by modern industrial and societal challenges and evolutions, and the integration of information and operational technology. It is widely accepted that Industry 4.0 is made up from the following five core elements**:**

- **ICT** – IoT, cyber security, cloud computing, big data artificial intelligence and wireless systems.
- **Connectedness** – simulation, digital twin, and systems integration.
- **Sensors** – built in intelligence, real time capability, traceability and completeness.

- **Robotics** – High flexibility, intuitive operation, human robot cooperation and intelligent control.
- **Innovative production systems –** complete cross linkage, augmented reality, cyber physical systems, self-configuration, and additive manufacturing.

In 2017, Hallward-Driemeier et al. reported on future trends in manufacturing for the World Bank Group. On page 95, in a chapter entitled "Trends Shaping Opportunities for Future Production", the technologies associated with Industry 4.0 are listed in descending order in Table 2.

Table 2 Industry 4.0 Technologies (Hallward-Driemeier et al., 2017)

IoT
Big Data Analytics
3D printing
Advanced (autonomous) robotics
Smart Sensors
Augmented Reality
Cloud computing
Energy Storage
AI or Machine Learning
Nanotechnology
Synthetic Biology
Simulation
Human Machine Interfaces
Mobile Devices
Cyber Security
Quantum Computing
Horizontal and Vertical Integration

They emphasise that emerging technologies will influence manufacturing exports. The location of the production facilities of advanced high-tech products will be beside research and development facilities in high-income economies. This is because of the advanced skills-set and infrastructure which is required throughout the product's value chain.

For the middle-and-lower-income countries, a major impact will be new manufacturing process technologies that will be used to manufacture the more traditional products. *"The focus here is on robotics, (particularly artificial intelligence. [AI] - enabled); digitisation and internet-based systems integration, including sensor-using "smart factories" (that may also be AI-enabled) and 3D printing".* (Hallward-Driemeier et al., 2017)

Haverkort et al. describes the research and innovation areas being focused on internationally in a journal article published by IEEE in 2017. They are:

- ***"Internet-enabled decentralised monitoring and control algorithms*** *that improve product and production-process performance.*
- ***Improved supply-chain management techniques****, utilising data acquired locally and globally.*
- ***Machine-learning algorithms and big data*** *analytics to improve the efficiency of industrial processes and to support predictive maintenance.*
- ***Effective, reliable, and secure data collection and sharing****.*
- ***Wireless sensor networks to monitor production processes and products.***
- ***Adaptive production techniques to address material diversity and individual customer wishes****.*
- ***Cloud-based generic services that enable the transfer to smart industries****.*
- ***Dependability, security, and privacy issues of the IoT.***
- ***Application-specific issues*** *regarding smart grids, production and manufacturing systems, transportation systems, and civil infrastructure".* (Haverkort et al., 2017)

Central to Industry 4.0 are embedded systems and software intensive systems which are found in high-tech components and products. There is an increasing connectiveness in the global network which enables the potential of Industry 4.0. Basically, the higher the number of units with embedded software, the greater connectedness of cyber physical system through sensors, which, in turn, will generate greater data volume. For example, radio frequency ID tags are used to supervise billions of transportations moves of automated guided vehicles. This is an example of a cyber physical system connecting seamlessly to the IoT. These systems are the connection between the cyber and physical worlds. They have three important elements: the sensor and processor to collect and gather the data, the communication element to communicate commands and the acting elements, for example, a robot or machine that can act on the environment.

The Industry 4.0 factory is connected in a similar manner with sensors and processers, communication devices and acting elements. Cyber physical systems connect the physical world seamlessly with the virtual world. This type of system comprises of sensors which gather data from the physical world (for example, vibrations on a milling machine). It has a communication system which can communicate data and commands (cyber) to the actors like robots or other machines which can act on the physical environment. Workers can be connected to the cyber physical systems by smart phones or tablets. Decentralised optimised decisions can be made which can involve machine usage, movement of stock, control of the environment and so on. Ultimately, this means decentralised planning and control of manufacturing processes, using real time information which accelerates decision making, resulting in the improved efficiency of plants. In addition, embedded systems in products connect the physical use of the product to the manufacturers using transmitted data from sensors. This loop can improve both the use of the product remotely, and its service life. It can also inform the manufacturer on how to improve the design of the product in future generations meaning a higher degree of adaptability and individualisation, and ultimately self-organisation.

2.2.3 Smart manufacturing

In 2017, Lalanda et al. state that manufacturing systems traditionally have two software systems. These systems have limited interactions and are usually located in different areas of the facilities; one in the production area and the other in the IT area. *"On the plant floor, field devices control local operations, collect data, and monitor the local environment. Control systems are used for acquisition and supervision of high-level data. The IT level provides supporting software, including for instance business processes, enterprise information systems, and data analytics."*

Industry 4.0 operates is a very different way to the conventional automated pyramid system. One of the major challenges is to understand how to transition older, traditional, less flexible technologies with the newer, more flexible ones. At each level and stage in manufacturing the focus changes. Table 3 shows in summary the change of focus.

Table 3 Comparing traditional manufacturing to smart manufacturing or Industry 4.0

Traditional	Industry 4.0
From a component level the focus is on precision.	From a component level the focus is on precision and comparison to a digital twin.
From machine level, the focus is on quality and productivity.	From a machine level, it is about a self-aware or self-compare and self-predict.
From a production system level, the focus is on efficiency.	From a production level, it is about a self-configuration and self-optimisation, eventually achieving an automated, optimised, self-regulating production facility.

By its very nature, Industry 4.0 builds on the connectivity of all systems. *“Field devices and control systems are horizontally networked and vertically connected to supporting software”.* As a result of the integration, specific orders can be placed and managed individually. There is scope to look at alternative ways to achieve manufacturing objectives. This allows the systematic oversight and improvement of production activities. Enhanced connectivity brings great benefits but also raises formidable challenges, calling for new architectures and techniques. (Lalanda et al., 2017).

Greater digitisation will shift production to smart factories. They use IoT (use of sensors, actuators, and data communication technology to build physical products), not just to automate production but to communicate and share information, thus optimisation of the value chain.

According to Hallward-Driemeier et al. *“These factories have two salient features: The first is the physical-to-digital technologies embodied in their machines and the equipment that enables sensing, monitoring and control. The second is communication between the two disparate parts of the value chain”.*

“Further investigation and application of existing and new technologies are fundamental to the ongoing development of industry 4.0. It is apparent from the first initial steps into industry 4.0 that it is no longer only developments in production, information and communication technologies that will form the vision of networked production. Instead, the future will be marked by transformation via flexible, modular production systems to

autonomous, learning systems. These systems will self-program, self-organize, set and adapt new requirements for themselves and self-optimize". (Hirsch-Kreinsen et al., 2019).

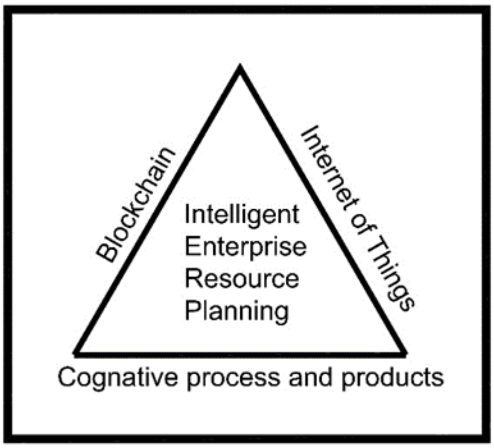


Figure 3. Adapted from future embedded intelligence in Industry 4.0 manufacturing. (www.Infineon.com, 2019).

Smart, connected systems are changing the way products are manufactured. In Industry 4.0 factories, most of the systems will be automated and machines will be able to communicate with each other and make decisions on their own. They will use sensors, "their sensory organs", to collect data, which is then filtered before being passed on to a platform.

The intelligent or smart system in Figure 3 can be seen as "the brain", the place where the *"machine data is pooled with information from other sources, such as ERP applications or the environment. The data is analysed to allow actions to be taken".* (www.Infineon.com, 2019).

Hirsch-Kreinsen states that the future markets will be volatile and complex. Production facilities will need to be flexible, modular, adaptable, and sustainable. They will replace the capital-intensive inflexible facilities of the past. One important feature is the flexible systems architecture required for these systems. (Hirsch-Kreinsen et al., 2019)

2.2.4 Implementation of smart manufacturing

Schumacher et al. in 2016 stated that companies find it difficult to grasp both the concept of Industry 4.0 and what is involved for successful implementation. This experience comes from several strategic orientation workshops that they carried out over a number of years. Companies find it difficult to relate Industry 4.0 to their area of manufacturing and also to their business strategies. In addition, companies failed to determine their "state of development" or in other words "how ready were they to move forward?" This stops them focusing on practical areas to work on, which, in turn, delays progress. *"To overcome growing uncertainty and dissatisfaction in manufacturing companies regarding the idea of Industry 4.0, new methods and tools are needed to provide guidance and support to align business strategies and operations".*

The authors then went on to develop *"A maturity model for assessing Industry 4.0 readiness and maturity of manufacturing enterprises"*. The maturity model evaluation has three steps:

- **Step one:** Measurement of relevant I4.0 items in the enterprise via questionnaire.
- **Step two:** Calculation of maturity level in nine dimensions which is software supported.
- **Step three:** Representation and visualisation of maturity via maturity report and radar charts.

The result of the evaluation is a dashboard showing the summary information from the maturity analysis of the company over the nine key dimesions. This summary is followed by a detailed breakdown of the dimensions with concise information in each area. This then led to recommendations for strategic decisions and the definition of specific projects and programs for the company. (Schumacher, A., et al., 2016)

The aim of Hermann's paper in 2016 was to use a quantitative text analysis and a qualitative literature review to identify four "design principles" which assist both academics and industrialists in understanding the scope of Industry 4.0 as well as offering implementation strategy using scenarios. (Hermann, 2016)

The four design principles found by Hermann et al. to guide industrialists and academics on the implementation of Industry 4.0 were found to be *"interconnection, information transparency, decentralised decisions, and technical assistance".*

The authors continued to define each of the four principles and explain their role in Industry 4.0 explaining that the literature was from industry (practical) and academia (theoretical).

Human-machine collaboration, data and information security are the most frequently discussed topics in the industry publications. Hermann states that these pose major challenges to industry.

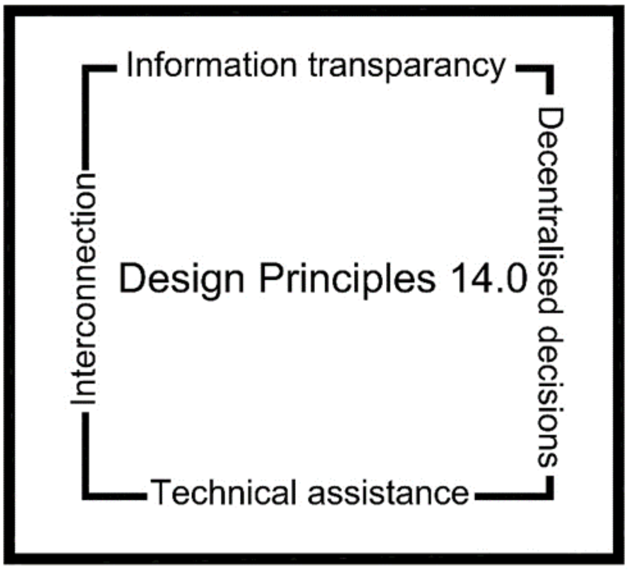


Figure 4 Adapted from Industry 4.0 design principles adapted (Hermann, 2016).

Decentralised decision-making as a key principle of Industry 4.0 and is seen as the most disruptive element, thus requiring extensive investigation and discussion.

- **Information transparency**
  As the number of connected entities increases, the physical and virtual worlds begin to replicate each other. This results in a new type of information transparency, and digital twins can be created. A digital twin is a digital model of the physical world created from sensor data which is linked to the physical world that created it. Examples are electronic drawings and documents as well as models and simulations. Machine tool data can be sent from a sensor and analysed. The data analytics can then be used for process optimisation if accessed in real time.

- **Decentralised decisions**
  With the IoT, the interconnection of objects and people and transparency of information, decentralised decisions can be made from both within and outside the manufacturing plant. Global decision makers can base decisions on real time data which helps improve the productivity and profitability. Cyber-physical

systems facilitate decentralised decision-making. The physical plant can be controlled remotely by using data from the embedded sensors and real time data analysis.

Caldarola et al. introduce the idea of industrial symbiosis where cross-company cooperation of different factories happens in Industry 4.0 to facilitate competitive advantage by trading and exchanging products, materials, energy, resources, and information. (Caldarola, E. et al., 2018)

Another important intelligent system used in manufacturing is Manufacturing Energy Management System (MEMS) mentioned by Jardim-Goncalves et al. in 2016. Here, data collected is used to improve energy usage during manufacturing. Energy consumption monitoring depends on where the monitoring devices are placed: on a machine on a process or on the factory floor. The data produced can be used to find action points for energy reduction. The use of IoT and intelligent electronic devices can optimise energy consumption.

Doyle-Kent et al. in 2016 outlined a case study in a research titled "Efficiencies through the automatic control of age-profiled manufacturing machines: A case study of cost-saving in an Irish production facility". The study looked at the consumption of energy and oil in Computerised Numerical controlled machines, both at rest and working. A low-cost meter was used to record energy data automatically and continuously with three sensor clamps attached to the three phases of a machine. This data was sent to a transmitter connected to the internet and the performance of the machines were logged over time. The finding shows that these two variables, when profiled against machine age, could be controlled in such a way as to significantly reduce production costs and emissions. (Doyle-Kent et al., 2016)

- **Technical assistance**

  In the connected world of smart manufacturing, the role of the operator, technician, engineer, and manager changes. Cyber-physical systems are more complex, and the human must become the flexible problem solver and strategic decision maker. To this end, the human relies on an assistive technology in the decision-making process as they are making decisions remotely. Tablets and smartphones are used to visually transmit information to the human and connect them to the processes. In the future, it is predicted that wearable technology will take over this space. Technical assistance is also provided by robotics. There is a vast range of robots available currently from collaborative to wearable robots. A human can programme the robot to undertake work that is unsafe, too difficult, or unpleasant to the human. Robots must be intuitively programmed and be safe to use. An important element of Industry 4.0 is the human machine collaboration.

- **Interconnection:**

  People, sensors, devices, and machines are interconnected by the internet of things. The internet is accessed using wireless sensors which facilitates the interconnection of people and machines. Three types of collaboration are possible; human – machine, machine – machine and human – human but to facilitate this common communication standards are necessary. These types of standards will allow machines from different vendors to communicate also. The requirement for cybersecurity is essential for the safe operation of these modular systems.

  The need to facilitate machine - machine connectivity has accelerated the development IoT platforms. In fact, Brynjolfsson and McFee in 2014 predict that machine - machine connection will increase from two billion connections in 2012 to 12 billion in 2020. Hobbs, Manyika and Woetzel in 2015 value the IoT market at 19 trillion. (Jardim-Goncalves et al., 2016)

2.3 Smart Products

Caldarola et al. describe how the closed loop lifecycles of products helps manufacturing systems to deliver high quality upgradeable and reusable future products at affordable prices to the global market. This is called Industrial symbiosis. (Caldarola, E., et al., 2018)

Products that are considered smart are at the centre of Industry 4.0. As mentioned previously, products that have been built in an intelligent manner can, in real time, direct how they are actually manufactured. They autonomously initiate actions in the manufacturing sequence. They can generate data and this data can be analysed and optimised in real time using AI over their working life.

Intelligent products can always be located and identified. Their history is recorded, and their status is known and information on alternative ways of manufacturing the product is available. *"Intelligent production systems are connected to company's business processes, IT-systems and to the entire value chain in the production network. This enables real-time control and optimisation of the value chain, starting with an order to the final delivery of the product. The convergence of the physical world and the digital world with CPS enables the new paradigm of autonomous and decentralised production".* (Gölzer, P., et al., 2017)

There is a wide variety of information available on the individual product including quality data and process parameters. The product information stream is connected to the product itself, to the customer order, to the machines it has been produced on and to the shop floor order. This data is available and can be easily accessed and analysed in the form of its digital twin. In addition, both the supplier and the customer can be accessed from the shop floor and machine level. This brings a new level of meaning to the term traceability.

According to Jardim-Goncalves et al. in 2016 real world smart objects and sensor networks are considered the lowest layer in a layered IoT framework. These cyber physical systems produce continuous data. In the next layer, the information integration layer, the real-world data is converted into a computational model. The layer above this is referred to as the situational awareness model and is responsible for the integration and implementation of data. Here, data collected from the lower layer is converted into useful information to be used in an upper layer. The result of well-defined interfaces is a seamless flow of data and actions. (Jardim-Goncalves et al., 2016)

2.4 Smart Employees

The view of Gausemeier et al. in a report in 2016, is that the focus of the European Union is on the implementation of strategic concepts. They continue to say that it is important to balance digitisation with human-centred world of employment. *"Industry 4.0 is seen as a socio-technological challenge"*. It is vital to reclaim manufacturing competitiveness, but the creation and preservation of sustainable jobs is also critical. Examples of two governmental strategies are given. In Germany, *"The High-Tech Strategy"* and in France, *"La Nouvelle France Industrielle"* are mentioned. (Gausemeier et al., 2016)

Caldarola et al. put the idea forward that the real value creation in Industry 4.0 is innovation process. They state that in order for European industry to flourish, the workforce needs to have the correct skills. They highlight that one of the key priorities of the "Factories of the Future 18-19-20 Work Program" is the focus on human factors. The development of human competences must be in synergy with technological progress. They outline the two enablers of this as:

- *"Models for individual and collective sense-making, learning and knowledge accumulation.*
- *Workers interconnection with machines, processes and development of context-oriented services towards safety practices and decision making."* (Caldarola, E., et al., 2018)

The learning or teaching factories are then seen as centres of excellence for this approach and are becoming more widespread across Europe.

The role of the employee has been transformed in the Industry 4.0 environment. Traditional roles in manufacturing either no longer exist or have been transformed dramatically. This is true at all levels, white-collar workers, blue-collar workers and all the way up to senior managers.

On the factory floor, the cyber physical systems can schedule, order raw material, load the tooling, move the work-in-progress from workstation to workstation, assemble the final product, do the quality control checks and package the final product. The worker is responsible for maintaining the cyber physical system and resolving extraordinary problems that may arise. This, in turn, requires the worker to be more digitally skilled.

Learning factories are an essential means of educating students and professionals in the essentials of production management principles. It is a practical pedagogy using problem-based scenario learning. It is seen as classifying learning objectives into different levels of complexity and uses Blooms Taxonomy as a basis.

According to Caldarola, it *"is used to classify educational learning objectives into levels of complexity and specificity, from knowledge to synthesis through application and analysis, by emphasising the final objective of the learning process, i.e., developing real competencies in learners rather than just knowledge transfer".* (Caldarola, E., et al., 2018)

The knowledge that is imparted is designed as a fit to the level and background of the learner. By using scenarios, it facilitates effective communications and eventually improved, and more well-defined outcomes. It is much easier to "do what you see".

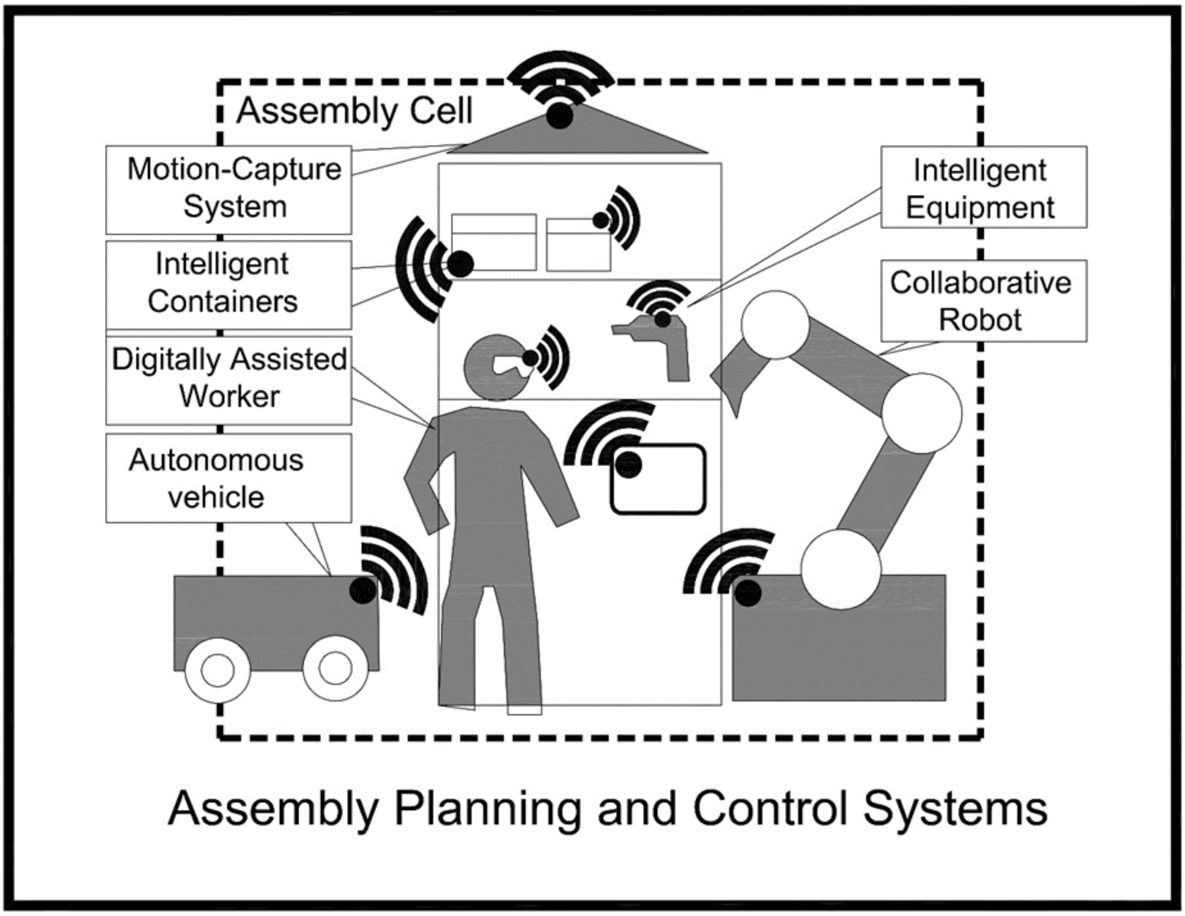


Figure 5. Adapted from Assembly Planning and Control System (Enrol et al., 2016)

Figure 5 shows an assembly cell which has an autonomous vehicle, a digitally assisted worker, intelligent containers, motion captured systems, intelligent equipment and finally, a collaborative robot. All the above are working in an intelligent manner with the human.

"The digital assistance system which is based on augmented reality technologies and a "wearable device" will display context-related work content information to the worker to enable the correct execution of an activity. In addition, the assembly process is monitored by ultrasound and different sensor systems. Handling errors of the worker are pointed out with adequate support information to correct the mistake. Here also ergonomic stress situations of the production worker are monitored in real time by a "Motion-Capture System". This information is used in order to identify and to analyse synergies between productivity and ergonomics quantitatively and to achieve a specific data flow to improve ergonomic stress situations continuously in the planning and control system of the work systems."

Enrol continues to describe how the worker is supported by the sensitive and collaborative systems. The worker will work in an ergonomically, age-appropriate manner. Each assembly workstation will be configured to the individual.

2.5 Drivers and Challenges

From a study sponsored by the German Federal Ministry of Education and Research, Gausemeier et al. in 2016 complied a list of drivers and challenges on page 42 of their report. By compiling these factors a global vison is outlined.

The common drivers are:

- **Sustainability**
- **User Friendliness**
- **Collaboration**

Greater energy and resource efficiency is a key driver for Industry 4.0. However, different countries have different priorities ranging from idealogical principles to resource bottlenecks. Sustainability is seen as a selling point for Industry 4.0. Demographic change in the workforce can be facilitated by improved working conditions in Industry 4.0 plants. Digital support lowers the intellectual demands on the employee. Physical supports improve the ergonomics of the tasks. Networked digital twin, cyber physical systems and virtual collaboration facilitate wider cooperation. This enables innovation and better use of existing potential internationally.

The challenges are:

- **Security**
- **Standards, migration, and interoperability**
- **Business models**
- **Industry 4.0 branding**

Because devices and machines are networked externally, this means that they are more vulnerable to security threats. To date, no global security protocols have been developed to combat this. Until global standards are established, Industry 4.0 cannot be successfully globally implemented. These standards need to guarantee the upgrade of components over time. Only openly interoperable standards will allow small to medium size enterprises and start-up companies to implement Industry 4.0. Business models will change with the introduction of Industry 4.0, but exemplars are not yet easily found. This is particularly important to start-up companies. Germany launched Industry 4.0 and has been seen to be the world leader in this field. Asian countries are gaining momentum. It was strongly recommended in the research that if Germany is to capitalise on this, it needs appropriate products and technological solutions to be made available to the marketplace. (Gausemeier et al., 2016)

2.6. Chapter 2 Summary

The vision of Industry 5.0 and the state-of-the-art model are the topic of this chapter. The State-of-the-art industry 4.0 and 5.0 are not commonplace in industry now. Several obstacles exist that hamper the introduction of fully smart products and processes. Factories are in high or low 'states of readiness'. Countries worldwide have different priorities when it comes to the implementation of this new, highly technical environment.

The ability of a company to move into the Industry 4.0 space depends on multiple factors and because of this high level of complexity they may require a third party to help them understand their strengths and weaknesses. A smart factory is one in which systems are fully integrated and collaborative. The customer drives the demand, and the system can adjust and react in real time to the order. The supply chain spans from the customer to the supply chain network to the supplier and factory floor.

This connected cyber physical system is data driven from the machine sensors all the way up through the multiple layers of ICT. From a component level, the focus is on precision and comparison to a digital twin. From a machine level, it is about a self-awareness or self-comparison and self-prediction. From a production level, it is about a self-configuration and self-optimisation, eventually achieving an automated, optimised, self-regulating production facility. Reliable and useable information is critical to the success of the smart factory enabling smart industry, its ecosystems of industrial innovation and collaboration, to thrive.

Working in a smart factory means that the computerised numerical machines, the automated guided vehicles, the robotics, and the products are controlled by apps on a smart device. Planning and control will also use apps. Data and analytics will be an invaluable part of the running of the factory, data from the physical systems being transformed into its digital twin. A common information model and standards are the key to standardising and normalising the systems required to make this smart factory more commonplace in industry.

It can be noted that the large automotive companies have recognised how learning factories can empower the knowledge of their workforces and going forward this type of learning environment should be more available in educational institutions. The current body of literature signposts to the pedagogy of learning factories for the future education of industry-based workforce.

Caldarola et al. state that *"in order to make modern factorie, and workers resilient to the changing market conditions and to the complexity of new technologies involved in the production process, it is necessary to act self-organised in unknown situation".* For this reason, traditional teaching methods are no longer sufficient to train competent employees, thus new approaches are needed. Training in realistic manufacturing environments modernises the learning process, bringing it closer to the industrial practice, and to leverage industrial practice through the adoption of new manufacturing knowledge (fostering the sharing and the elicitation of knowledge), while also improving young (future) engineers' competences. They state that the real value creation in Industry 4.0 is through the adoption of human centred technology. Here, the worker is at the centre of the innovation process. They state that in order for European industry to flourish, the workforce needs to have the correct skills. They highlight that one of the key priorities of the "Factories of the Future 18-19-20 Work Program" is the focus on human factors. The development of human competences must be in synergy with technological progress. (Caldarola, E., et al., 2018)

A significant omission in the academic literature available at this moment in time is in the collaborative robotics area. This was made obvious in the review of academic literature at this stage of the research. In Industry 4.0, industrial automation robotics have the capacity to replace the worker in manufacturing. Industry 5.0 requires single customised units of product to be produced. This can be effectively accomplished with the implementation of collaborative robotics and humans working alongside each other and 'collaborating'.

Finally, the German Federal Ministry of Education and Research released a paper authored by Gausemeier et al. in 2016 which outlines the most important drivers and challenges going forward. The common drivers will be sustainability, including greater energy and resource efficiency, user friendliness of the technology to facilitate employees and increased collaboration between human and machines. Equally, one of the main challenges will be security. To mitigate against security threats, openly interoperable standards available worldwide, Industry 4.0 business models and branding with appropriate products and technological solutions need to be made available to the marketplace.

Chapter 3. Methodology

3.1 Introduction

The section outlines the theoretical framework used for the research. It also provides an overview of the research methods, which were employed to gather evidence with the overall aim of answering the research questions.

3.2 Conceptual Framework

Miles et al. (2013) provide an approach which helps with formulating a focus by constructing what they refer to as a conceptual framework. *“This describes in narrative, and often in graphical format, the key factors, constructs and variables being studied – and the presumed relationship between them.”* This is not the formation of a hypothesis in the positivistic sense, but a way of showing the researcher the possible relationships that exist, and which may be explored through the formulation of research questions.

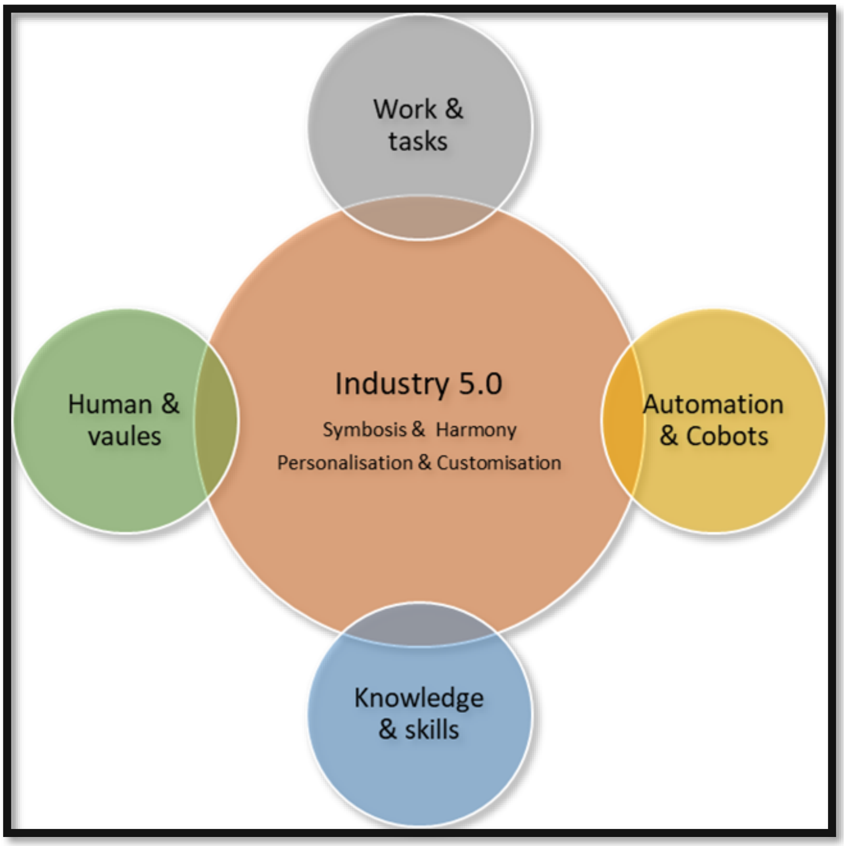


Figure 6 The conceptual framework for this research.

Figure 6 is a conceptual framework for the research which is to be undertaken in this thesis. Industry 5.0 is, at its core, a symbiosis of the Human, Work, Knowledge and Learning and Automation with a focus on Collaborative Robotics. At the centre of Industry 5.0 is the personalisation and customisation of value-added products. This framework will be used to focus the Literature Review at the initial stage.

3.3 Methodology

As Flick (2009) notes, the less clearly research questions are formulated, the greater the chance that researchers will find themselves confronted with mountains of data. As Figure 7 shows, starting with a purely inductive approach (which implies relatively little focus and no research questions) usually leads to the accumulation of large volumes of data, which then have to be analysed.

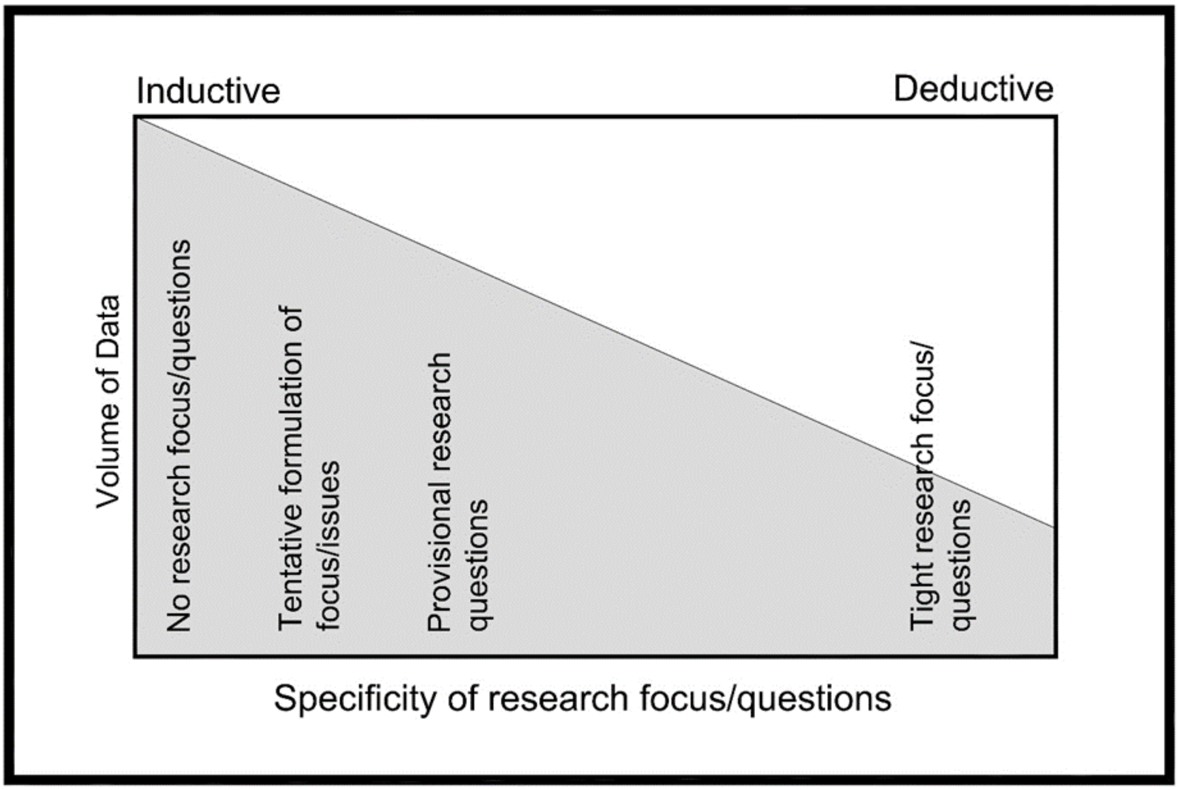


Figure 7 Adapted from inductive and deductive approaches and research questions (Gray, 2018)

It can be said that this research is neither strictly inductive nor deductive in the true sense. In this case provisional research questions are constructed as a result of the Literature Review.

These questions were highlighted in an academic paper written by the researcher titled "Industry 5.0: Is the Manufacturing Industry on the Cusp of a New Revolution?" and can be found in appendix 1. The scope of these questions was considered too broad, so a decision was made to narrow it down into a more manageable piece of work.

To gain an understanding of how, in real terms, industry is aware and organising itself for Industry 5.0, a case study of Irish industry was undertaken. A decision to focus on the deployment of Cobots was made. A mixed method approach was used to gather data.

Qualitative research is intense, engaging, challenging, contextualised and highly variable (Bazeley, 2013). It is not built upon a unified theory or methodological approach (Flick, 2009). Qualitative research can adopt various theoretical stances and methods including the use of observations, interviews, questionnaires, and document analysis. (Gray, 2018). A mixture of approaches will be used in this research.

To summarise the phases of this research over a three-year period a flow diagram has been constructed (Figure 8).

Phase 1: Initial phase which includes the topic exploration between Supervisor and Researcher.

Following a comprehensive review of the academic literature, the results of this phase include the development of a conceptual framework as well as the publication of academic papers presented at conferences and peer reviewed.

Phase 2: The second phase is the scope definition phase.

This is where the research questions developed are refined and a scope is agreed between supervisor and researcher. This scope focuses on human centred systems and collaborative robotics in Industry 5.0. A mixed model approach is chosen to collect data and Ireland's manufacturing industry is chosen for data collection as the researcher lives in Ireland and has connections with local industry.

Phase 3: The third phase is the data collection phase.

A mixed method approach is considered for data collection. Preliminary case studies with Cobot industry specialists as well as a review of Cobot manufacturer's blogs, website, and social media posts is undertaken. Following this, an online questionnaire survey is developed and administered.

Phase 4: The fourth phase is the data analysis stage.

The preliminary case studies are codified manually and analysed for emerging themes using the thematic analysis technique.

Phase 5: The fifth and final conclusion and recommendation phase.

Throughout the research, academic papers were published and presented at conferences.

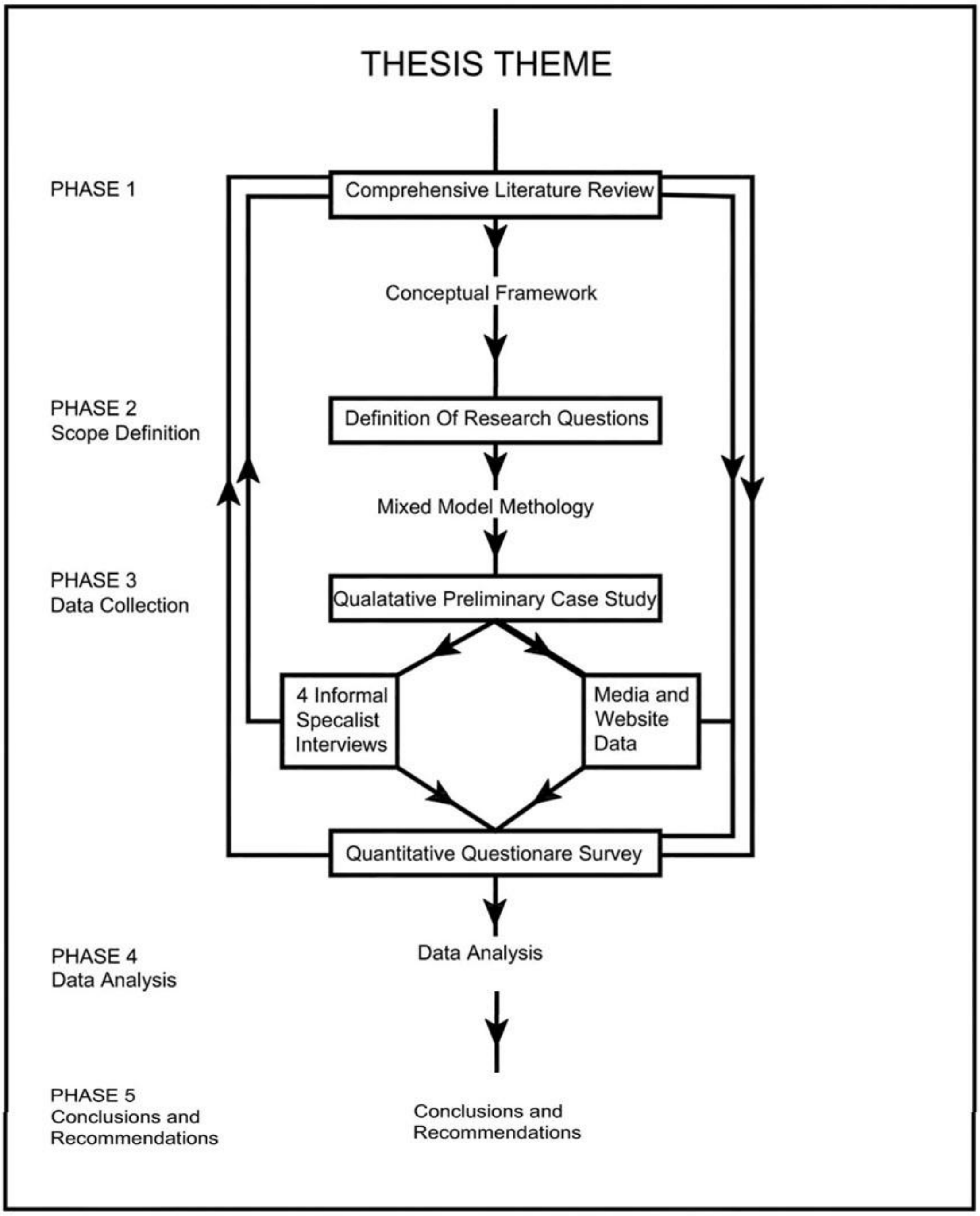


Figure 8 The flow diagram showing the thesis phases and deliverables in phases.

3.4 Literature Review

The first objective of this thesis will be to critically examine the body of knowledge in the area of manufacturing, Industry 4.0 and 5.0. A literature survey shall provide a methodical review of current practices and previous research. Information on the topics shall be gathered from a variety of sources including, peer reviewed journals, articles, and databases. These documents will be meticulously reviewed and critiqued to gather an understanding of the author's opinions and findings on the subject matters. The referral to additional information obtained from unauthenticated sources such as the internet, newspapers and magazines may be unavoidable in the context of the literature survey; nonetheless, their inclusion in the study shall be kept to a minimum.

Since the collaborative technology is a relatively new technology, the companies manufacturing these robots mainly use their websites to share their information and these resources will also be used. There are also many videos available on these websites and on YouTube which provide user experiences, case studies, webinars, lectures, blogs, and product information. The author will use these up-to-date resources and make transcripts where necessary as they are a valuable source of rich information.

The literature survey should lead to a clear set of research questions according to Grey in 2018 (page 55) and these research questions should lead to the methodology used in the research.

The broad research areas of Industry 4.0 and 5.0 show a clear absence of scholarly articles in narrower areas of the human centred systems of collaborative robotics, which is a new emerging technology. Since the collaborative technology is a new technology, it is acknowledged that the companies manufacturing these robots mainly use their websites to share their information and these resources will also be used as part of the case studies in this research. This will include videos available on these websites, and on YouTube, which provide end-user experiences, webinars, lectures, and product information. These up-to-date resources will be used by making transcripts out of discussions. This type of information is seen as a valuable source of rich up-to-date knowledge.

3.5 Qualitative Research

Qualitative research involves the exploration of issues in a bid to gain insight into interpretations of individuals to specific topics or issues. Qualitative research uses specific techniques to gather data. This entails using groups of consenting participants to gather in-depth information through the medium of in-depth interviews, focus groups, observations, questionnaires, and case studies. Qualitative research is often used when there is no expectation for specific results and, as such, is used at the outset of research to assist in developing a research hypothesis or questions.

3.6 Qualitative Inductive Research Process

It was decided to use an inductive qualitative research process. Figure 9 shows the typical steps involved in an inductive research process which is based on Grey's multiple case study method, (page 265). (Gray, 2018.)

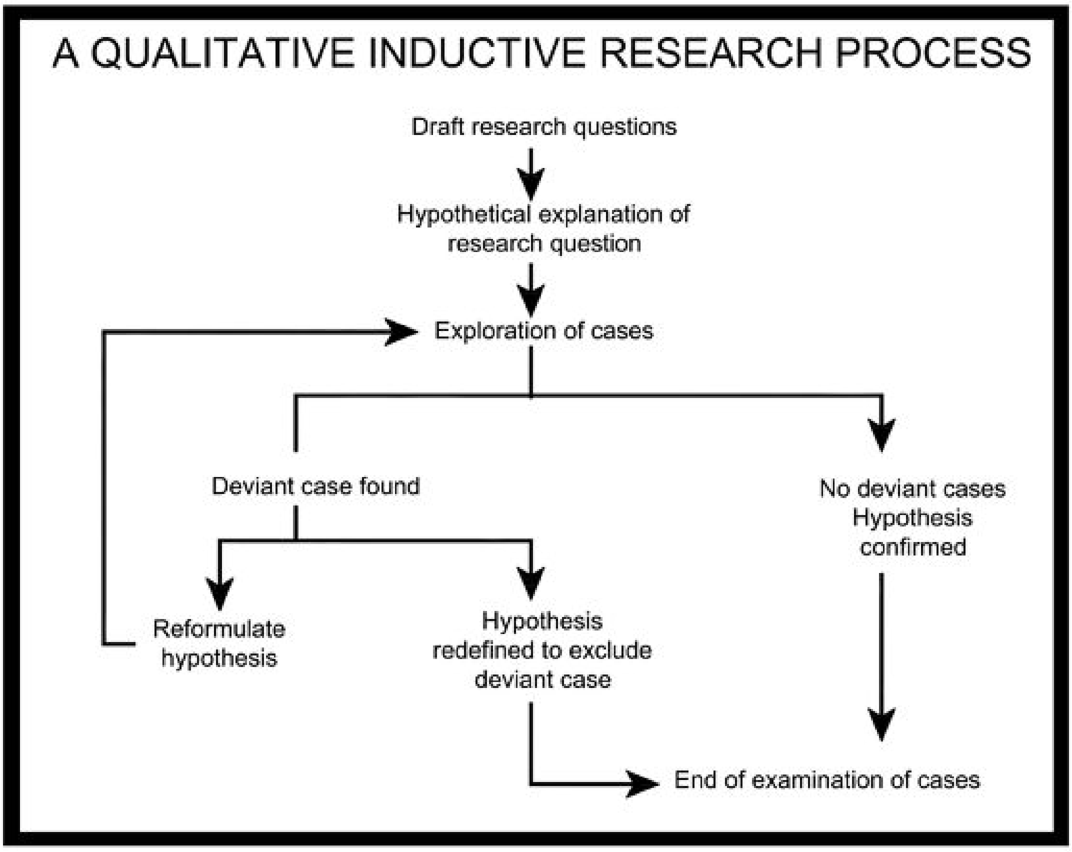


Figure 9 Qualitative inductive research process.

3.7 Preliminary case study

What is case study research? Elsenhardt in 1989 argues that the understanding of phenomena can be attained via a case study approach and in 2018, Yin (page 4) describes it as being *"An empirical inquiry that investigates a contemporary phenomenon within its real-world context - especially when the boundaries between the phenomenon and context are not clearly evident"*.

The decisive factor in defining a study as a case study is the choice of the individual unit of study and the setting of its boundaries. By choosing to do a case study, it becomes more about what is being studied rather than the methodology chosen which is an important focusing tool. Mintzberg, in 1979, argues in favour of 'direct' research in an organisational setting and Yin, in 2018, highlights that a case study is particularly good at examining “why” as well as “how” and “what” questions regarding a contemporary set of events over which the investigator has little or no control. *“Case studies have often been viewed as a useful tool for the preliminary, exploratory stage of a research project, as a basis for the development of the ‘more structured’ tools that are necessary in surveys and experiments.”* (Rowley, 2002)

The most interesting aspect of the use of case study research is raising the investigation from a descriptive account of what is happening in a current scenario into a worthwhile piece of research which can be an addition to the existing body of knowledge. The direction of the case study can be defined by the researcher.

Informal interviews will be undertaken as case studies at the start of this research with a number of experts in the collaborative robotics sector in Ireland. The first case study will be with a sales director of a Cobot company, the second interview will be with an industrial solutions architect in a research centre in Ireland, and, finally, the third interview will be with two postdoctoral researcher engineers specialising in a collaborative robotics working group in the same national research centre. The transcripts of these interviews will be in the appendices. It is anticipated that all three case studies will be over the phone conversations and that the researcher will record the information by taking notes and transcribing them afterwards. Patterns of information will be noted.

A number of Cobot user videos from a Cobot website will be transcribed as additional case study material. They will be stored in the appendices.

The use of multiple case studies in this research is important as it will provide tentative evidence to inform the research questions. This is the equivalent of multiple repeated experiments that are required before an experimental quantitative methodology. The Literature Review and case studies will be the foundation on which the online questionnaire survey will be designed.

According to Gray in 2018 (page 266), *“While surveys tend to collect data on a limited range of topics but from many people, case studies can explore many themes and subjects but from a more focused group of people, organisations or contexts.”* This is particularly true in this research. Up-to-date case studies can be very informative in the specialist area of Cobots in Industry.

3.8 Questionnaire Survey

According to Bourque et al. in 1995, *"A questionnaire survey can be used only when the objective of the study is clear and not complex"*. Because the area of collaborative robotics is relatively new worldwide, there is little data on how they are being used in Industry. The case studies may highlight this difficulty with the uptake. It was felt that these needed to be investigated in a larger population. It was decided to undertake an online survey with the view to collecting data which would give a snapshot of this technology in Ireland in 2020. One advantage of an online questionnaire survey is its lower cost compared to other methods. Online questionnaires also have sample-related advantages including geographic coverage, larger samples, and wider coverage within a sample population.

This benchmarking exercise will consider the following areas; the classification of the company, the product type, the areas where collaborative robotics are currently working, the type of work being performed by the collaborative robotics, what are the advantages and disadvantages, how easy are they to install and use, education of the operators, automation of business process in the company, and so on.

Questionnaires have been used by researchers to gather data for many decades. A well-designed questionnaire is seen as the key to success with regards to survey results. Good insight into questionnaire development was gained from reviewing other practitioners' attempts, but no guiding theoretical base exists to develop flawless questionnaires.

According to Gillham in 2007 (p. 4-8), the advantages of questionnaires are as follows:

- low cost in terms of time and money
- easy to get information from a lot of people very quickly
- respondents can complete the questionnaire when it suits them
- analysis of answers to closed questions is straightforward
- there is less pressure for an immediate response
- respondents can have anonymity
- lack of interviewer bias
- standardisation of questions which is also true for structured interviews
- can provide suggestive data for testing an hypothesis or answering research questions

On the negative side he says that:

- the questionnaire may have data that is not of high quality in terms of completeness and accuracy
- the questionnaire has low response rate typically, and respondents may not be unmotivated
- questions need to be short and simple and easily understood
- if the question is misunderstood this cannot be corrected
- surveys can be of poor quality and are limited to asking questions to gather the required information
- the questionnaire assumes that respondents have required knowledge to answer the questions
- there is no control over the order and context in which the survey is being answered
- wording of questions can influence how it is answered
- literacy can be an issue and verbal communications can be easier than written
- honesty of answers cannot be checked.

All of the above points will be taken into consideration in the design of the questionnaire. There are several necessary steps involved in carrying out an effective survey which are outlined:

- Designing the questionnaire
- Sampling
- Pre-test or pilot
- Administration of the questionnaire
- Codifying the data
- Interpreting and disseminating the results

The primary step ***'**designing the questionnaire'* is the most crucial and there is a need to rigorously define the survey objectives. Construction of the questions along with their appropriate measurement scales needs time and consideration to ensure they match these objectives. The questionnaire will be designed primarily consisting of closed questions (choice between a limited number of answers), along with a number of semi open questions (a list of options with the answer "other" included to allow a respondents opinion to be collected).

The secondary step *'sampling'* involves defining the survey population. The population in the context of this study will be defined as including all Irish manufacturing industries and the unit was individual professionals ranging from plant manager to technician. This wide range of company employees was deemed necessary as several professions have connections to the automation profile of the company, either from as the end user, or the decision makers on how and where to invest capital.

Engineers Ireland is the professional body of the Engineering Industry in Ireland. The researcher has been a chartered member of this institution for 30 years. She also has held office as chair, vice chair and secretary over several years. Engineers Ireland has approximately 26,000 members from all the engineering disciplines. They have been contacted and have agreed to distribute the questionnaire using the Engineers Journal and social media (LinkedIn, Twitter and Facebook). (Engineers Ireland, 2020)

Another group of manufacturing engineering companies contacted were through the group "Engineering The South East" which is *"an industry led group which seeks to address skills needs, promote careers and advance the engineering capabilities of the region".* (Wexford People, 2020). The researcher is on the steering committee of this group.

The final but most important sampling tool is the Alumni of Engineering graduates from Waterford Institute of Technology where the researcher has been a lecturer since 2000. The third step *'pre-test or pilot'* involves the survey being sent to a limited number of respondents who provided a critical review of the form and content of the questionnaire. This will enable the filtering of the questions to avoid badly worded sections or the requirement of complex answers. A number of pre-tests will be carried out and the questionnaire will be refined as required from the feedback received from these pilots.

The fourth step concerns the *'administration of the questionnaire'*. The well-established SurveyMonkey^{TM} tool will be used to host and distribute the survey. A self-administered questionnaire will be developed using the SurveyMonkey^{TM} software and the option 'distributed by e-mail' will be selected. It is envisaged that the survey release dates will be from June 2020 to August 2020. (SurveyMonkey, 2020)

The fifth step *'Codifying the data'* entails recording the data for subsequent analysis. Thematic Analysis will be used for this.

The final step *'Interpreting and disseminating the results'* which involves conducting an analysis of the results to uncover any meanings of significance in the findings will be undertaken in chapter 6. The online survey questionnaire transcript is available for review in the appendix.

3.9 Research Limitations

An important element of any research is that the researcher is aware of, and declares, the piece of research's limitations. As Patton in 2005 states *"There is no perfect research design, there are always trade-offs"?*

The trade-offs in this case will be noted to be that the technology is relatively new and there are relatively few companies in Ireland who are both aware of it and have this technology up and running in their company. In addition, another limitation will be seen to be that the study is taking place during SARS 2 Covid-19 pandemic. The result of this is it will be difficult to motivate people to take the time to engage with the survey and interviews.

3.10 Ethical Issues

According to Cohen et al. in 2017 "A code of ethical practice makes researchers aware of their obligation." Gray in 2018 states on page 68 that conducting research ethically means conducting it "in a way that goes beyond merely adopting the most appropriate research methodology but conducting research in a responsible and morally defensible way."

The principle of voluntary participation and informed consent were applied to this research. Gray (page 75) in 2018, describes ethical principles in data gathering. He states that participants will not be coerced into taking part in the survey and prospective participants will be fully informed about the procedure and risks involved in research before consenting to participate.

Gray (2018) states that to ensure informed consent the introductory section of the survey should outline the following:

- What are the aims of the research?
- Who is the research team?
- Who is being asked to participate?
- What kind of information is being sought?

- How much time is required?
- Participation is voluntary
- Responding to all the questions is voluntary
- Where will the data be used once collected?
- How will anonymity be preserved?
- What is the timeline of the questionnaire?

All respondents to the online questionnaire will be guaranteed confidentiality in a declaration at the beginning of the survey. The case study participants will be ensured confidentiality also and this will be important as it will ultimately allow more freedom when discussing market sensitive areas.

3.11 Value, Validity, and Reliability

The finding of the study will be of value to engineers and engineering managers in a manufacturing industry setting. They will be also significant to the manufacturers and distributers of the collaborative robots and the automation specialists. In addition, the research will stand to inform future policy makers, educationalists, and the research community in general. The findings will be published in academic papers and presented in conferences.

Validity and reliability will be strengthened through adoption of the chosen research methodology. Careful structuring, preparation, and data analysis will contribute to the internal validity, whilst a strong representative sample, extensive literature review and mixed method research will serve to strengthen the external validity. Reliability is obtained through the acknowledgement of limitations, recognition and mitigation of bias, piloting to reduce errors and any ambiguity, and via rigorous scoping.

3.12 Chapter 3 Summary

Chapter three outlines the theoretical framework used for this research. It also provides an overview of the research methods that were employed to gather evidence, with the overall aim of answering the research questions. Firstly, a conceptual framework was established. This framework graphically highlights the key factors being studied. It was established that this research is strictly neither inductive nor deductive, and the research questions were constructed from the Literature Review.

Five phases (figure 8) of the study were defined as part of the mixed methodology. The case study was undertaken in the Irish manufacturing industry as the researcher is Irish living and working in Ireland. The data was gathered from initial qualitative preliminary case studies, the results of which informed the quantitative industry survey.

The limitations of the research were assessed as part of this chapter noting that the study was carried out during a global pandemic. The result was that it restricted physical access to companies, so all the data gathering was undertaken virtually. In terms of ethics, it was clear that the data was gathered with the understanding that it was on a voluntary basis with informed consent. The confidentiality of the participants was ensured, both in the preliminary case studies and the industry survey.

Finally, the results of the research will have value for many stakeholders including Industry and academics. The research will stand to inform future policy makers, educationalists, and the research community in general. The findings will be published in academic papers and presented in conferences. The reliability and validity of the results are strengthened by the robust preparation and delivery of the research methodology.

Chapter 4. Literature Review

4.1 Introduction: The Evolution of Industry

Over the past two hundred and fifty years, life has been transformed for human beings by the introduction of new technologies. The term 'industrial revolution' was introduced to mark the transformation or evolution of industry. According to the Oxford dictionary, the definition of industry is "economic activity concerned with the processing of raw materials and manufacture of goods in factories" (Oxford, 2019). The term "industrial" should not just refer to manufacturing and factories but to all activities that come from human effort, as coined by the 19th Century thinkers, John Stuart Mill and Thomas Carlyle.

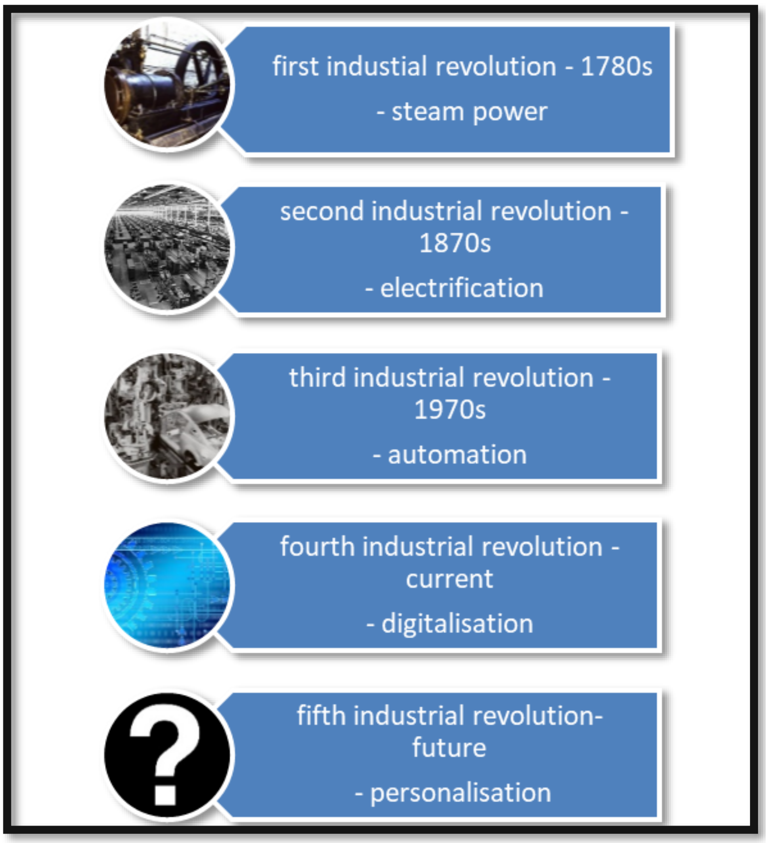


Figure 10 The sequence of industrial revolutions throughout the ages.

4.1.1 First Industrial Revolution

In the eighteen century the first industrial revolution changed manufacturing processes across Europe and the United States of America (USA) by the introduction of mechanisation. This meant that previous hand production methods were replaced by machines powered by steam and water. One of the impacts of the first industrial revolution was an unprecedented rise in population growth. The standard of living began to improve, life changed dramatically for the working classes, and the United Kingdom, (UK) led the way. What were the influencing factors in the UK that optimised conditions to facilitate these changes?

Allen, in 2011, wrote in the Economic History Review that the demand and supply of new technology was related to the radical inventions of the eighteenth century. During this period *"Britain had a unique wage and price structure. British wages were exceptionally high compared with wages in other parts of Europe and in Asia, while the prices of capital and energy were exceptionally low. The price and wage structure affected the demand for technology by giving British businesses an exceptional incentive to invent technology that substituted capital and energy for labour. The high real wage also stimulated product innovation since it meant that Britain had a broader mass market for 'luxury' consumer goods including imports from east Asia. The supply of technology was also augmented by the high real wage. It meant that the population at large was better placed to buy education and training than their counterparts elsewhere in the world. The resulting high rates of literacy and numeracy contributed to invention and innovation"*. (Allen, 2011).

According to Schwab in 2018, the first Industrial Revolution gave root to 100 subsequent years of change. *"It transformed every existing industry and gave birth to many more, from machine tools to steel manufacturing, the steam engine and railways".* (Schwab, 2018)

4.1.2 Second Industrial Revolution

In the 1870's, the introduction of electricity and the roll out of electrification in the 1880's led to the Second Industrial Revolution. Ian McNeil in his book An Encyclopaedia of the History of Technology shares the different stages of technological advancement by citing the developments in technology. He states that the development of the incandescent light bulb both by TA Edison in the USA and JW Swan in England made public lighting a reality. Ferranti's Deptford power station went into operation in 1889 and he says that electricity was born at this time. This invention has been the biggest transformation of our daily lives, bringing convenience, comfort, transport and well-being. (McNeil, 2002)

Manufacturing plants evolved from steam and water to using electric power. Electric motors were much more efficient than the previously used steam, water and human power. Electric motors from this era were around 30% efficient. Hydroelectric and chemical power were also invented at this stage, including chemical fuel from petroleum.

4.1.3 Third Industrial Revolution

Automation *“The use or introduction of automatic equipment in a manufacturing or other process or facility.”* (Lexico, 2019)

The introduction of automatic equipment into manufacturing companies became popular in the 1970‘s and 1980’s. The first automated equipment was used for tasks that were challenging to humans such as welding, materials handling and product assembly. In heavy manufacturing industries, such as steel and automobile manufacturing, robotics played an important role as the working environment proved to be unfit for humans. In the 1980’s, as robots became more sophisticated and less expensive, they were used for routine work.

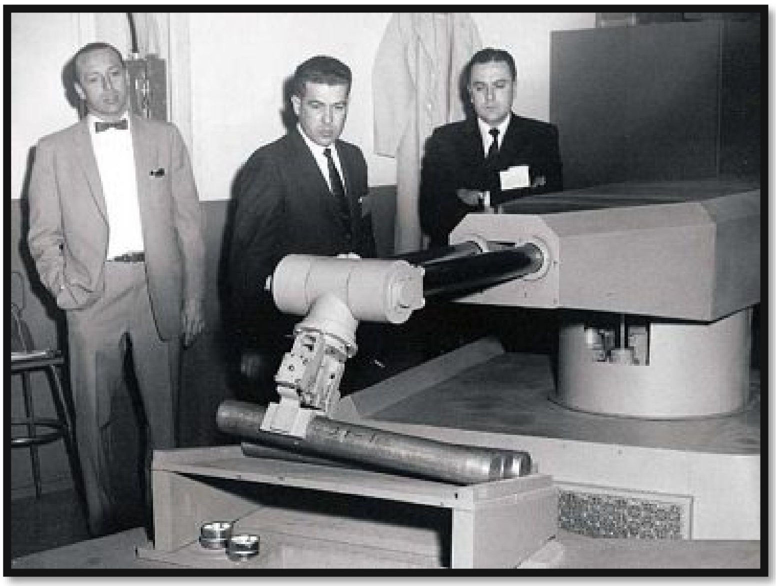


Figure 11 shows George Charles Devol. He is credited for inventing the first industrial robot called the ‘Unimate’ in 1954.

The following outline lists the important automation and robotics developments in the USA from the 1950’s to the 1980’s. (DesignNews.com, 2019)

- George Charles Devol was credited for inventing the first industrial robot called the Unimate in 1954. A few years later, Devol and entrepreneur Joseph F. Engelberger launched Unimation.

- The Ultimate robot was produced in 1961 and was used in a General Motors factory spot welding and diecast handling.
- The Rancho Arm was developed to help people with disabilities. It had six joints and gave flexibility resembling the human arm. This model went on to be used in industry.
- In 1963, Stanford University added the capability of computer control to the Rancho arm.
- The naval arm called The Tentacle was designed in MIT in 1968. Its application was in underwater naval research.
- The Stanford arm was invented in 1969. This was a six-axis articulated robot and the design configuration allowed the robot to accurately follow arbitrary paths in space under computer control. This widened the potential use of the robot to more sophisticated applications in assembly and arc welding.
- In 1973, Scheinman started 'Vicarm Inc' to manufacture robots and in 1977 he sold his design to 'Unimation'. Scheinman then co-founded 'Automatix' in 1980.
- By 1974, the 'Stanford Arm' had developed to the point of assembling a 'Ford Model T' water pump. It used optical and contact sensors for direction and guidance, and this led to commercial production. It had a full six degrees of freedom.
- In the early 1980s, rougher gripper designs inspired by the Stanford Arm, which was now run with increasingly powerful microchips, were in mass production and used in heavy industry.
- In 1974, the Silver Arm was created by MIT's David Silver. Its function was to perform precise assembly using touch and pressure sensors and a microcomputer. Its movements resemble the movement of human fingers.
- The PUMA (Programmable Universal for Manipulator for Assembly) was designed for 'Unimation' in 1974 and continued to be manufactured until 1980 when the rights were sold to 'Stäubli' in 1988.
- In 1981, the companies Sankyo Seiki, Pentel, and NEC introduced a completely new concept for assembly robots. The robot was developed under the guidance of Hiroshi Makino, a professor at the University of Yamanashi. The robot was called Selective Compliance Assembly Robot Arm, or SCARA. Its arm was rigid in the Z-axis and pliable in the XY-axes, which allowed it to adapt to holes in the XY-axes.

In the 1980's there was a steep decline in orders for robotic equipment. This drove most American producers out of the business of manufacturing industrial robots. Only a few small American robot makers remained, as did the larger Japanese robotics firms. Sales started to grow again in the 1990s and this increase was felt globally.

4.1.4 Traditional manufacturing

Hirsch-Kreinsen et al. in 2019 discuss the obstacles and challenges facing manufacturing companies when moving from a more traditional system to a proposed smart system. They state that the structure of the traditional automated, flexible production system is the conventional automation pyramid, which can be seen in Figure 12. This system, they stress, will need to be disassembled or broken down if cross system networking of the individual components is to be feasible, which is the requirement of Industry 4.0. Solutions to this challenge are not readily available at the moment. Configurable generic solutions are the key. (Hirsch-Kreinsen et al., 2019).

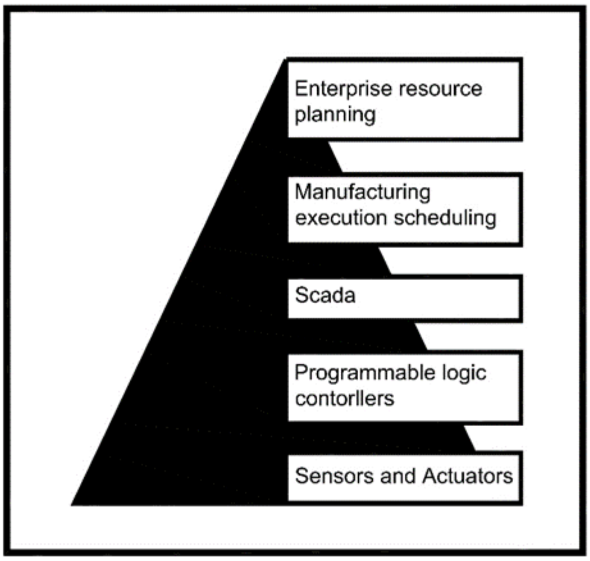


Figure 12 Current embedded intelligence in manufacturing.

This diagram represents the embedded systems that are typically found in the conventional automated pyramid; at the base level are sensors and actuators, then programable logic controllers (PLCs), following this Scada controllers, then the MES (manufacturing enterprise scheduling) and finally, ERP (enterprise resource planning). Supervisory control and data acquisition (SCADA) is a system of software and hardware that facilitates manufacturing plants to:

- Control industrial processes locally or at remote locations
- Monitor, gather, and process real-time data
- Directly interact with devices such as sensors, valves, pumps, motors, and more through human-machine interface (HMI) software
- Record events into a log file.

These systems are vital to the functioning of the plant as they help to maintain efficiency, process data for smarter decisions, and communicate system problems so as to keep downtime to a minimum.

"The basic SCADA architecture begins with PLCs or remote terminal units (RTUs). PLCs and RTUs are microcomputers that communicate with an array of objects such as factory machines, HMIs, sensors, and end devices, and then route the information from those objects to computers with SCADA software. The SCADA software processes, distributes, and displays the data, helping operators and other employees analyse the data and make important decisions." (Inductiveautomation.com, 2019)

MES (manufacturing executing scheduling) is described by Siemens as software solutions that track the transformation of raw materials into finished goods whilst ensuring the high quality of the product and optimised efficiency of the process. These software programmes connect multiple plants, sites, and supplier's live production information. They integrate easily with equipment, controllers, and enterprise business applications. The result is complete visibility, control and manufacturing optimisation of production and processes across the enterprise.

According to Siemens MES systems:

- Monitor and synchronise manufacturing activities across globally distributed plants and link them in real-time for optimal performance
- Track product and order details on the plant floor, collect transactions for financial and planning systems, and electronically dispatch orders and manufacturing instructions to shop floor personnel
- Help eliminate human error in manufacturing by providing real-time quality data checks. It also facilitates the yield monitoring, automatic enforcement of specifications and business rules, and as-manufactured lot, batch, device or unit traceability – all resulting in improved product and process quality, and higher productivity

- Paperless manufacturing with MES helps to reduce scrap and eliminates paperwork errors and redundant checks.
- Provide the flexibility to model and change complex processes and enforce them immediately.
- Provide the real-time feedback needed to quickly identify and resolve issues for continuous product and process improvement and optimization of manufacturing processes. (Plm.automation.siemens.com, 2019)

Enterprise resource planning (ERP) is a type of software that organisations use to manage day-to-day business activities such as accounting, procurement, project management, risk management and compliance, and supply chain operations. A complete ERP suite also includes enterprise performance management. This software helps plan, budget, predict, and report on an organisation's financial results. A key ERP principle is the central collection of data for wide distribution. Instead of several standalone databases with an endless inventory of disconnected spreadsheets, ERP systems bring order to chaos so that all users use the same data coming from common processes. With a secure and centralised data repository, all members of the organisation can be confident that data is correct, up-to-date, and complete. (Oracle.com, 2019).

Lalanda et al. in 2017 state that manufacturing systems traditionally have two software systems. These systems have limited interactions and are usually located in different areas of the facilities; one in the production area and the other in IT. *"On the plant floor, field devices control local operations, collect data, and monitor the local environment. Control systems are used for acquisition and supervision of high-level data. The IT level provides supporting software, including for instance business processes, enterprise information systems, and data analytics."*

A simple model can be drawn to explain how systems have developed over time. Figure 13 is a representation of this simple model. In the early days there was the manual worker without automation (level 1). These workers were trained for many years in their trade and held the tacit knowledge mainly in their brains. The trades were handed down from Master to Trainee over many generations. The following level, level 2 can be referred to as the data level. Here, machine data is available due to the advances in automation; Numerical Control (NC), Computerised Numerical Control (CNC), Computer Automated Manufacturing (CAM).

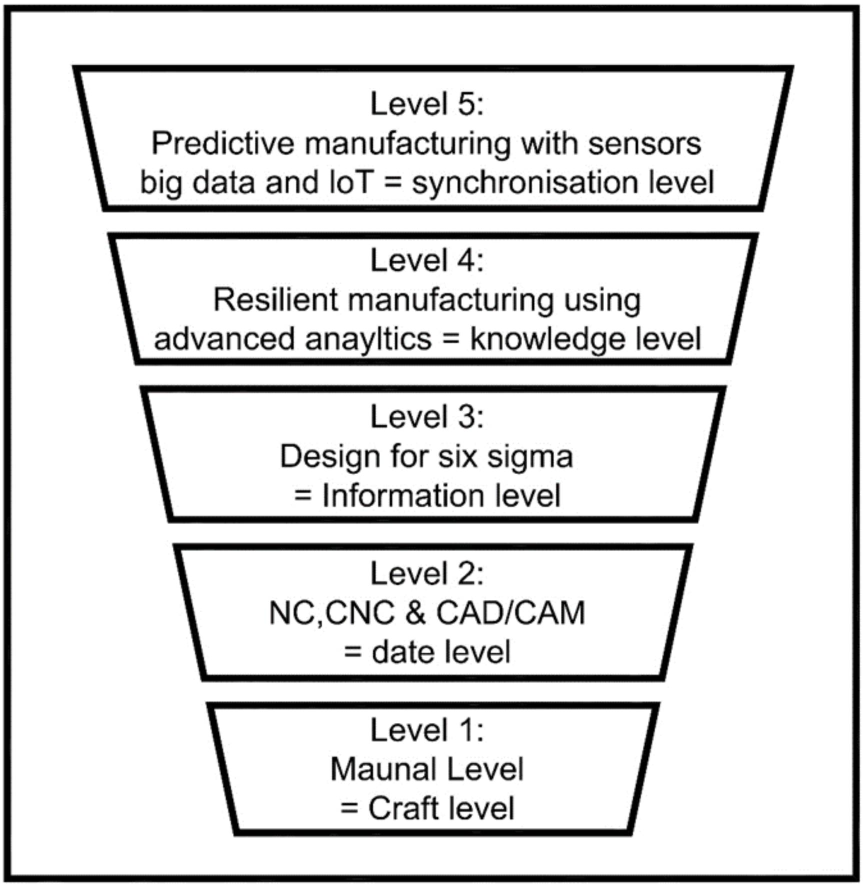


Figure 13 A simple model showing the five levels of productivity.

At level 3, the information level, data produced in the post processors can be captured and analysed to assist with improving quality standards in manufacturing. Statistical process control is a tool used in the quality standard Six Sigma. Here, data which comes directly from the process is analysed and used to get a clear picture of what is happening. This picture assists with an understanding of the capability of the process and is captured in real time. This, in turn, facilitates improvement actions which optimises manufacturing, reduces tolerances on components and, in turn, eliminates waste. The data is used to create new control algorithms and reconfigurations, enabling the system to become smarter.

Level 4 is known as the knowledge level. Here, the humans involved in manufacturing use the advanced analytics to optimise operations. The result is an optimised resilient plant which is customer focused. Quality is excellent, waste is minimal with high operational efficiencies all round.

Level 5 works with synchronicity. This means that cyber physical systems are in place with smart embedded systems. Machine to human, machine to machine and human to human communications are facilitated by IoT. Big data can be used to predict scenarios and preventative measures can be put into place ensuring resilient, optimised manufacturing systems. Predictive analytics become the driver of the whole system and it becomes self-configuring.

4.1.5 Fourth Industrial Revolution

This the age of the digital technologies. The key elements are; the internet of things, digitisation, blockchain, advanced materials, additive manufacture, artificial intelligence and robotics, drones, energy technology, biotechnology, neurotechnology and virtual and augmented reality.

In 2018, Klaus Schwab in his book *'The Fourth Industrial Revolution'* explains that the fourth industrial revolution extends and transforms digital technologies. They are connected to one another and this connection allows the digital technologies and capabilities to expand. Information storage, processing and communication are the vital elements. The fourth industrial revolution technologies disrupt creating new value sources, and the new digital technologies will be the 'usual' going forward. (p. 20-21). The digital networks facilitate the movement and manufacture of physical products by knowledge transfer. Digital products can be reproduced at very low costs. In the third industrial revolution, physical systems disappeared into the digital, for example, digital recording of music, and, in the fourth, the digital is remerging into the physical, for example, 3d printing. (Schwab, 2018)

4.1.6 The Fifth Industrial Revolution – looking into the future

The fifth industrial revolution will bring challenges for humanity. More and more income inequality will become a worldwide problem. The few will possess most of the world's wealth and control. Automation will increasingly change the dynamics of the workforce. Work can be classed into either *'highly exposed to automation' or 'less exposed to automation'.*

The new type of work created in an automated environment will require a highly developed set of skills which will not be within the reach of most. Current online security techniques will become outdated. International laws, regulation and governance will need to be reinvented to be agile and relevant to the emerging challenges.

The fifth industrial revolution has yet to be defined and is currently an exercise in predicting what might come about. From the literature, there are different understandings and visions of post-Industry 4.0. Following is an outline of different theories put forward which have been gathered from very different viewpoints and sources.

4.1.7 The Fifth Industrial Revolution - the paradigm shift

It is widely accepted that the advent of robotics and automation in previous industrial revolutions brought about paradigm shifts in the manufacturing industry - worldwide. It is therefore conceivable that the fifth industrial revolution will bring about a similar shift in norms and make the fundamental changes in our approach to industry and manufacturing.

Automation and robotics excel in the manufacture of standardised products using manufacturing processes in high volumes to an excellent quality level. When creativity or customisation is expected, the human being is key. The solution is collaboration of robots and the human. Traditional robots cannot work side by side with humans but collaborative robots or "Cobots" are designed to work in sync with human employees. The robot prepares the product in a rigorous manner, meeting specification requirements to a high standard, and the human then takes over to add the finishing touches to the product.

In 2018, Deloitte wrote a piece entitled *'The skills gap in US manufacturing 2015-2025 outlook'* and stressed that humans need to be put back into the loop but to do this, new and differently skilled employees are required to fill new job specifications. In summary, they noted that the skills gap is outlined in the following themes:

- Putting humans in the loop
- Expanding digital and "soft" skills
- Leveraging the digital toolbox (Deloitte, 2018)

As noted by Manmonthly, *"it is reported by recent report into skills gaps by Deloitte suggests that in the next decade, there will be 3.4 million jobs with only 1.4 million qualified workers to fill them. Robots are perfectly matched for many of these roles and cobots, in particular, can work side-by-side with human workers. Cobots are useful because they can take over mundane, repetitive and dangerous jobs while human workers move into higher-value positions".*

Continuing on, this report states that *"Cobots compared to other industrial robots can increase employment opportunities within businesses as they can increase productivity and encourage upgraded skillsets. Rather than replacing their human counterparts these devices work alongside people in manufacturing and processing tasks. Moreover, as manufacturers aim to increase outputs and develop new product lines, cobots can help them multiply their workforce and transition employees from monotonous positions into roles with greater job satisfaction and compensation. The cobot is not designed to replace the human workforce, but to take over strenuous or even dangerous tasks. As a result, human employees can use their creativity to turn to more complex projects. For instance, when robots take over minor assembly tasks, employees can move on to more nuanced assignments that require human ingenuity". (Manmonthly, 2019)*

In Industry 5.0, collaboration between Cobots and humans will mean an increase of productivity, quality, output level and, most importantly, innovation. Safety will be increased, and workers will experience more personal satisfaction because the work that they undertake will be more interesting and motivating. Because of the 'connected' workforce of man and machine working together, there will be a knock-on benefit of agility. This means that the company will stay ahead of its competitors in terms of diverse product offerings, operational efficiency and keeping labour costs down in an increasingly competitive world.

Manufacturing in Industry 5.0, according to Accenture, is where each actual product to be manufactured will be based on the individual customer needs. The final product will be designed for the individual based on their personal requirements. The product will be manufactured in an agile manner, taking the digital requirements and using radical new manufacturing techniques and materials. These products, in some cases, can be an extension of the human mind or body which will require new radical ethical protocols and governance to be put in place. It is predicted that the products manufactured by the fifth industrial revolution will bring new technologies to the mass population. This means manufacturing will not be just agile and lean but automated, digital and data driven. Products will be of extremely high quality and available at more affordable prices. These products must be the best available and the supply chain optimised to support manufacturing.

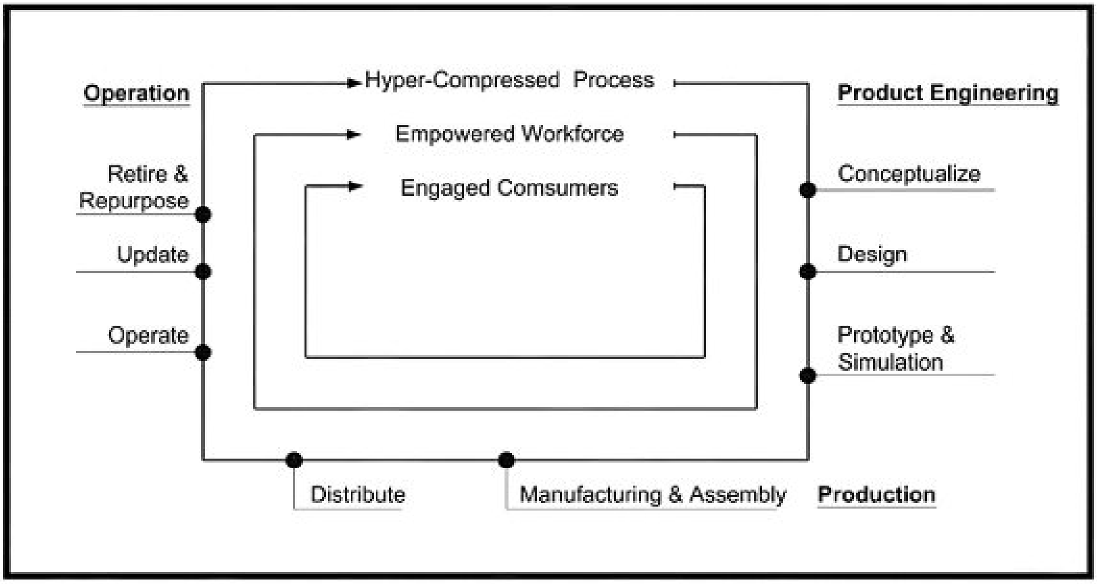


Figure 14 Adapted from Industry X.O product manufacturing reinvented. (Accenture, 2019)

"In the Industry X.0 era, manufactured products become a mechanism for understanding the product attributes that consumers value. Today, new products are launched onto the market only after significant investments have been made into design and prototyping. With always connected products, that will change fundamentally. The products themselves become a data point for automating the design of new products and modifying products that are already in use by customers in real time. Leveraging Industry X.0, businesses will integrate multiple technologies to compress timelines from months to days, and digital businesses will go to market with new products in a fraction of the time it takes their 'less' digital competitors.

Industry X.0 will be pervasive much sooner than most people think. Encompassing every area of operations from processes, to workers, to customers, it will drive completely new digital setups across business functions, operating models and new software-enabled connected products. Wholesale digital disruption of the industrial sphere will follow.

To succeed and remain relevant in this transformed industrial landscape, companies will need to grow the 'new' across their businesses, combining emerging technologies holistically to reimagine how they operate." (Accenture, 2019)

Phill Cartwright, executive chairman of the Centre for Modelling & Simulation, looks forward to the fifth industrial revolution and predicts the role humans will play in an automated manufacturing environment in an online article from Raconteur.net. Moving from Industry 4.0 to Industry 5.0, will lead to the creation of even higher-value jobs than before. The reason for this is that the freedom of design and the associated responsibility is handed back to the human designer/engineer.

Cartwright continues *with "a recent study from Meggitt shows the workspace doesn't become smaller in terms of a manufacturing cell around the human being; it actually becomes bigger. The human being has more responsibility and you end up with a bigger, lighter environment that's safer than the previous environment. The manufacturing operative within the manufacturing cell starts to become more involved in the design process rather than the manufacturing process, which is more, or less, automated. It allows freedom of design to work with you and it enables products that are more bespoke and personal."*

He continues, *"If you take that to the next stage and you have true, seamless data between the field, the manufacturing process and the design, you're taking humans out of the manufacturing route, but they'll be more involved in how the product is being used and how it can be designed because they have more information. Flipping the aeronautical and automotive industries from a fossil-fuel world to an electrical world, for example, is going to be a significant design challenge and it will be much easier for humans to solve if the mundane tasks are being dealt with by AI techniques and robots".* (Raconteur, 2019).

Imagine a manufacturing system where the humans are not involved, where the customer and the data used for the bespoke product are connected to the design. Human intervention is at the design end, and focuses on how the product is used, which, in turn, is based on the real time data from the field.

Universal Robots state that Industry 4.0 facilitates mass customisation, but the modern customer wants more than this. They state that *"they are looking for mass personalisation, which can only be had when the human touch returns to manufacturing. This is what we call Industry 5.0. The vision is that Industry 5.0 products will empower people to express themselves and this will be at a higher premium price to do so".* Universal Robots believe that these premium products can only be made through human involvement and human engagement.

They state that *“collaborative robots (Cobots) are exactly the tools companies need to produce the personalised products consumers demand today. Cobots bring the human touch to the masses”.*

In terms of the manufacturing environment, by bringing humans back into the centre of industrial production, the customer will get the premium product that they desire and workers will have more meaningful jobs in a factory environment and this changing working environment will be a more interesting and stimulating one for the worker. (Universal.com, 2019)

Korcomptenz are a technology company who provide a competitive advantage for their customers with innovative technology solutions by addressing business challenges and driving growth. They explain that industry is *“currently still in the midst of Industry 4.0, where manufacturing has become "smart" through the development of AI, the Cloud, the Internet of Things, and other such systems. The basic principle behind the fourth industrial revolution was that through linking machines and other intelligent devices, manufacturers could create smart networks throughout the value chain (from materials to production) that could control each other.”*

They state that *“the pace of technology change keeps increasing, the emergence of industry 5.0 before many companies have fully implemented 4.0 should put the topic to rest. We're living in an era of Moore's Law—the Intel co-founder's dictum that processing power would double every 18 months. However, it's not the evolution in microchip technology that's causing such rapid acceleration in industry, it's the nature of the software. The emerging combination of big data and intelligent algorithms, often called machine learning and AI, connected by an increasingly ubiquitous mobile internet is on the cusp of changing everything, again”.*

As Industry 5.0 is rapidly approaching it will bring with it an increased human touch back to manufacturing. It is thought that “where Industry 4.0 put smart technology at the forefront of manufacturing, 5.0 will encourage increased collaboration between humans and smart systems.” Bringing the high speed, optimised automation together in a meaningful way with the cognitive, critical thinking of the human being in Industry 5.0 will mean human and machine will be working together in a revolutionary manner to solve problems of the future and produce personalised products of high value.

“While Gartner predicts that by 2020, artificial intelligence will have eliminated 1.8 million jobs due to automation, they also predict that there will be 2.3 million more jobs created in their place due to the use of this technology. As you go from industry 4.0 to industry 5.0, you create even higher-value jobs than you did before because you're giving the freedom of design responsibility back to the human. Industry 5.0 is not about replacing humans in the workplace but about getting rid of outdated and "dead-weight" processes and using humans in much more valuable positions”.

Korcomptenz state that increasingly more manufacturers are using the skills and adaptability of human beings to increase efficiencies in difficult to automate areas, as well as customisation. They give the example of Toronto's Paradigm Electronics, which manufactures high-end loudspeakers. *“The company uses Universal Robots' UR10 robotic arm to polish the speaker cabs to a high-lustre sheen, but it takes considerable time to do so. By adding a human counterpart, however, it increased its production efficiency by 50%. The idea of collaboration between humans and robots on the assembly line is not a vision of the distant future. In fact, consulting firm Accenture recently released an outlook from a survey they conducted with 512 manufacturing executives from all over the globe, revealing that 85% of them envision a collaborative production line between humans and robots in their plants by 2020. It's quite the impressive outlook, considering that target date is just three years away“* (Korcomptenz.com, 2019).

Vural Özdemir and Nezih Hekim have written about the new debates of extreme automation IoT, AI, and the Industry 4.0. They say that Industry 4.0 is a high-tech strategy for manufacturing automation that employs the IoT, thus creating the Smart Factory. Extreme automation until *“everything is connected to everything else” poses, however, vulnerabilities that have been little considered to date”.* The vulnerabilities that they outline are risks in the event of network failures or failure of individual elements of the networks and risks due to the authoritarian governance of networks. If individuals are in control of networks this can create new social and political power structures.

A solution to these risks is using a three-dimensional symmetry in innovation system design or “a built-in safe exit strategy*”* in case of demise of hyperconnected entrenched digital knowledge networks. Importantly, such safe exists are orthogonal—in that they allow “digital detox” by:

- employing pathways unrelated/unaffected by automated networks, for example, electronic patient records versus material/article trails on vital medical information
- placing equal emphasis on both acceleration and deceleration of innovation if diminishing returns become apparent
- undertaking next generation social science and humanities (SSH) research for global governance of emerging technologies.

"Post-ELSI Technology Evaluation Research" or PETER considers the technology opportunities in the areas of cost, ethics, ethics-of-ethics, framings (epistemology), independence, and technology policymaking. They state that Industry 5.0 is in a position to harness extreme automation and big data with "*safety, innovative technology policy, and responsible implementation science, enabled by 3D symmetry in innovation ecosystem design"*. (Özdemir, V., and Hekim, N., 2018)

4.2 Ireland's Manufacturing Industry

4.2.1 Introduction

Blomström et al. in 1994 emphasised the importance of multinational enterprises when analysing the technological footprint of a country. They stated that *"technology transfer can trigger and speed up economic development, for instance, by facilitating the production of goods with higher value-added content, by increasing exports and improving efficiency. Multinational enterprises possess the bulk of all patents worldwide, most of the world's research and development takes place within multinational enterprises, and multinational enterprises possess many of the technologies that are pivotal to economic and industrial development."*

In the context of the Irish case study in this research, this statement is important as, historically, Ireland was seen as a low-tech country. He goes on to say that these critical technological competencies cannot be obtained easily, and foreign direct investment is *"the fastest, most efficient and sometimes only way for developing countries to get access to these competencies. Multinational enterprises can also play a central role in the transfer of know-how, knowledge and experience to the local workforce through its employment of indigenous professionals and managers."* (Blomström et al., 1994).

4.2.2 A unique history

The manufacturing landscape of Ireland has evolved since the 1990s when the Irish economy experienced high rates of economic growth and relatively low unemployment rates relative to other European Union and OECD countries. The increase in the real

Gross Domestic Product was over 10 per cent between the period of 1995 and 2000 when compared to growth rates of between two and three per cent in the EU and OECD countries. Ruane and Ugar in 2005 noted that the result in Ireland of this high growth rate of employment and output was that there were substantial increases in the general level of labour productivity in the economy, as output growth exceeded employment growth. (Ruane, F., and Ugur, A., 2005)

In 2006, Buckley and Ruane noted that Ireland is unusual in Europe because it *has "consistently promoted export platform inward investment into the manufacturing sector for over four decades. Starting in the 1970s, it promoted multinational enterprises selectively, and from the mid-1980s, it has sought to develop strong industrial clusters based on multinational enterprise investments in key high-tech sectors".* They go on to state that multinational enterprises now account for almost 50 per cent of manufacturing employment and define the Irish manufacturing sector over the past 20 years. (Buckley, P.J., Ruane, F., 2006)

The Irish government state that *"Ireland has a strong manufacturing base employing 227,000 people in key sectors such as Pharmaceuticals and Chemicals, Food and Drink, Medical Devices, Computers and Electronics, and Engineering in 2018."* Its vision is that by 2025 it will be a competitive and innovative hub pushing the boundaries to be a leader in the adoption of Industry 4.0. (Department of Business, Enterprise, and Innovation, 2019)

Following are some statistics from the Irish Governments Irish Central Statistics Office. (CSO, 2020) GVA represents the value of the goods and services produced.

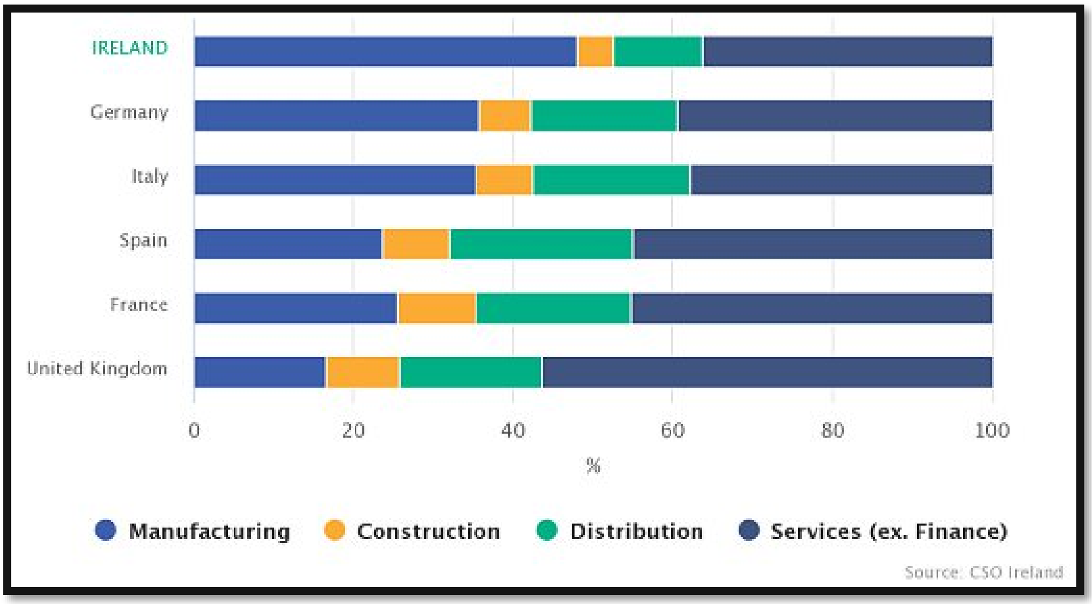


Figure 15 GVE by detailed sector in 2018. (CSO, 2020)

The manufacturing sector in Ireland accounted for the highest share of total Gross Value Added (GVA) at 48.1% in 2017 as compared to other European countries. This figure excludes financial services. This highlights the importance of manufacturing to the Irish economy.

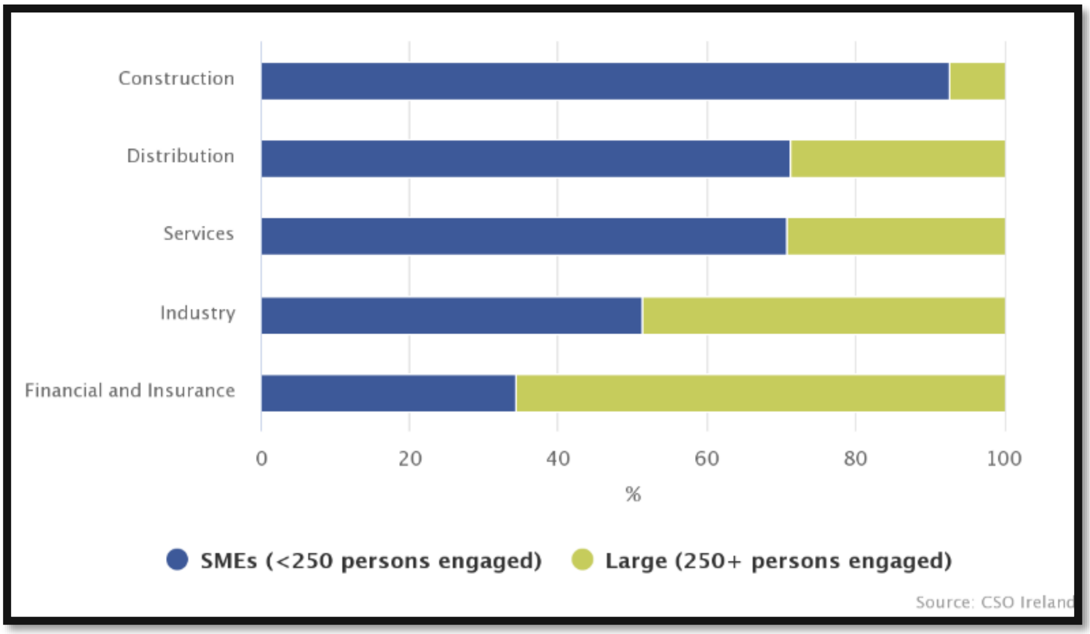


Figure 16 SME percentage share of persons engaged by sector 2018. (CSO, 2020)

In 2018, in Ireland, 51.4% of employees in the industry sector worked in small to medium enterprises and therefore, 48.6% worked in large enterprises. This demonstrates that the large enterprises play a significant role in Irish industry employing nearly half of the workforce.

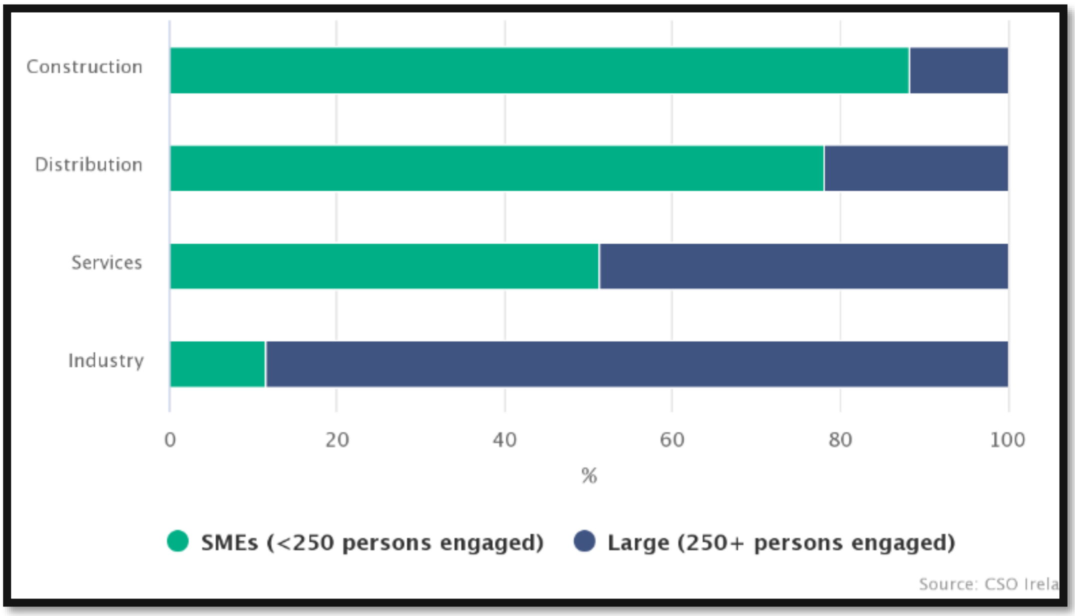


Figure 17 Percentage share of GVE by sector in 2018. (CSO, 2020)

In Ireland, in 2018, 11.5% of GVE in the industry sector is attributed to small to medium enterprises, therefore, 88.5% was attributed to the large industries.

In summary, it can be deduced from the above graphs that manufacturing plays an especially important role in maintaining Ireland's economic stability. The larger companies account for just under half the employees in the manufacturing industry. In addition to the employment figures, the Gross Value Added by these large manufacturing companies accounts for 88.5% of all the GVA in the industry sector. The importance of manufacturing in Ireland cannot be understated. The contribution of the small and medium companies is a lot less than the larger ones, but both are particularly important moving into the next phase of Industry 4.0 and 5.0. Both must be at the cutting edge to remain competitive, and therefore viable, into the future in the global marketplace.

4.2.3 The future of the pharmaceutical industry in Ireland, a particular case

Liam O'Brien is the Managing Director of Enterprise System Partners (ESP) in Cork, Ireland and was interviewed by the Irish Times newspaper in 2019. This company is a life sciences specialist firm founded in 2003, providing consulting and support services for manufacturing operations in biotechnology, pharmaceutical and medical devices.

ESP digitally tracks and documents the bio-pharmaceutical production process, leading to increased automation in the supply chain.

O'Brien talks about the 'compressive disruption' which is facing the pharma industry globally and is concerned that Ireland could be susceptible to another 'patent cliff or patent slope'. To mitigate against this risk, O'Brien recommends that Irish companies need to *"ensure sites here are well positioned for the increased pace of change and complexity coming from new sciences will be key".* He continues with *"investment in digitalisation in pharma manufacturing, quality control and supply chain can help the sector cope with the shortened lead times, cost pressure, increasing complexity and mix of treatments in their portfolio. If the Irish life sciences sector can use these digital tools to retain its reputation for agility and flawless execution in supply chain, it can ensure it is well positioned for the upside from disruption".*

New science and pharmaceutical products will lead to personalised medicine. The result is that drugs will be increasingly complex and this will give rise to increasingly complex drug manufacturing with a reduced development cycle. This will put increasing pressure on the manufacturing and supply chain. *"The only real response is digitisation and control, to give you the flexibility and agility you need to cope,"* says O'Brien. It's amazing now that the world's best-known blockbuster drugs *"were produced on paper-based systems,"* he says. *"The future is digital. It will see a mix of new technologies from the Internet of Things and data analytics to artificial intelligence, robotics, and 3D printing. In other words, for the personalised medicines that new science is helping create, a new manufacturing prescription is required: Industry X.0. The large installed base of biopharma manufacturing and R&D in Ireland, together with the well-developed support ecosystem, means we are well placed to develop a global leading digital environment for the development and manufacture of these 'new science' drugs".* (The Irish Times, 2019)

4.2.4 The future of Irish industry and Government policy

Leal-Ayala et al. in 2018 described Ireland as being well positioned to take up opportunities from the *"digitalisation of manufacturing."* They state that *"the country has built important industrial capabilities over decades and hosts a disproportionate share of top global firms in a few manufacturing sectors and process industries".*

The report continues by saying that Ireland has a relatively highly skilled workforce, and has good regulatory know-how, an increasing number of industry-academic collaborations which all contribute to Ireland being seen as a 'digitalisation front-runner' in Europe. In addition, Ireland is a small country which means stake holders can work together more easily and troubleshoot problems efficiently. *"Finally, Irish enterprise agencies' continuous interaction with firms and accumulated industrial expertise represent another distinctive advantage when it comes to effective policy implementation and coordination."* Some industry clusters in Ireland are ahead in the digital journey but in general *"manufacturing firms based in Ireland will need to further exploit the potential of digital technologies to remain competitive internationally."* (Leal-Ayala et al., 2018)

The Department of Business, Enterprise, and Innovation in Ireland in 2019 sets out the goals for 2025 as:

- *"To stimulate firms to adopt and build capability in Industry 4.0 technologies.*
- *To stimulate firms to harness the new opportunities enabled by Industry 4.0 technologies.*
- *To become a global leader in RD&I which underpins Industry 4.0.*
- *To facilitate the current and future workforce to develop the skills to deliver the Industry 4.0 transformation and exploit the new opportunities arising in manufacturing and supply chain firms through Industry 4.0 technologies.*
- *To establish a world class business environment for Industry 4.0 which is underpinned by an appropriate regulatory, legal, standards, and internationally connected ecosystem."*

It continues to highlight specific strategic themes to help implement these goals at a national and regional level. (Department of Business, Enterprise, and Innovation, 2019)

4.2.5 Previous collaborative robotics Irish survey [Irish Manufacturing Research]

2010 saw *"ICMR and i2e2 established as Industry-led initiatives to pilot a new type of research model in Ireland: independent, applied-research centres, to act as a bridge between Academia and Industry. A consortium of industry partners established the centres in partnership with the state's enterprise agencies. ICMR focused on delivering manufacturing productivity solutions and i2e2 on Industrial Energy Efficiency."* (IMR, 2020a)

This organisation has gone from strength to strength over the past 10 years and in 2020, Irish Manufacturing Research celebrated its sixth year in partnership with a large and expanding industry network with over 60 experienced staff and a portfolio of highly impactful research for industry. IMR has grown strong linkages to Europe and won multiple EU funded programs. IMR is seen as the expert body in Ireland of automation integration into Irish industries.

"IMR's comprehensive R&D program offers collaboration across the four thematic pillars: Digitisation, Automation & Advanced Control, Design for Manufacturing and Sustainable Manufacturing, to deliver solutions that enable industry to increase productivity, improve efficiency, upskill and build resilience, win new business and launch new products." (IMR, 2020a)

Over the period of this research, staff from IMR have been extremely helpful. One of the ways they helped was by sharing a survey undertaken in the area of automation and collaborative robotic adoption into Irish companies. (IMR, 2020b) The objective of the survey was to understand the current state of collaborative robotics applications in Irish manufacturing and to identify the major concerns that engineering managers and manufacturing directors have which prevent the wider adoption of collaborative robotics applications. The sample size was small (n=23) but the results were very informative.

The profile of the survey respondents was as follows:

- Engineer (production, applications, automation, project) x 8
- Managers x 4
- Director of Technology or Innovation & Excellence / Domain leader x 3
- Researcher x 2
- General manager x 2
- Managing director x 2
- CTO - CEO x 2

The profile of the companies that the respondents came from was as follows:

- Large 39%
- Medium 9%
- Small 30%
- Micro 22%

Current level of robotic engagement in their companies:

- We do not have any Robotic applications in our organisation: 5%

- Some of the processes in our organisation include Robotic Systems: 68%
- Most of our processes in our organisation include Robotic Systems: 25%

Note: The surveyed companies whose processes included robotics systems were small and large organisations.

The most insightful result of the IMR survey was the question on the ranked concerns that the respondents have over the adoption of the Cobots. These can be seen in the figure below.

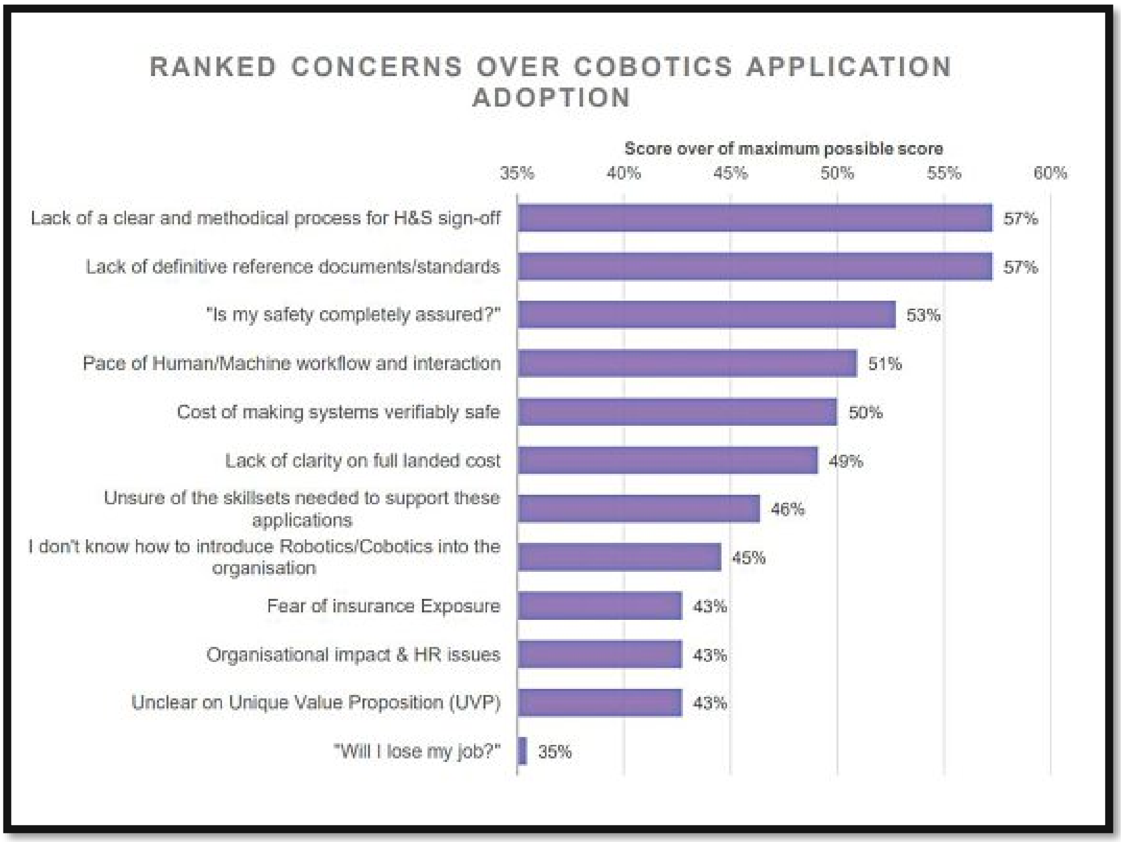


Figure 18 Ranked Level of Concerns (IMR, 2020b)

Details of how the ranking were established are as follows:

“Participants were asked to rate pre-identified challenges on a scale from 1 to 5 according to the participant’s level of concern. A rating of 1 corresponds to un-existing concerns, whereas a rating of 5 corresponds to a challenge preventing the surveyed from meaningfully engaging with HRC application at this time.

The scores for each of the 12 challenges were summed up and divided by the maximum score possible (5 x number of participants). Results are shown in the "Ranked concerns over Cobotics application adoption bar chart."

They found that the highest scoring concerns over collaborative robotics applications were:

- Lack of a clear and methodical process for Health & Safety sign-off (57% score)
- Lack of definitive reference documents/standards (57% score)
- Is my safety assured? (53%)
- Pace of human/machine workflow and interaction (51%)
- Cost of making systems verifiably safe (50%)
- Lack of clarity on full landed cost (49%)
- Unsure of the skillsets needed to support these applications (46%)
- I don't know how to introduce Robotics/Cobotics into the organisation (45%)
- Fear of insurance exposure (43%)
- Organisational impact & HR issues (43%)
- Unclear on Unique Value Proposition (UVP) (43%)
- "Will I lose my job?" (35%)

Themes emerging are from the IMR research are:

Health and Safety – ("lack of clear and methodological process for H&S sign off, lack of definitive reference documents/standards, is my safety assured?")
Cost – ("Pace of human/machine workflow and interaction, cost of making systems verifiably safe, lack of clarity on full landed cost, fear of insurance exposure, unclear value proposition")
Skills, education, and training – ("unsure of the skillsets needed to support these applications, will I lose my job?")
Technical / Ease of use – ("I don't know how to introduce Robotics/Cobotics into the organisation")
These themes, it will be shown, will correlate with the themes derived from the case studies undertaken in this research both in the literature reviewed and in the case studies following.

In conclusion:

"This industry survey indicates that while most of the surveyed are starting or have deployed collaborative robotics applications (73% of the participants), the level of human-robot collaboration is mostly limited to sequential collaboration and below (12 participants over 16 who have started/already deployed HRC applications). The lack of a clear and methodical process for Health & Safety sign-off and the lack of definitive reference documents/standards are the most prevalent concerns across the 23 surveyed individuals and have been the most frequently rated as preventing a meaningful engagement with human-robot collaborative applications at this time." (IMR, 2020b)

4.3 Robotics in the modern manufacturing industry

Robots have, over the past 30 years, developed at an increasingly rapid rate. The diagram from Kopacek below illustrates the wide and varying directions these development trends have taken.

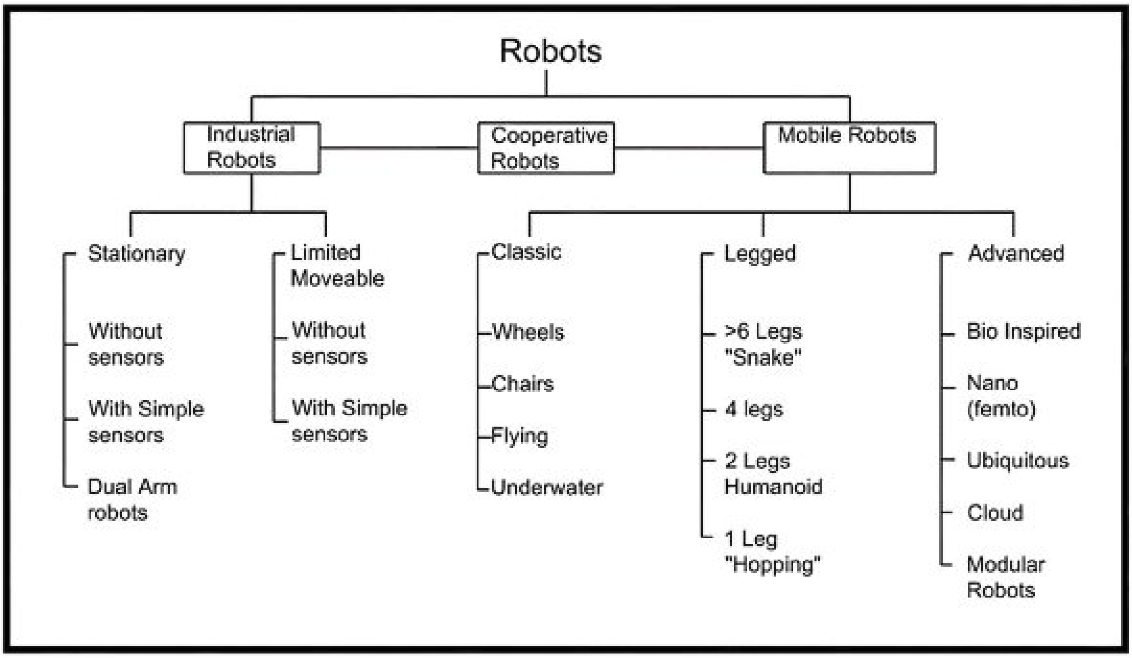


Figure 19 Adapted from the categorisation of robots (Kopacek, 2019)

The range of robots starts with the basic stationary industrial robots that used either numerically controlled, computer integrated or intelligent manufacturing systems. These are categorised as "unintelligent".

In modern factories, these "unintelligent" robots can be fitted out with simple external sensors for intelligent tasks. They also can have 7 or 8 axes to increase the degrees of freedom. Some industrial robots can have limited mobility, some with sensors and some without. These are referred to as service robots. Kopacek continues by explaining that mobile robots are divided into three categories, classic, legged, and advanced. Autonomous Guided Vehicles (AGVs) have intelligent sensors and have an ever-increasing number of applications.

Classic mobile service robots can be used for cleaning pools, as lawnmowers, for healthcare assistance and so on. They can also be used for hobbies such as playing sport. Another category in the mobile robotic field are the legged robots. They have been around for a number of decades. According to Kopacek, *“usually they have more than 6 (snake), 4 (multiped) to 6 (hexapod), 2 (biped) or one leg (hopping) degrees of freedom (DOFs). Walking on two legs is from the viewpoint of control engineering a complex stability problem. Biped walking machines equipped with external sensors are the basis for “humanoid” robots. Some prototypes of such robots are available today.”*

As can be seen from Figure 19, cooperative or collaborative robots are an important trend in modern robotics as are advanced robotics. Both of these categories will be described next.

4.3.1 Modern robots

In 2015 an award-winning book by Martin Ford called “The rise of the robots” describes how we are on the precipice of a new automation wave which is different to previous eras. Ford depicts an upcoming explosion in robotics some of which is linked to free, open source robot operating system (ROS). One of these systems has been designed by Stanford University. This means that software developers worldwide can have free access to it which will result in widespread use. *“The history of computing shows pretty clearly that once a standard operating system, together with inexpensive and easy to use programming tools, becomes available, an explosion of application software is likely to follow”.* (Ford, 2015, P. 6). Standard, low cost available software and hardware will be used as building blocks for invention and applications.

Kopacek, in 2016, describes ROS as *“a common system for exchanging information through a peer-to-peer network between robots. With a wide compatibility with other applications and the goal of code reuse, it is already one of the most used platforms.”* He continues to say that “ROS is compatible with Europe’s “RoboEarth”, which is a platform where robots can share their data like the internet for humans. This knowledge is easy to use and accessible for other robots. The United States invented “RoboBrain” and has similar skills with one extra step. It also has a knowledge representation layer on top of data storing, sharing and communication”. (Kopacek, 2016)

So, what are the other important features of modern robots which are transforming how they are used in manufacturing environments? Figure 20 shows these features, and they are summarised in the following paragraphs.

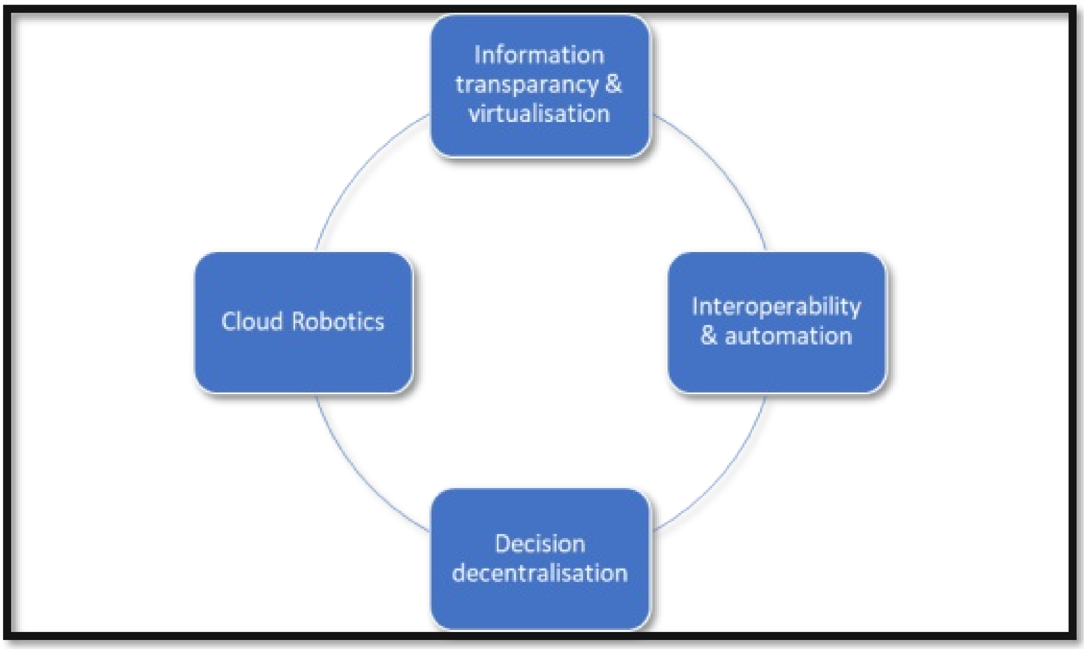


Figure 20 Features of modern robotics.

Information transparency and virtualisation - current information systems have the ability to create a copy of the physical world. They enrich digital factory models with sensor data producing a cyber physical system and digital twin.

Inter-operability and automation - the inter-operability of machines and devices, sensors and people has become mainstream. Industry provides the possibility of connecting physical systems and humans. They can communicate with each other by using the IOT. Greater automation is the result.

Decision decentralisation - the ability of a cyber physical system to make decisions on their own makes it possible for decisions to be decentralised. Humans can intervene to make modifications where necessary, but the majority of decisions are made by the machine.

Cloud robotics - the migration of much of the intelligence that mobile robots have into powerful centralized computing hubs. This enables dramatic acceleration in the rate data can be communicated, offloading the computation required to huge data centres.

According to Kopacek, *“cloud robots use a cloud computing infrastructure for fast processing of data, particularly data intensive tasks such as image processing and voice recognition. This has the advantages of reducing the memory and processing requirements of the onboard processor or other computing device, since the robot uses the processing power of the cloud computing infrastructure.”* He says that conventional robot’s task (grasping an object, moving a foot or image recognition) requires powerful computers with large on-board batteries. All of this has changed with cloud robotics and increased capabilities are the key. (Kopacek, 2016)

As a result, individual robots can use the network for resources. This leads to less expensive robots with less on-board computational power and memory. Also, instant software upgrades are possible across multiple machines. Cloud robotics is required especially where visual recognition is required. Privacy issues, hacking and cloud security are an important risk factor in cloud robotics, transport of vital goods, industrial machinery, medical devices, electrical grid and so on. (Kopacek, 2016), (Ford, 2015)

Kopacek continues by stating that in the near future improvement to algorithms will bring exciting possibilities. Most importantly, with the use of cloud, these new software breakthroughs will be available to the widespread robotics community and not just to specific laboratories. Specialists have the ability to collaborate and work openly with other specialists. He states that the same is true for hardware as there are a lot of breakthroughs in the mechanical engineering robotics sphere also. *“Those results are lighter, more powerful and easier to handle hardware.”* (Kopacek, 2016)

4.3.2 Opportunities

In recent times, the effect of the latest robotics and automation in a high cost environment, such as the USA, is to allow the reshoring of manufacturing industries to come back to the mainland. Ford, in 2015, describes the example of Parkdale Mills South Carolina which was cited in the New York Times. Here, high levels of automation have resulted in low levels of employment; 140 instead of 2,000 for the equivalent volume of product without automation. (Ford, M., 2015)

In the USA between 2009 and 2012, the textile industry has increased by 37%, to 23 billion dollars, due to the introduction of modern robotics and automation. This is providing employment that had been eliminated by off shoring to China, India, and Mexico due to their inexpensive labour. This turnaround is being driven by automation technology so efficient that it is competitive with even the lowest paid offshore workers.

Another example mentioned by Ford is that UK clothing exports have doubled between 2003 and 2013. Continued reshoring is expected to result in the creation of 20,000 new jobs in this industry by 2020. This is due to the introduction of robotics and automation.

The introduction of these sophisticated labour-saving technologies has a mixed impact on employment – they do not directly create large numbers of jobs, but they tend to drive an increase in employment in suppliers with increased volume of raw materials, for example.

Overall, competition is improving because of rising offshore labour costs and availability of this new technology. Ford quotes that labour costs have risen in China by 20% between 2005 and 2010. Nearly half of American companies with sales of over 10 billion dollars were considering reshoring in 2012, and in the UK in 2014, one in six companies were reshoring to improve product quality and delivery times (p. 9-10). Bringing back manufacturing near the consumer has multiple advantages: reduction in transport costs and associated emissions, lead times are cut, and manufacturing is more responsive to customers. As automation becomes more flexible and sophisticated, more customisation will be offered to customers. Flexible robotics allows the manufacturing environment to keep up with changeable outputs demanded by costumers.

4.3.3 Risks

Eventually, factories will become fully automated so these newly created jobs may be transient and not last. In China, for example, between 1995 and 2002 approximately 15%, (16 million), of manufacturing jobs have been lost due to automations and this will accelerate into the future. In China, government policy facilitates capital investment, rolling over loans, facilitating sizeable investments to happen continually. This allows companies to invest in expensive automation.

There is an assumption that the workers that are 'freed up' by automation can be upskilled for higher skilled jobs with higher wages. This is not guaranteed given that they need to acquire additional skills.

4.3.4 Collaborative machines

As technology advances and automation threatens more jobs, the strategy has been to offer education and training to up-skill, but the machines are coming for the higher skilled jobs as well. Jobs of the future will involve human collaboration with machines. Andrew McAfee from MIT says humans should learn *"to race with machines not against them."* (Ford, 2015)

According to Kopacek, a current trend in robotics is cooperation. *"Robots are connected by their controllers for synchronisation or controlled by one controller. Latest developments deal with a modularisation of the robots as well as the control system and collaborative robots (Cobots) for safe cooperation with humans."*

Kopacek continues to describe modern advances in robotics*: "Mobile platforms with external sensors are available since some years and cover a broad field of new applications. They are the basis of mobile robot platforms. On such platforms various devices, like arms, grippers, transportation equipment, etc., can be attached. Possible applications including tele-operation or semi-autonomous operation of robot platforms in various scenarios could be factory automation: operation in hazardous environments, planetary and space exploration, deep-sea surveying and prospecting, services…. Biped walking robots are much more flexible than robots with other movement possibilities. The main advantage of legged robots is the ability to move in a rough terrain without restrictions like wheeled and chained robots. Legged robots can work in environments which were until now reserved only for humans. Especially fixed and moved obstacles can be surmounted by legged robots. In addition to walking such robot could realise other movements like climbing, jumping… Intelligent robots – especially intelligent, mobile platforms and humanoid robots are able to work together on a common task in a cooperative way."* (Kopacek, 2019)

According to Cambridge.org dictionary: *cooperation* means showing a willingness to act or work together for a shared purpose and *collaboration* means the act of working together with other people or organisations to create or achieve something. (Cambrige.org, 2020)

Kopacek describes a multi- robot system as displaying cooperative behaviour *"if due to some underlying mechanism, there is an increase in the total utility of the system. There are three fundamental aspects for cooperative behaviour:*

- *the task the robots must perform*
- *the mechanism of cooperation*
- *the system performance"*

The International Federation of Robotics began to gather data in 2019. They produce forecasts for the collaborative industrial robot uptake based on the sales figures of robot suppliers. They state that in 2018 approximately 14,000 Cobots were installed out of approximately a total of 422,000 industrial robots. This is approximately 3.3% and is an increase of 23% over 2017. (IFR, 2019) Cobots are an ever-increasingly important subset of industrial robots in the manufacturing companies of Industry 4.0, 5.0 and 6.0.

In order to perform such collaborative tasks, a new generation of robots - collaborative robots (Cobots) were introduced in 2012. These robots are safe around humans by using sensors, force limiting and rounder geometries than traditional robots. This safety aspect is key to their success. In addition, they are lightweight which means they can be moved from task to task without much effort. Another very revolutionary feature is that they are easy to implement and technicians and operators, with minimum training, can use Cobots with very little programming experience.

It must be noted that a collaborative robot is not a replacement robot; it assists workers rather than replacing them. Figure 21 shows a family of Collaborative robots. UR3 on the left has a payload of 0-3 kg, UR5 has a payload of 3-5 kg and the larger UR10 has a payload of 5-10kg. (Universal Robots, 2019)

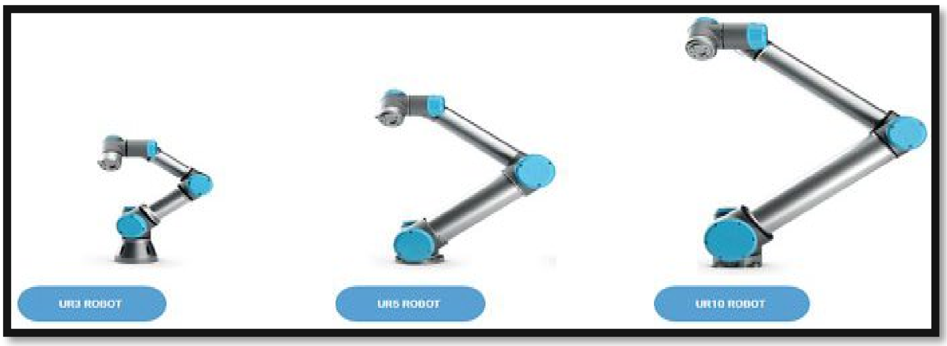


Figure 21 Cobot examples from Universal Robots. (Universal Robots, 2019)

Doyle-Kent et al. states that collaborative robots *"as detailed by the ISO10218 standard, robots can have four types of collaborative features. They are:*

- *Safety Monitored Stop*
- *Hand Guiding*
- *Speed and Separation Monitoring*
- *Power and Force Limiting.*

The Safety Monitored Stop is implemented in environments where the robots operate mostly alone, with occasional human interference. The feature will cause the robot to pause (though not shutdown) when the safety zone is violated (i.e. a human enters its workspace).

The speed and separation monitoring feature are an extension of Safety Monitored Stop. Instead of adopting a single behaviour throughout the robot's entire workspace, the latter is graded into several safety zones, Figure 22.

Hand Guiding enables the robot to move while the worker is in its workspace (as is possible with Speed and Separation Monitoring). Using an end-of-arm device capable of detecting applied forces, the robot can be guided by an operator for hand guiding and rapid path teaching." (Doyle, Kent et al., 2020(b))

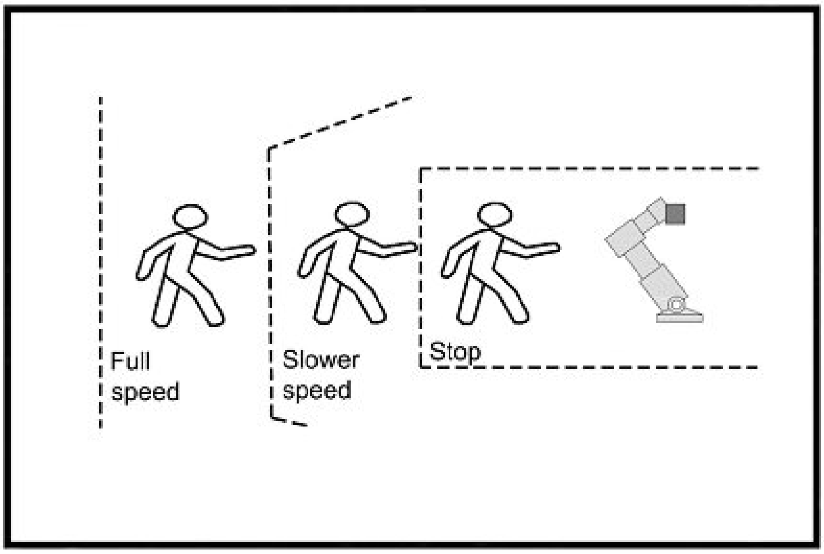


Figure 22 Adapted from speed and separation monitoring. (Doyle, Kent et al., 2020(b))

Cobots are designed to work alongside and in cooperation with humans. If it comes in contact with a human, it is designed not to hurt or injure them. The power and force limiting feature ensures this.

Elprama et al. in 2016 stated that *"Collaborative robots (Cobots) differ from the traditional industrial robots used in manufacturing, because they are designed to be safe (i.e. sensors on the robot can feel when a worker is approaching) without the need for the fences usually surrounding traditional robots. These technical developments lead to new opportunities in which factory workers and Cobots can work (closely) together in manufacturing".*

Teams of humans and robots collaborating efficiently can reduce the human idle time greatly. In addition, they are easy to include in a network, require minimum space on the factory floor, are easy to program and are low cost and safe.

Elprama et al. also says that with the remarkably high expected growth of the Cobot market in the future, it is surprising how little research is available that focuses on factory workers. They ask the questions; do we know if these workers are willing to work with these Cobots and what will the impact be on their working practices?

This is an important finding in the literature, especially when the forecasted number of Cobots and their value is considered.

The International Federation of Robotics describes the safety requirements of Cobots. *"Like any other piece of industrial machinery, collaborative robots must be safe. The International Organisation for Standardisation (ISO) has developed standards for robots operating in four types of collaborative mode. Compliance with these standards means the robot can in principle be used safely. However, a safe robot does not guarantee a safe collaborative application in practice. A process in which a safe Cobot wields a sharp tool is unsafe no matter how slowly the Cobot operates. End-users must conduct a risk assessment of the intended application to be certain they meet the legally binding standards for health and safety at work in their country. The assessment covers the entire application, including the workspace, the robot, end-effector, tools, work pieces and other elements such as cabling and lighting, that could pose hazards".* (IFR, 2019)

This interpretation of the safety requirements could be the most important influence on the uptake on Cobots in industry and further investigations into the case study in the Irish industry are required.

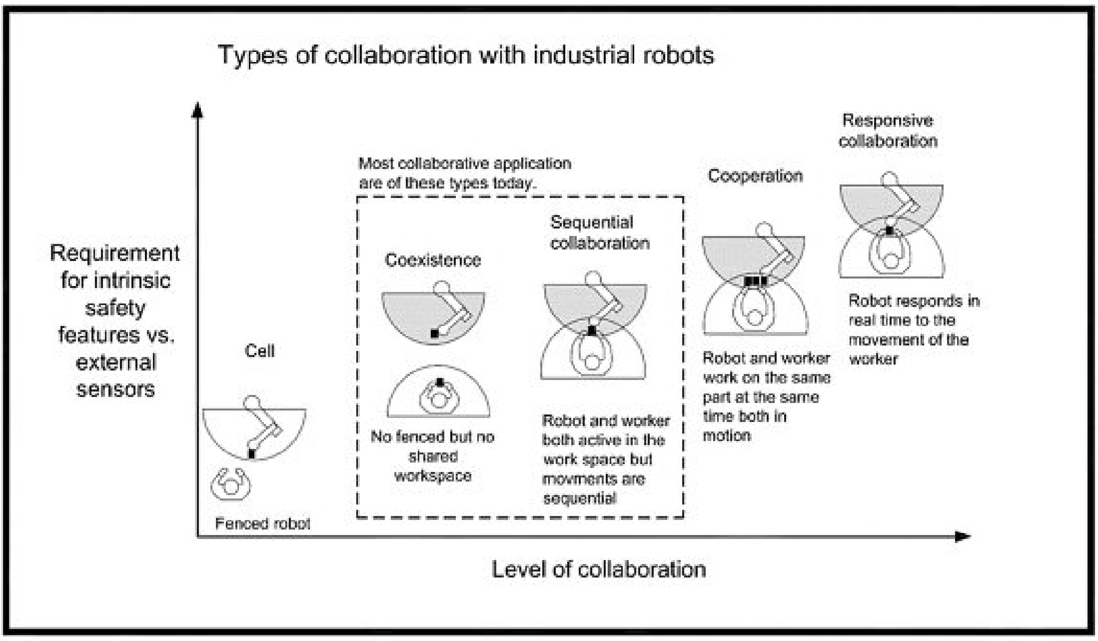


Figure 23 Adapted from Types of Human-Industrial Robot Collaboration - adapted (IFR, 2019)

Another significant point is how Cobots work with humans in the workplace and various options are illustrated in Figure 23 which has been adapted from the IFR paper. *"Human-industrial robot collaboration can range from a shared workspace with no direct human-robot contact or task synchronisation, to a robot that adjusts its motion in real-time to the motion of an individual human worker."* (IFR, 2019)

The trends highlighted by the members of IFR are that the most common application of this technology is the shared workplace with tasks being completed sequentially. An example of this is the Cobot tackling the more unergonomic or tedious tasks (lifting heavy parts to performing repetitive tasks such as tightening screws) that would have previously put the operator at risk of repetitive strain injury.

IFR continue to describe other ways that the human operator and Cobot work together. *"Applications in which the robot responds in real-time to the motion of a worker (altering the angle of the gripper to match the angle at which a worker presents a part, for example) are the most technically challenging. Since the robot needs to adjust to the motion of the worker, its movements are not completely predictable and therefore the end-user must be sure that the full parameters of its potential scope of motion meet safety requirements."*

The importance of *“how”* humans and Cobots work together cannot be underestimated as responsive collaboration which builds on *“precision and repeatability to achieve productivity”* is where Cobots become economically viable in robotic automation.

This research will look at the level of collaboration between humans and Cobots in the case study in the Irish industry and this should give an understanding of the value brought to the company by using this technology.

Cobots can be used in multiple ways in industry and the type of industry (products manufactured) and the level of previous automation (industrial automation level) in the factory are important when considering how Cobots can be integrated.

Examples of how they can be incorporated are provided by IFR (2019)

Example 1:
Cobots can be used to automate parts of a production line with minimal changes to the rest of the line, providing companies that have not yet automated production processes. This is particularly significant in small-to-medium-sized manufacturers (SMEs). The technology can bring automation the productivity and provide quality improvements.

Example 2:
In large multinational companies, for example, automotive manufacturers that have already automated the production of car bodies, the additional use of collaborative robots offers the opportunity to support workers in completing final assembly tasks that are often the source of chronic back injuries. Collaborative applications enable manufacturers to automate parts of processes that are tedious for humans – from fetching parts and feeding machines, to quality inspection which is hard for humans to do consistently well over long periods of time.

Thus, type of industry and the level of existing automation will be important in the case study.

In addition, IFR make the point that *“Cobots are usually lightweight and can be easily moved around the factory. They generally take up less factory floor space - a significant cost factor for manufacturers.”* Factory space, flexibility and cost are important factors for engineers and managers when justifying new technology.

“In the past, systems integrators and internal robot experts have been required to install, programme and operate industrial robots. Programming interfaces are now increasingly intuitive in both traditional robots and newer Cobots. Systems integration experts are still needed for complex applications and those requiring a re-design of the entire production process. For simpler, stand-alone applications, workers with minimal robot training can now easily re-deploy the robot to a new task. This is particularly important for manufacturers that operate short production runs and need to be able to quickly re-task the robot for a new run.”

An investigation of who programmes, installs, maintains, and operates the Cobot will be investigated in the case study.

When a company has limited or no experience of automation a comprehensive assessment needs to be made on the application before capital investment is made. The important questions here include: When to choose industrial robotics over Cobots? What are the defining features of each, how can one be justified over the other?

According to IFR, *“industrial robots often operate from a fixed mounting, but there is demand for mobile industrial robots that combine a mobile base and a (collaborative) robot. These robots can, for example, carry materials from one workstation and unload them or feed a machine at a second workstation. The right choice of robot – traditional or collaborative – is determined by the intended application. When speed and absolute precision are the primary automation criteria it is unlikely that any form of collaborative application will be economically viable. In this case, a traditional, fenced industrial robot is – and will remain – the preferred choice. If the part being manipulated could be dangerous when in motion, for example due to sharp edges, some form of fencing will be required. This applies even for Cobots that stop on contact.”*

Another important area that must be considered is the extent to which the robot must be integrated with other machines in a process. The costs will be significant if there is a high level of integration required with existing equipment.

IFR make the point that there are still many instances where it is more feasible to use humans. For example, where irregular shapes need to be sorted. At this moment, Cobots vision systems are not sophisticated enough to do this job as efficiently as a human. In the future this will probably change but for now this is the case. Another example is when finishing by polishing or grinding that requires fine tuning of the applied pressure. This is still exceedingly difficult to automate by Cobots. Where customisation is essential, the human is more suited to this task in certain instances.

The International Federation of Robotics began to gather data in 2019. They produce forecasts for the collaborative industrial robot's uptake, based on the sales figures of robot suppliers. They state that in 2018 approximately 14,000 Cobots were installed out of approximately a total of 422,000 industrial robots. This is approximately 3.3% and is an increase of 23% over 2017. (IFR, 2019)

ABI Research state *that "various (industrial) robot manufacturers are bringing collaborative robots to the market. This market is expected to rise from $100 million to $1 to $3 billion by 2020." (ABIResearch, 2020)*

ABI Research undertook an assessment of Cobot manufacturers and ranked the leading 12 in a study in 2019. They stated that there are currently over 50 manufacturers worldwide, but most do not have a product that is available on a meaningful scale.

The "*Industrial Collaborative Robots Competitive Assessment"* concluded that Universal Robots (UR) were in front, particularly in the implementation.

The companies ranked were:

- ABB
- Aubo Robotics
- Automata
- Doosan Robotics
- FANUC
- Franka Emika
- Kuka AG
- Precise Automation
- Productive Robotics
- Techman Robot
- Universal Robots
- Yaskawa Motoman

The innovation criteria included:

- Payload
- Software
- Ergonomics and human-machine interaction experimentation and safety

The implementation criteria focused on:

- units and revenue
- cost and ROI
- partnerships
- value-added services
- the number of employees.

"Market leaders in Cobots generally have well-developed Cobot rosters, in many cases backed up by an ecosystem platform that integrates applications, accessories, and end-of-arm-tooling (EOAT) solutions in with the base hardware," said Rian Whitton, Senior Analyst at ABI Research.

In the report it is noted that UR leads the number of units sold standing at 37,000, in second place is Taiwanese provider Techman with 10,000, and in third place is Korea-based Doosan with over 2,000.

The report states that Precise Automation, which uses an advanced direct drive solution to develop collaborative robots with higher speeds, was the most innovative of the 12 Cobot vendors, just leading Universal Robots.

There are several companies that are too young to be challenging the dominant parties in the Cobot market but are developing new and disruptive technologies that will allow them to rise to prominence in the years to come.

Productive Robotics in an example noted to be a future disruptive technological leader but it is at an early stage of development. The California-based developer has an arm with inbuilt vision, seven axes for superior flexibility, long reach, and a very affordable price point, but has yet to deploy at scale.

Automata is a low-cost disrupter suing ROS opensource software. This British company develops a ‘desk-top’ Cobot costing less than US$7,000. This will, in the future, make Cobots much more accessible.

Germany based Franka Emika, and Chinese American provider Aubo Robotics, also represent relatively new entrants to the market and are following Universal Robots and starting to compete with them.

ABI Research state that the large industrial robotics manufacturers like ABB, FANUC, KUKA AG and Yaskawa Motoman, whose clients tend to buy fixed automation solution through bulk orders are not as successful in the Cobot marketplace. They pose the question, is this down to focus? Are the clients of Cobots more one off or smaller volumes in comparison to industrial robots? Are the clients more varied? In addition, all four of these companies are competing for the higher Chinese volumes, where the Cobot opportunities, relative to the market for traditional industrial systems, are smaller than in Europe or North America. *“Though many of the Cobots deployed by these companies are impressive, and they have a lot of software services, the high-cost and lack of easy use among their systems largely defeat the current value proposition of Cobots, making them the laggards in this competitive assessment,”* says Whitton.

Whitton predicts changes in the Cobot market. He believes that the larger industrial robot manufacturers and smaller innovative newer companies will improve their position in this market because:

- Higher volumes/scaling up to demand
- Second generation Cobots with significant hardware improvements
- Innovative lower cost models improved flexibility, and common platforms
- Ability to retrofit collaborative capability on industrial robots

4.3.5 Robotics and the human workforce

In 2020, Acemoglu et al. undertook a study to analyse the effect of increasing the use of industrial robotics in manufacturing on US local labour markets, between 1990 and 2007. They point out that between 1993 and 2007, the stock of robots in the United States and Western Europe increased by a factor of four. In fact, in the USA, this was a ratio of one industrial robot per 1,000 workers and in Europe, the ratio was 1.6 to every 1,000 workers. Acemoglu et al. go on to state that “*the IFR estimates that there are currently between 1.5 and 1.75 million industrial robots in operation, a number that could increase* *to 4 to 6 million by 2025. The automotive industry employs 39 per cent of existing industrial robots, followed by the electronics industry (19 per cent), metal products (9 percent), and the plastic and chemicals industry (9 per cent). We also document that the employment effects of robots are most pronounced in manufacturing, and in particular, in industries most exposed to robots; in routine manual, blue collar, assembly and related occupations; and for workers with less than a college education."* In addition, they find that there is a more profound effect on the employment of men than women, but both are negatively affected. (Acemoglu, 2020)

Another study that reflects the outcomes of Acemoglu et al. is a pioneering paper by Graetz and Michaels (2017). This research focuses on the variation in robot usage across industries in different countries and the results state that industrial robots increase productivity and wages but reduce the employment of low-skill workers.

In 2019, Massachusetts Institute of Technology (MIT) published its Fall 2019 report entitled *"The Work of the Future: Shaping Technology and Institutions."* It describes the negative historic relationship with increased automation in the American automobile and electronics industries stating that *"industrial robots have displaced production workers and had negative impacts on earnings and overall employment in the local labour markets where large manufacturing plants are based. These effects are economically, socially, and politically consequential, but their economy-wide impacts are modest so far since most industrial robotics is concentrated in a few industry sectors."*

The authors anticipate in the future, additional displacement of skilled production workers by robotics as these technologies advance, and, in addition they noted that companies are struggling to find and keep workers at current salaries and conditions. This struggle, as well as the retirement of aging workforce and offshoring of companies, is seen as a motivation and justification of increased investment in automation and robotics.

They state that industrial robots are complex systems and *"remain expensive, relatively inflexible, and challenging to integrate into work environments." Nonetheless, "precise manipulation has been making great strides, but human-like flexibility remains out of reach. Similarly, autonomous navigation for mobile robots works well in structured environments but has trouble in dynamic or unstructured areas. Larger robots, or those operating as vehicles or heavy machinery, are dangerous to people, so safety requirements further moderate the pace of change".*

In contrast, the authors make the important point that not all robots displace workers. Cobots enhance and are complementary to the human worker. They note that when compared to traditional industrial robots, they are less expensive, easier to program, and safer to work alongside. *“While collaborative robots are a small fraction of the total robotics industry, they do represent the vanguard of a new wave of ‘augmented intelligence,’ wherein AI and related technologies assist human workers to make them more productive—enhancing the complementary nature of new forms of automation.”* The MIT team state that when speaking with companies in the USA they say, *“our robots complement human workers rather than replace them.”*

In line with the author of this thesis, the opinion of the MIT team is that, in order to come to a conclusion and evaluation of the impact of Cobots on the workforce, it will be necessary to study, observe, and evaluate real life case studies. The MIT researchers state *“we do see potential here for technology to greatly augment human work and productivity. We imagine factories of the future that have achieved the safe, harmonious coordination of large numbers of people and robots, and indeed innovation is occurring in this area already.” (MIT, 2020)*

4.3.6 Conclusions

Robotics are rapidly evolving all the time. In the past ten years, collaborative robotics have emerged in industry and they have the ability to make significant changes in how humans and robots can work together. In contrast to the traditional industrial robot, Cobots do not replace the human operators but they work with them, supporting them. This new man machine collaboration has the ability to revolutionise modern manufacturing if used to its full potential.

There is an expectation for an explosive increase in the introduction of Cobots into factories over the next decade. There is extraordinarily little published literature in this area. Anecdotally, the researcher has been informed that Cobots are not well known in the Irish manufacturing setting. Very few third level Institutes in Ireland actually have Cobots on site and the technology does not actually feature on the Irish third level curriculum.

For the Cobots to reach their full potential it will be necessary to understand how well this technology is understood and appreciated by engineers and managers. Questions such as the following need to be answered. Do the Cobots meet the health and safety regulations of their particular industry? Do they comply with product and process validation requirements? How effectively and efficiently do they work in different work environments? And so on. There are many questions that need to be asked and evaluated in an industrial setting. This will be the focus of the data collection in this doctorate.

4.4 Work and its Organisation

An important aspect of human life is work. Work can be divided up into paid and unpaid, both of which are vitally important. Paid work provides us with a platform on which we can construct a life which is stable and fulfilling. In modern life, work has changed profoundly in developed worlds and is likely to continue changing into the future. In developed societies, work is defined as a division of labour. There are a very large number of occupations available which was not always the case. Industrialisation meant the demise of the traditional craft worker, and work was broken down and replaced by specialised skills that were part of a larger manufacturing body. The nature of work has changed over the centuries, industrial revolutions playing a key role in these changes.

In the late 1800's and the start of the 1900's, manufacturing blue collar workers were in the majority. At the turn of the next century, this trend had completely changed as white-collar workers were in the majority. The service industry has taken over as the biggest employer and the numbers of men and women working in manufacturing is declining year by year.

Giddens and Sutton state that in the UK in the 1900's more than three quarters of the employed population were in manual work or held blue collar jobs (35% skilled and 10% unskilled). The number holding manual jobs by the mid 1900's had decreased to two thirds of the working population. They continue by stating that by 2006 the percentage of men working in manufacturing is 17% and women 6%. (Giddens et al., 2017)

As well as the numbers of people working in manufacturing decreasing, it can be stated that the nature of work itself has greatly changed, and the security of work, or job security, has been greatly diminished. Automation and information technology has changed the way products are designed and manufactured.

4.4.1 Sociology and the economy

"Economic sociology: The classical sociologists differentiated their ideas from pure economics by showing how 'the economy' is part of society as a whole. Economic sociology differs from mainstream or 'orthodox' economics in various ways, but the

central difference is that 'the analytic starting point of economics is the individual; the starting points of economics sociology are typically groups, institutions and societies" (Giddens et al., 2017)

4.4.2 Work and society

Sociology's founders Karl Marx, Emile Durkheim and Max Weber invested considerable effort into understanding and explaining the origins of industrial capitalist societies. An important aspect of this is the idea of work and its relevance in society. Marx investigated the concept of capitalism as a dynamic, exploitative and destructive force in the economy. Durkheim put forward that industrial capitalism continually expanded the division of labour. This division led to specialisation of skills which informed an integrative function in society. Weber focused on the economic forms of action and organisation with the concept of 'interest' and 'self-interest' and how this defines the way a market operates.

Giddens et al. suggest that 1980's economic sociology was reinvigorated. They look at works by White in 1981, Burt in 1982, and Granovetter in 1985, who argue that economic action cannot be rational individual calculations of profit. They state that work *"must be seen as embedded within social networks involving social divisions, power relations, organisations, culture and politics".* This is an important concept and is referred to as social embeddedness. (Giddens, 2017)

To gain a better understanding of how current large-scale global organisations came to be, it is useful to look back in time and consider the different stages in institutional developments.

Family capitalism: this is where large firms are run by families over generations or by entrepreneurs. Here, the managers remain in control.

Managerial capitalism: this is where managers have displaced the family in the large organisations and offer services for their employees (childcare, paid holidays, etc.) to encourage the workforce not to join unions, thus remaining independent.

Institutional capitalism: this is where the corporations with shareholders emerged. Individuals, rather than directly investing in businesses, invest into the money markets that are controlled by financial organisations. These then invest in the industrial corporations where the board of directors influence the decision-making process. The result is the managers have less control, the shareholders and board of directors are the main decision makers.

It is still common to see entrepreneurship style businesses, especially in the small to medium size, but in the 21st century capitalist economies are mostly made up of corporations. Giddens et al. quote Michie (2012) that in 2009 *"large multinational corporations were responsible for approximately one third of international trade as products flowed between subsidiaries located in different countries, but all integrated into global production and sales networks".*

Transnational corporations (multinational): when corporations extend to two or more countries they are referred to transnational. These transnationals can be very wealthy and the industries that fit into the definition are traditionally the car, petroleum, pharmaceuticals, telecommunications and electrical and electronic equipment. The manner in which labour is divided in these corporations is an important observation: the labour can be industrial, agricultural, high or low skilled, depending on the country. The world has become dominated by a small number of very large companies, as has the world economy (Giddens et al., 2017). Large corporations offer offshore manufacturing to other companies worldwide and the business model is a web of different enterprises spread internationally. Investment is no longer made in the parent country. This style of doing business is facilitated by IoT and modern technologies that allow the flow of information and money from country to country.

A result of transnational corporations is the lack of accountability. Rules and regulations vary from country to country. The corporation may decide to follow local laws only which can influence safe working practices, environmental decisions and taxation norms. Some corporations decide to enhance their role in the community by defining a corporate social responsibility set of rules that they apply internationally with all stakeholders. This can promote stable relationships with stakeholders and attempt to put in place environmental safeguards.

4.4.3 The evolution of work in factories

As far back as 1776, labour has been studied and understanding of the division of labour and how this affected efficiency was described by Adam Smith in his book, the Wealth of Nations. (Smith, A., 1937)

Taylorism is a system of maximising work output through optimum layout in factories. This approach was spearheaded by an American management consultant, Frederick W. Taylor. In 1919, his book entitled 'The Principal of Scientific Management' was published by Harper & Brothers Publishers. The concept of time-and-motion studies fundamentally transformed work practices and improved efficiencies but had a negative effect on the skills and the autonomy of the workforce. It is widely accepted that this system of dissecting work into small succinct tasks, has enabled the deskilling of the worker. This is the key to modern production facilities from this time onwards.

4.4.4 Fordism and post Fordism

According to Giddens et al., in 2017 Henry Ford used Taylorism work practices when he established the Model T Ford manufacturing facility in the early 1900's in Michigan. This historical period is known as Fordism in economic sociology terms and the associated characteristics are union agreements in the area of wages and working conditions. Wages were linked to productivity with an understanding that there was an adequate demand for products to ensure negotiated conditions. In summary, Fordism's mass production was linked to mass consumption of his products. To ensure the workers could afford this consumption, he implemented the "five-dollar day" wage for his employees. This period lasted from early 1900's to around 1970. Multinational organisations became more popular in the 70's and work began to be outsourced to other countries which led to a lack competitiveness of USA companies along with an appetite for foreign goods (Giddens et al., 2017)

The ideology behind Taylorism and Fordism was to take control from the worker with a view to increase efficiencies. The creation of 'low trust' systems in the workplace basically meant that *"those who carry out work tasks are closely supervised and have very little autonomy. In order to maintain discipline and high-quality productions standards, employees are continuously monitored through surveillance systems and scientific management"*. It was noted that the actual outcome of this system where the employees had little or no autonomy is that workers have very low morale and are not committed to the job or their employers. Conflict is high and absenteeism and dissatisfaction is high. This can often lead to industrial conflict.

A 'high trust system' is the opposite and allows the employee to take control of the work within specified guidelines. They can have control over how the work is accomplished as well as the speed at which it is undertaken. This has been the norm post 1970 in modern industries where team building, problem solving, working groups, gain sharing are commonplace in modern companies. Otherwise known as 'post Fordism,' it facilitates flexible specialisation in the workplace. The invention of computer aided design (CAD) and computer aided manufacturing (CAM) facilitated the design of customised products. Mass customisation in the 1990s is seen as the next industrial revolution after automation.

As noted by Pietrykowski in 1999, mass consumption in the USA was under threat due to a multitude of reasons in the 1980's. The customer no longer wanted standardised mass-produced products and this, in turn, led to changes in manufacturing work organisation. He states, *"Yet the changing structure of consumer markets is a characteristic feature of the breakdown of Fordism, Advertising, of course, played a role in the rise of mass consumption but other mechanisms were devised or refurbished throughout the twentieth century to acclimate the working classes to the idea of shopping as a productive, culturally legitimate leisure-time activity".* He continues by saying that Fordism increased the demand for unskilled and semi-skilled labour which included manual dexterity, physical strength, hand-eye coordination and the ability to understand directions. Along with these skills a set of 'additional cultural skills' were helpful on the shop floor. *"Such "skills" included deference (submission) to authority, high tolerance for rules and bureaucratic structure, conformity, personal autonomy, competitiveness, and belief in the legitimacy of managerial decision-making, Indeed, it may well be the case that the forces underlying changes in labour relations and labour market structures have as much to do with the reconfiguration of these cultural attributes of work as they do with the changing nature of skills as traditionally defined."* (Pietrykowski, 1999)

Post Fordism is about flexibility in the working environment, and, flexible specialisation is where skills and techniques used in craft production are used in several small batch production factory layouts. These layouts are where smaller quantities of products or batches are manufactured. Small numbers of customised products could then be produced using these techniques for 'just-in-time' delivery to the customer. As a result of changing from mass production to flexible specialisation, the skills of the factory operators, technicians and engineers had to change. This was evident to Peter Cappelli in 1993 and is detailed in his paper 'Are skills requirements rising? Evidence from production and clerical jobs.' In essence, he highlights a job skills evaluation method used in the 1970s and 1980s by a large US compensation consulting firm, Hay Associates. Hay collected data on jobs and their characteristics that allow an assessment of skill changes to be made over time and assessed the autonomy and complexity of the work. He details that the *"sub measures are detailed into 3 classifications:*

- *"Know How" which measures the capabilities, knowledge and the techniques needed to do the job ranked in order of their complexity*
- *"Problem Solving" which measures how well defined and predictable job tasks are*
- *"Accountability" which measures the autonomy in decision making*

These measures get the autonomy- complexity dimension of a skill that is a concern in fields such as psychology and sociology". (Cappelli, 1993) Capelli states that, in conclusion, the results of his research, based on empirical data, implies that *"significant upskilling is occurring within most production jobs in manufacturing, shifts in the composition of the workforce towards higher skilled production jobs contribute a smaller amount to the overall rise in average skill requirements*". Pietrykowski adds that as well as core skills that it is vital that the *"Communication between workers and between labour and management needs to be able to provide workers with the ability to raise claims as to the truth, sincerity and legitimacy of management statements, rules and regulations".* In other words, the company needs to operate with a credible 'high trust system' to facilitate the flexible manufacturing practices.

4.5 Systems and Models

4.5.1 Introduction

Over the past two industrial revolutions, the human was not always at the centre of decisions made in the factory. This has, in effect, led to deskilling of the worker and also has contributed to motivational difficulties. This section looks at different systems and models that have been used in various work environments and this information will prove to be an important feature of the outcomes in this research.

4.5.2 The Delinquent Genius, human centred systems, and the factory model

"Human centred systems are where the technology platforms would support humans, allowing the creativity ingenuity and skills to remain to the forefront of development." (Cooley, 2018)

Historically, machines have been developed to help humans with their fragility or weaknesses. Machines are developed to save labour which results in humans being moved or displaced from previous occupations. This inactivity, in the long run will have a negative effect on our ability to be active and creative. When machines take over more of our tasks, they represent us often isolating ourselves from the real world. We lose out on real feedback; visual, tactile, audio and sensory which affects us psychologically. The human generally cannot resist becoming free of the ‘real physical’ world. The actual result is that we now accept a secondary or virtual reality. *“We have less access to or experience of practical, physical world around us, with all subtle knowledge we absorb through all our five senses, we tend to deal more with models of reality than with reality itself. The artificial is seldom presented to us in a context, or in a holistic way. If reality is just presented to us in narrow, fragmented, artificial forms as a set of disconnected images, we cease to know reality itself”.* (Cooley, 2018)

This is at epidemic level amongst our young people with virtual interactions on social media, gaming using the internet and online shopping. We are losing our ability to communicate both verbally and in the written formats, to work in teams and to live in community and to show empathy. This disconnect manifests itself also in the destruction of nature. Because we are no longer in touch with the natural world we do not understand or respect it and are damaging it beyond a point of being able to save the world.

It must be said that the human has been very ingenious in manufacturing products and has produced technology of very high calibre to accomplish this. We live in the age of Industry 4.0 where robotics, automation, IoT, and AI produce high quality goods at an ever-increasing rate with limited input from humans. *“All the world is a factory and men and women are units for production. Furthermore, all that surrounds us, be it flora, fauna or mineral, solid, liquid or gas is seen as raw material for technology’s all-consuming factory. We should of course give credit where credit is due and graciously admit that man has been fiendishly ingenious at the mass production of goods, even if they are in the main of a throwaway kind. They are usually the end result of highly sophisticated production technology and an outrageous and cretinous waste of energy and raw materials…. As a technologist, I (Cooley) marvel at the ingenuity of a designers of such equipment but I also admit to being alarmed at the long term consequences of such a design philosophy and the priorities it sets itself. What we all need to consider is how the skill and ingenuity in those processes and techniques could be redirected from present “trivialities” and transformed into socially useful, sustainable production techniques.“*

Henry Ford stated that, *“I have tired of the production of automobiles to the point where I now wish to produce people. Standardisation will be the name of the game”.* Standardisation is where each component is manufactured to strict design tolerances which allows interchangeability of components in the assembly of the final product. Control of the quality of the component starts at the raw material suppliers. All raw materials are required to meet quality control standards before shipping. Certification of the raw materials accompanies it to the factory. If the quality standards are not met, the raw material is rejected. A small variance in quality is allowed and this is called the tolerance. As Cooley remarks, *"sameness becomes the hallmark of quality, interchangeability the passport to success….. we have in-process quality control, inspection, testing monitoring, classification and certification."* There is a requirement for high quality standards in products especially in certain circumstances where risk to human life is in question if the product fails. Examples are in the automotive and aircraft industry where performance predictability is vital and the medical device industry where the person's health, and perhaps life, depends on the quality and reliability of the product.

Cooley raises the question though why our whole society is turning into a 'factory like' model and gives several examples to justify and explain his analogy. He states that universities are being transformed into this type of model. Students are the 'goods', exams and quality control standards are used to grade and check that 'standards are met' and graduation is the passing out ceremony of the 'finished goods.'

Cooley believes that modern education is a form of compliance training for modern employment, stating that the education that a young person receives moulds them into the required conformist. He says that, *"they will do what they are told, and their defence whenever challenged, is that they were simply following the rules. In their corporate roles, they produce equipment which pollutes the environment; they instigate, then directly and indirectly support policies which result in the destruction of rain forests. You can find them running development corporations which destroy the centres of cities and communities."* The heads of these corporation have dual roles; at work they follow instructions and parameters without question, with little or no though for the consequences to mother earth or the people around them but at home they embrace family life and assume the role of a caring, moral citizen. *"One is frequently asked if schools are really successful. The answer must be that they are incredibly successful in producing the kind of people required by the vast multinationals and bureaucracies. The disastrous state the world is in, and the minimalist reaction we seek to the absurdities about us, is eloquent tribute to the educational system."*

4.5.3 Socio Technical Design

Mumford in 2003 stated that there are major organisational changes happening in industry now. The nature of work is also changing where service jobs are becoming more common than manufacturing ones and in addition, part time work has become more common. She states that there has been growth in highly skilled knowledge-based work and predicts that this will be the largest growth area going forward. *"Because many of the new 'knowledge workers' will be self-employed, the 'job for life' will disappear and individuals will have to become skilled at selling themselves, running their own lives and protecting their knowledge".* Modern work environments, which she describes as either the 'wired world' which is composed of individual contracted workers or 'built to last' companies which she describes as stable and relatively large companies both look for loyal, skilful and dedicated employees. The employee wants an acceptable income job, satisfaction and job security. Both parties must feel confident for the relationship to prosper. Mumford states that in the world of globalisation many employees feel exploited and are unhappy with working conditions. "Global competition provides employment for many, but it also results in unemployment for those who do not have the right skills to participate in the world of the future".

Change in organisations is difficult and can lead to social breakdown if not introduced in a cohesive manner. Many design problems are very complex. When bringing change to an organisation Mumford states that, *"the rights and needs of the employees must be given as high a priority as those of the non-human system. The world of socio-technical design is democratic, humanistic and provides both freedom and knowledge to those who are part of it".*

Mumford in 2003 describes a methodology called 'socio-technical' which was originally pioneered in the early 1950's by the London Travistock Institute. It meant that the technology (defined as machines and their associated work organisation) should be equal but not superior to a high quality and satisfying work environment for employees when new work systems and methodologies were being designed and implemented. Mumford states that, *"Socio-technical design also had an important democratic component: employees who used the new systems should be involved in determining the required quality of working-life improvements". (Mumford, 2003)*

4.5.4 Conclusions

This section is centered around work and society. It reviewed different types of societies and the importance of labour in these societies. An understanding of organisations and organisational structures was put forward through describing institutional developments. A comprehensive analysis of the evolution of work in factories was undertaken, ranging from 1770s to the modern day. Finally, an understanding of how different systems and models can be extended to the manufacturing industry was described which will prove to have significance in the output of this research.

4.6 Workplace Culture and Values

4.6.1 Introduction

"The world is facing a series of challenges and difficult adjustments. Each day seems to bring news of a fresh conflict. The social contract that binds us together is broken and social trust is at an all-time low, particularly in developed economies. Inequality is rife and we are struggling to equitably distribute already limited resources, leaving many people in extreme poverty. Austerity and retrenchment are exacerbating all these problems. How we choose to deal with each of these issues depends on our values – the values that government, business, civil society and individuals use to guide their actions. These choices need to be self-conscious, not merely driven by the inertia of accumulated interests". (World Economic Forum (a), 2014).

This World Economic Forum report goes on to say that recent economic crises have damaged trust, and many are disillusioned with the way our organisations operate. *"Former assumptions and shared notions about fairness, agreements, reciprocity, mutual benefits, social values and expected futures have all but disappeared. The social contract between business, government and society seems to be broken."* Giddens et al. in 2017 state that work that generates income is the key to generating the wealth required to sustain a varied and fulfilling life. (Giddens et al., 2017, p. 285)

Employees now expect more collaborative, sustainable and inclusive ways of working. The push now is to create new social covenants which are made up with moral values and commitments instead of trying to put together the broken contract of before. It is suggested that the new covenants could have the following elements and must be shared between government, businesses, and citizens:

- *"Agreement on basic, universal values and ethics*
- *Consensus on the need to reflect these values in a country's legislation and regulation, and in the international economic agreements that define countries' duties to each other*
- *Education systems that are open to all and that foster equality of opportunity*
- *A goal of providing good-quality jobs for all those who need them, focusing in particular on jobs for non-graduates, increasing access to technical education, putting in place apprenticeships, establishing a proactive tax and incentive system and ensuring industrial strategy is fit for the 21st century*

- *Fair rewards for hard work and contributions to society*
- *Adequate security for savings and assets*
- *A commitment to reduce inequality and to keep income and rewards within fair bands at the top and bottom of the scale*
- *Stewardship of the environment and a commitment to preserving natural capital for the benefit of future generations, as far down as the "seventh generation", which indigenous people use as a moral metric*
- *Stable, socially useful, and accountable financial sectors*
- *Increased opportunities and social mobility*
- *The promotion of human well-being, happiness, flourishing and freedom to live a valued life as key societal goals*
- *Adapting new ways to measure progress at both national and company levels*
- *Measures to ensure personal privacy and public transparency in an increasingly digital world*
- *Moving from a shareholder model of companies and a client model of other vital institutions (such as schools and universities) to a stakeholder model*
- *Engaging the next generation in designing new models and practices"*

It can be said that each of us wants our working lives to have a purpose as well as earning a fair wage. That said, many end up in jobs feeling unhappy and unfulfilled. We often hear *"we don't feel valued in our place of work".* The question is how can companies overcome this and ensure correlation between personal values and profits of the company? How can the company have a positive and engaged workforce that are committed to their workplace in the longer term? How can this workforce and company play a positive role in the surrounding communities and the environment?

The modern worker's commitment to a particular job is different to the employees of bygone years. The younger generations evaluate *"what's in it for me"* and this may lead to a contradiction if the company has a different culture and set of values to the employees.

"A study of young employees found that in several instances, employees suspended their own values temporarily in the belief that laudable ends justify questionable means. Rarely did these employees have the support from others within the company to voice their values and question the work they were being asked to undertake." The relationships between employer and employees can be known as ""personal compacts,"

and corporate change initiatives (such as a transition to a sustainable business model) require changing the terms of these compacts to align personal and corporate values. *“These personal compacts have three dimensions: formal (job descriptions, employment contracts, performance agreements), psychological (rewards, recognition, expectations, and commitment), and social (perception, culture, and values).”* (Poleman et al., 2016)

In the sociological aspect of the relationship, employees look to see if the employer respects the values proclaimed by the company by checking to see if there is consistency between what it does and what it has set out to do. *“Perceptions about the company’s goals are tested when employees evaluate the balance between financial and non-financial objectives, and when they determine whether management practices what it preaches.”* (Poleman et al., 2016)

4.6.2 Introduction to values

Values are *“ideas held by human individuals or groups about what is desirable, proper, good or bad. Differing values represent key aspects of variations in human culture. What individuals’ value is strongly influenced by the specific culture in which they happen to live.”* (Giddens et al., 2017, p. 1019) An example could be the values held by Buddhist Monks whose main objective is to create a moral community in comparison to the values held by Eastern capitalists whose main objective is to make profit.

Parsons, in 1968, defined values as *“the conceptions of the desirable type of society held by members of the society” and “a value pattern then defines a pattern of choice, and consequent commitment to action.”* (Parsons, 1968, p. 136) In other words, the values in a society are an agreement of what is important to that society. The actions and patterns of behaviour of that society demonstrate what their set of values are, for example, democracy, equality, and conformity.

Bardi et al., in 2003, state that *“values are a motivational construct. They represent broad goals that apply across contexts and time”.* This holds importance when considering a company’s ethos and culture. Rokeach, in 2008, ties together the concepts of *“values, ideology and norms”* which play such an important role in the modern workplace:

“When we can identify interconnected sets of values and beliefs which describe a preferred or “obligatory” state of a social system, we speak of an ideology. Actual concrete specifications of preferred conduct are norms, which in turn are referred to

values of legitimation, for boundary setting, for redefinition, and for linkage to other norms." (Rokeach, 2008, p. 21)

In 1960's, Kohn describes what are the important variables when distinguishing how a person gains a value system. Education and occupation play a significant role. Analysis of data from a US survey indicates that social class is the most important single variable accounting for differences in patterns in values. Amongst the components of "class", education is the most important, followed by occupation; income adds a little to the prediction of values from education and occupation. The relationship of these variables to values are continuous, linear, and additive. (Kohn, 1969, p. 27)

Kilpatrick et al. continue with this idea when stating *that "There are consistent and marked differences between educational and occupational levels of the American population in the criteria of desirability invoked in judging the 'ideal' and 'worst' features of occupations. Emphasised by persons of lower education and occupational are security, fringe benefits, physical conditions, and nature of supervision. Mentioned more frequently at the higher levels are self-expression and development, creativity, active personal relationships, worthwhileness of work, challenge, and opportunity for personal achievement."* (Kilpatrick, Cummings, & Jennings, 1964, pp. 82-83) We begin to see different sets of values here based on education and occupation or profession.

Rokeach states that *"In repeated earlier analyses (1951, 1960 and 1970) we drew upon a large and diverse body of data from historical, economic, political and sociology studies to describe some 15 major themes of value-belief orientations that have long been salient in American society."*

Table 4 List of value belief orientations (Rokeach, 2008)

Activity and work	Science and secular rationality	Democracy
Achievement and success	Material comfort	External conformity
Moral orientation	Progress	Nationalism and patriotism
Humanitarianism	Equality	Individual personality
Efficiency and practicality	Freedom	Racism and related group superiority

Williams points out that conflict and unrest can be sparked easily if values and beliefs at different levels in society move suddenly to different positions of strength. (Williams, 1959)

In 1992, the Schwartz value theory defines 10 broad values which were based on the universal requirements of human existence. The values outlined are presumed to include *"the range of motivationally distinct values recognized across cultures".*

Following are the value definitions and examples:

- *"**Power:** Social status and prestige, control or dominance over people and resources (social power, authority, wealth)*
- ***Achievement:** Personal success through demonstrating competence according to social standards (successful, capable, ambitious, influential)*
- ***Hedonism:** Pleasure and sensuous gratification for oneself (pleasure, enjoying life)*
- ***Stimulation:** Excitement, novelty, and challenge in life (daring, a varied life, an exciting life)*
- ***Self-direction:** Independent thought and action-choosing, creating, exploring (creativity, freedom, independent, curious, choosing own goals)*
- ***Universalism:** Understanding, appreciation, tolerance and protection of the welfare of all people and of nature (broadminded, wisdom, social justice, equality, a world at peace, a world of beauty, unity with nature, protecting the environment)*
- ***Benevolence:** Preservation and enhancement of the welfare of people with whom one is in frequent personal contact (helpful, honest, forgiving, loyal, responsible)*
- ***Tradition:** Respect, commitment and acceptance of the customs and ideas that traditional culture or religion provide the self (humble, accepting my portion in life, devout, respect for tradition, moderate)*
- ***Conformity:** Restraint of actions, inclinations, and impulses likely to upset or harm others and violate social expectations or norms (politeness, obedient, self-discipline, honouring parents and elders)*
- ***Security:** Safety, harmony and stability of society, of relationships, and of self (family security, national security, social order, clean, reciprocation of favours)"*

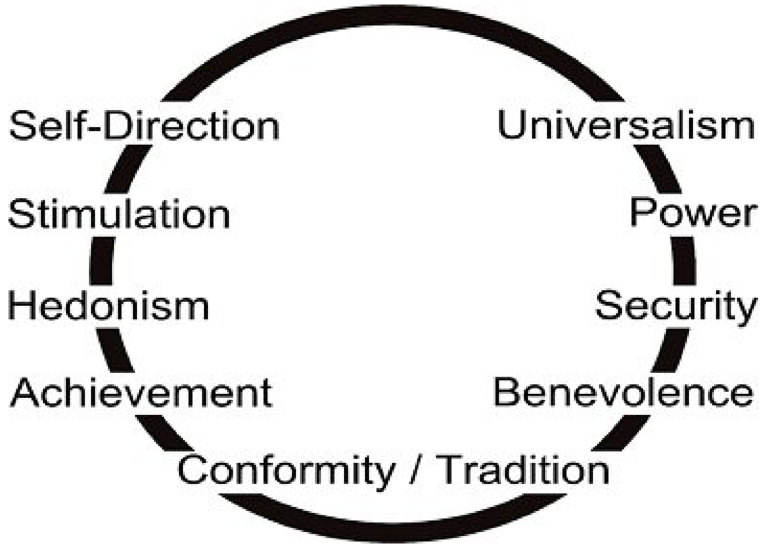


Figure 24 Adapted from Universal Value System Model (Bardi & Schwartz, 2003)

Bardi and Schwartz state in 2003 that values have relationships with one another. This means that the pursuit of one value may conflict with the pursuit of another or may act in a positive or negative manner in terms of psychological, social, and practical consequences. The relationship is represented in Figure 24 as the graphical representation of their theoretical model.

4.6.3 Values in an organisational context

Rokeach states that the modern society is very energised, and this can lead to a fragile stability. *"Clashes of values resonate with speed and force in a permeable social structure, existing social arrangements. The growth of the public sector increasingly makes societal allocations a highly visible political process. It remains to be seen what the consequences will be in a world of energy crises, explosive population growth, basic interdependence, serious political instability, and incessant change. Greater understanding of the place of values in social systems surely warrants intensified intellectual effort in the years ahead."* (Rokeach, 2008, p. 46). He continues by saying that values as standards help us rationalise out thoughts, actions, and judgements. This, in turn, helps us feel better about ourselves and enhances self-esteem as well as allowing us to feel we have satisfied the definition of morality and competence. (Rokeach, 2008, p. 48)

"Value hierarchies or priorities are organisations of values enabling us to choose between alternative goals and actions, and, enabling us to resolve conflict. At the

individual level, for instance, value priorities guide decisions about occupational goals and interests, on how to spend our money, or for whom we vote. At the supra-individual level, value priorities guide decisions about such things as the setting of organisational goals, the allocation of resources, and the formulation of new policies." (Rokeach, 2008, p. 49)

So, values can be linked to the individual and organisation. Rokeach states that *"If individual values are socially shared cognitive representations of personal needs and the means for satisfying them, then institutional values are socially shared cognitive representations of institutional goals and demands."* In other words, organisations and individuals can share the same values and this is an important and defining factor of the institution. *"There is a reasonably good consensus among sociologists that the most distinctive property or defining characteristic of a social institution is its values."* (Rokeach, 2008, pp. 50-51)

Williams defines an institution as "*a set of institutional norms that cohere around a relatively distinct and socially important complex of values."* (Williams, 1951*) "If the most distinctive defining property of a social institution is indeed its "complex of values" then its most distinctive functions can be suggested to be value transmission and value implementation."* (Rokeach, 2008, pp. 50-51) Institutional values can be clustered to represent the ethos of a particular society and this is known as value specialisation. (Rokeach, 2008, pp. 55-56.)

According to Rokeach, apart from the effect that values have on the socialisation of members of a society there is little understanding of how values affect or are affected by and even interact with organisational properties, processes, and management actions. *"Organisational-member values, or value orientations, may be more accurately characterised by the concept 'value profile'. Probably the best methodological approach to assessing values in an organisation is the use of profiles and profile analyses. Thus, the average significance attached to a particular value by a set of organisational members may be viewed and assessed in relation to the significance attached by them to other selected values."* (Rokeach, 2008, p. 76)

Hodgkinson in 1970 found that values differ by hierarchical level, and not by age, sex and seniority. The following hypotheses are made by him:

- *"Value orientations vary systematically with hierarchical position*
- *Value orientations vary in accordance with variation in organisational formalisation*
- *Value orientations vary in accordance with variations in education and training of members*
- *Value orientations differ in accordance with differences in dominant technology."*

4.6.4 How values influence the organisation

Rokeach continues to discuss how the values in an organisation can influence different aspects of that organisation is a significant manner. On pages 78-80 of "Understanding Human Values" he argues that values as variables influence communication, conflict, and group behaviour in an organisation. He states that the values of the decision makers influence their decisions. Examples of his hypotheses are:

- *"Conflict occurs more frequently and is resolved with greater difficulty, the greater the value differences between parties*
- *Accuracy of communication among organisational members varies directly with value consensus among the members*
- *Group cohesion is directly related to value consensus among group members*
- *Effectiveness of intergroup cooperation is directly related to between group consensus of members."*

Another important point made by Pennings, in 1970, was that promotion rates are directly related to the values of the workers. In other words, an employee was more likely to move up the promotion ladder if they had the same set of values as the manager in the company. (Pennings, 1970)

4.6.5 Company values, culture, ideology, and strategy

In 2019, Grant, in his book *"Contemporary Strategy Analysis"* states on page 14 that looking back, company strategy changed in the 1990's from profit in the external environment to the internal environment. The capabilities and resources within the company were increasingly important and became the basis on which the company's strategy was based. Emphasis on how companies were different from their competitors was the main competitive advantage. In the twenty-first century digital technologies have had a huge influence on the competitive dynamics of firms. Acceleration of changes and disruptive technologies are seen to create options into the future. Strategic innovation is seen as invaluable. (Grant, 2019)

Rokeach asks the following important questions:

- *"Is there a direct stable relationship between organisational performance on various dimensions of efficiency and the management value profile? Worker value profile? Management-worker value consensus?*
- *How are worker values related to output quality? Is output quality related to degree of management-worker value consensus?*
- *Is value consensus between management and worker related to properties of organisational climate such as job satisfaction, leadership style etc?*
- *Is the organisation's ability to be responsive related to top management's value profile? Middle management's? Top-middle consensus? Management-worker consensus? Do the same relationships hold for both external adaptability and internal flexibility?*

In a modern manufacturing environment what are the important factors for success and is value consensus important?

According to Stapleton in 2020, culture is *"the system of shared beliefs and values which develop within an organisation and guides the behaviours of its members."* In addition, the *"two main ideas of culture are:*

- *an integrated pattern of human knowledge, belief, and behaviour that depends upon the capacity for symbolic thought and social learning*
- *the set of shared values, attitudes, goals, and practices that characterizes an institution, organisation or group."*

Stapleton continues stating that a successful company is more than just a highly profitable company. It is insufficient to just define the company's value statement, vision statement and mission statement. *"It is more important (and much more difficult) to create alignment between management styles, organisational systems and the values and vision. Most organisations do not understand what values are really at work in their business performance."* (Stapleton, 2020)

Collins et al. in 1996 have the view that successful companies are ones that have alignment of their core values and core purpose, and these remain fixed whilst their business strategies and practices evolve in a changing world. For example, *"Johnson & Johnson continually questions its structure and revamps its processes while preserving the ideals embodied in its credo*." *Core ideology* defines the enduring character and identity of the company and Collins et al. refer to it as the glue that holds the company together long term. It comprises of *core values* and *core purpose.*

Referring to *core values,* Collins et al. state that they are a set of timeless guiding principles that require no external justification. They state that *"a company should not change its core values in response to market changes rather it should change markets to, if necessary, to remain true to its core values".* It is vital for the company to define its core values by gathering a subset of the workers and start by asking them what are their individual values? From this the company values can be defined. This is possible by asking the workers a number of questions as outlined in the article and can be effective in a diverse group of workers.

With regards to core purpose, they say this *"is the company's reason for being".* It is a reflection of the idealistic motivation for working for the company, and, as such, should capture the soul of the company? An example is Merck is "*to preserve and improve human life".* A method of discovering a company's purpose is to start with a descriptive statement of a product and then ask why five times. *"Why is this important"?* (Collins et al., 1996).

4.6.6 Conclusion

The importance of workplace culture was described in this chapter. The world of work has gone through many changes and the recent economic crises have damaged the trust of the employee in the organisation. The modern employee has expectations, and if the company does not live up to their expectations they often leave. The future is the establishment of social covenants which have moral values and commitments built into them. The employer's values must align with the employees. A discussion of values and the value system model was undertaken. Values from an organisational context was looked at and this led to how individual values and organisational values were connected. The organisation's values can affect how it operates and this leads to the culture, ideology, and strategy of the company in a more general sense.

4.7 External Influences on an Organisation

A manufacturing company has many external influences including customer demand, globalisation, climate change, global pandemics and so on. The list is endless. Some of the influences can be experienced as threats and some as opportunities. Indeed, even the threats are often looked upon as opportunities by technologists and engineers.

4.7.1 Introduction

Chelsom et al. in 2005 discuss the threats and opportunities albeit before a global pandemic. They describe the business objectives as:

- Maximising customer satisfaction
- Maximising the quality goods and services
- Minimising operating costs
- Keeping capital costs to a minimum
- Shorter lead times ensuring faster time to market
- Maximising profit
- Ensuring a safe and stable working environment
- Survival during difficult periods

In addition, keeping qualified talented workers, minimising environmental damage through sustainable manufacturing, and protecting the company against cybersecurity threats are also important in a modern context.

All these requirements need to be addressed if a company is to stay in business in a globalised marketplace which has slow economic growth, ever increasing competition in terms of cost, changing consumer requirements, increasing market complexity, technology transformations, pressures from consumers, governments, and regulatory authorities.

4.7.2 Classification of external factors

Figure 25 illustrates a conceptual model designed by Chelsom et al. in their book called 'Management for Engineers, Scientists and Technologists'. The researcher uses this model to establish the external factors that play an important role in company strategy.

From this model it can been seen that there are, effectively, two layers of influencing external factors depicted by the inner and outer circles. The inner circle is composed of groups of people, shareholders, financial institutions, suppliers, competitors, employees, unions, customers, and regulatory authorities. The outer layer is composed of more abstract concepts, climate change, demography, geography, politics, culture, media, technology, government, ecology, education, and economics.

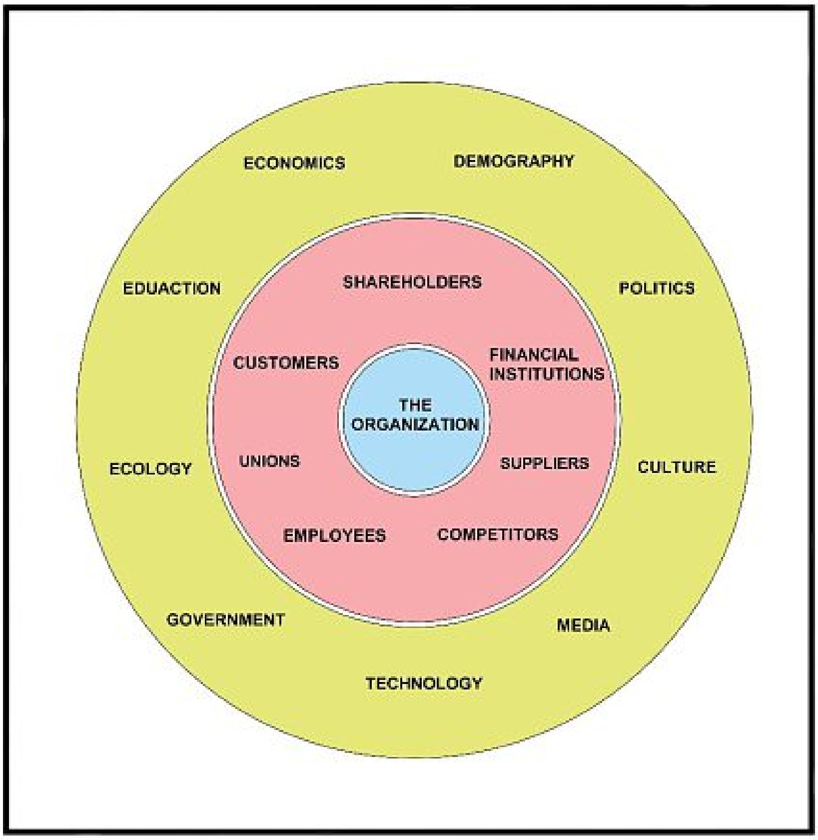


Figure 25 An illustration of an adapted external factor classification model by Chelsom et al.

It is beyond the scope of this research to detail the effects that each of the above external factors might have on a manufacturing company. Suffice to say that each company is individual and unique, and the factors are continuously changing.

4.7.3 External factors and company strategy

In the external factor classification model in Figure 25, Chelsom proceeds to explain how these factors can be broken down into external threats and external opportunities (p. 25). These factors feed into the business strategy and then the manufacturing strategy. A company could use the model as a live document.

These factors can then feed down into a manufacturing strategy of the plant. Examples, with modifications, from Chelsom are as follows:

Successful product introduction: customer driven designs for new products. A design using connected digital tools and a motivated multiskilled team that have access to the latest information.

A better factory: focused factory entities that are easily adjusted to fluctuating volumes. Effective process and automation flexibility and reliability. Equipment that is environmentally positive.

Integrated logistics: simplified networks that are user friendly. Effectively manage variety and volume mix. Flexible facilitating rapid response to required changes. Excellent partnership with suppliers.

Better organisation: ability to attract, retain and develop employees. A simpler, flatter organisational structure. Promotion of teamwork. A continuous improvement ethos throughout the plant. Agility in managing change.

Integrated information: local IT experts trained in the latest IT tools. User-friendly interfaces. Powerful connected application software. Open integrated systems with robust network communications. A high-level cyber security.

Engineers and technologists focus on several of the strategies outlined above. These strategies are given different emphasis and importance depending on the company.

4.7.4 Twenty first century threats

In addition to the external threats and challenges outlined by Chelsom et al., there are additional threats that need to be highlighted that play a particularly important role in the twenty first century.

Global pandemics: Anyone working through the SARS 2 COVID-19 pandemic will have different experiences of the threat encountered when working in industry. Some businesses seem to cope well, and others do not. In some manufacturing industries, particularly the biomedical and pharmaceutical, social distancing, hygiene etiquette and other requirements have been incorporated into the plant without difficulty. In meat processing plants it has been much more difficult and the result is regular disease outbreaks worldwide.

New technology: A problem with ever changing technology is that there is insufficient knowledge of new technologies and the opportunities that they can offer to a company. Engineers and technicians are not learning fast enough or are not familiar enough with the technology capabilities so they can use the technology to its full potential. This also implies that product development and marketing do not have the capability to make the most of the emerging technology to produce new products and services.

Data analysis: With the use of sensors and also sensor-embedded devices, mobile devices in other types of fixed equipment enormous quantities of data are being generated. Manufacturing industries current equipment infrastructure have not been designed to handle this massive increase in the volume of data, as well as the traffic in which these data is coming through. This means that there are challenges in system modelling and in the analysis of the models to ensure that the most beneficial gains for the organisation, its products and services can be made.

Intelligent decision making: Traditionally, engineers and technicians are trained to work by collecting relevant information and data on a problem and then making decisions themselves based on their knowledge of the situation. The transition then to intelligent decisions and negotiating mechanisms will require a change of mind-set. There may be a hurdle in terms of letting machines handle all this decision-making, letting machines talk to other machines, and letting them make decisions purely based on the data that they received and analysed.

Cyber security: In modern manufacturing plants, factories are now designing and installing new types of modularised plug and play, interchangeable components. These components can have the ability to collect and analyse data. They need to be integrated into the company’s systems. With the installation of Industry 4.0 related devices with sensors and so forth, there are many additional points that can be vulnerable for cyber security attacks.

Investment: Any company that intends to implement Industry 4.0 requires substantial capital funds. This is often outside the reach of SMES and even for large organisations investment is required from the conglomerate. In addition, government incentives may be required.

Skills shortage: For organisations trying to transform their operations to take advantage of Industry 4.0, the skills gap is one of the major critical factors that inhibits this kind of successful transformation.

4.7.5 Conclusion

Various points in this section were used to formulate a number of questions on the survey. These more general topics will give an insight into the strategies and priorities of the different types of companies and, in addition, what areas they will be focusing on in the future.

4.8 Industry 5.0 and Societal Questions

4.8.1 Introduction

The creation of a world where every member of society is valued regardless of gender, gender identity or expression, sexual orientation, race, colour, national or ethnic origin, religion or religious belief, age, marital status, disabilities is a society that is rich and inclusive.

An inclusive and diverse society that encourages the open expression and exchange of ideas, that is free from all forms of discrimination, harassment, and retaliation, and that is welcoming and comfortable to all members and to those who participate in its activities is one which is rewarded with the best possible outcomes.

4.8.1 Diversity and inclusion

Workplace diversity is understanding, accepting, and valuing differences between people including those of different races, ethnicities, genders, ages, religions, disabilities, and sexual orientations, with differences in education, personalities, skill sets, experiences, and knowledge bases.

Following are insights into the influence of diversity and inclusion in businesses in the USA (Builtin.com, 2020)

- Ethnically diverse companies are 35% more likely to yield higher revenue, while gender diverse companies are 15% more likely to yield higher revenue.
- Diverse companies are 70% more likely to capture a new market audience.
- When employees perceive their organization as committed to diversity and inclusion, and they actually feel included, employees are 80% more likely to rank their employer as high performing.
- As of March 2019, 25 (4.8%) of Fortune 500 CEOs are female (up from 2.4% in 2008).
- In addition to white men, as of 2018, there are more white women at every stage of the corporate pipeline than men or women of colour.
- Only 17.9% of people with a disability were employed in 2016 compared to 65% of people without a disability.
- Of people who post personal religiously affiliated content on social media, Muslims are 13% less likely to receive a call back for an interview.
- Men earn a 6% higher wage when they have a child, whereas women earn 4% less when they have a child.

In a report by Deloitte, they state that diversity is perceived differently by generations. Millennials view workplace diversity as the combining of different backgrounds, experiences, and perspectives, and they believe taking advantage of these differences is what leads to innovation. (Șchiopu, A. et al., 2016)

Industry 5.0 has a unique opportunity to facilitate diversity and inclusion in the workplace due to emerging technologies such as exoskeleton and collaborative robotics. By employing a more diverse workforce it will lead to unleashing more ideas and harvesting more potential from a more diverse society. Gender equality needs to be a priority in the workplace of the future to ensure the company is at the cutting edge of innovation. In addition, people with disabilities have the potential to augment their capacity by new emerging technologies making the idea of disability obsolete. Schwab states *"if we are* *truly to feel part of something much larger than ourselves – a true global civilisation – with a shared sense of destiny, all stake older must be included in the course we chart. We share a responsibility to empower and ensure equal opportunities for growing populations in developing countries, particularly the youth who are still struggling to grasp the benefits of prior industrial revolutions."(*Schwab, K., 2018)

"Gender equality is more than a question of justice or equity. Countries, businesses, and institutions which create an enabling environment for women increase their innovative capacity and competitiveness. The scientific endeavour benefits from the creativity and vibrancy of the interaction of different perspectives and expertise. Gender equality will encourage new solutions and expand the scope of research. This should be considered a priority by all if the global community is serious about reaching the next set of development goals." (Huyer, S., 2015)

Women account for fewer than 30% of those employed in scientific research, with an even smaller representation in STEM fields. (Mullet et al., 2017) In a study by UNESCO, they state that women are consistently very poorly represented in engineering, manufacturing and construction and it states that in many cases, engineering has lost ground to other sciences. Overall, globally, less than 20% of engineering graduates are women. (Huyer, S., 2015)

Inclusion in the workplace is one where there is a collaborative, supportive, and respectful environment that increases the participation and contribution of all employees. True inclusion removes all barriers, discrimination, and intolerances. When these principles are applied properly in the workplace, it is natural for everyone to feel included and supported.

When diversity and inclusion are a company's mission it requires strategies and practices to support a diverse workplace and leverage the effects of diversity to achieve a competitive business advantage. Companies that create diverse and inclusive work environments are more adaptable, creative, and become magnets that attract top talent. (Bula et al., 2020)

4.8.3 Social and ethical

An important aspect in future manufacturing scenarios is defining the human-machine interaction. Changes in technology will continue to be dynamic in nature. How will human and robots communicate and interact together? Training and education will define the success, or otherwise, in the collaboration. Humans will be required to maintain the complex systems when they break down. Current technical skills need to be valued and elaborated. Workers roles will change from a machine operator to a strategic decision-maker and a flexible problem solver. (Hirsch-Kreinsen, H. et al., 2019)

The workforce of the future will need skills different from those it has today. There will be less manual work and more planning, coordination, and decision-making. People will not vanish from factories because even the best computers and machines will never be able to relieve people of the most important thing they do - deciding on the best solution from a number of alternatives, managing unforeseeable events, or deriving new and creative ideas from experience. (IFR, 2019)

A new type of ethics in engineering has had to be developed called ‘roboethics’ because of the autonomous features of new technological systems in Industry 4.0. (Kopacek, P., 2019) These new systems are capable of dealing within a human-like complexity and as a result the old rules are no longer sufficient. According to Doyle-Kent et al., *“the central driver is the enhanced IT technology, mainly in the field of (distributed) artificial intelligence. Multi Agent Systems (MAS) are important architecture to deal with systems of distributed intelligence. They represent interacting, autonomous, heterogeneous agents and are inspired by social system and biological models*.” (Doyle-Kent, M., et al., 2020)

In 2017, in a study by Djordievic on the ‘Laws of Robotics’, the author concludes that the Directive 85/374/EEC can cover only the damage caused by the robot as a result of manufacturing defects. They state that “*the current legal framework would not be sufficient to cover the damage caused by the new generation of robots insofar as they can be equipped with adaptive and learning abilities entailing a certain degree of unpredictability in their behaviour since those robots would autonomously learn from their own variable experience and interact with their environment in a unique and unforeseeable manner therefore new legislation must be found”.* (Djordjevic, I., 2019)

4.8.4 Conclusion

Establishing an inclusive and diverse workplace that welcomes all minority groups results in a company that is high achieving, innovative and more profitable. Modern technology enables individuals of different abilities to collaborate together in ways that were heretofore unthinkable. We can choose to enable by using technology or the inverse.

This employee of the future will require a completely different set of skills as they will be working in a human-machine collaborative environment. New ways of educating the employee need to be established in addition to the actual knowledge imparted. Data analytical and problem-solving skills will be critical.

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Because of the collaborative nature of this new working environment, a new set of ethical guidelines need to be established. They need to be dynamic as technology development and innovation is moving at a fast rate. In addition, a new legal framework for collaborative working environments need to be developed.

4.9 Chapter 4 Summary

Chapter 4 is a comprehensive review of the current body of literature spanning the areas mentioned in the theoretical framework. The first sections tell the story of the first, second and third industrial revolutions from a manufacturing viewpoint. It then moves on to investigate the literature available on Industry 5.0. This body of literature was mainly extracted from internet sources, but nonetheless, gives a vision of the future as described by websites and online articles.

The next section of the Literature Review looks at the Irish manufacturing industry and explains how this industry is mainly comprised of large multinationals (50%). The result is an evolution from a low-tech status in the 1970's to one, which, in the 2020's takes its place as a progressive, competitive and innovative hub pushing the boundaries to be a leader in the adoption of Industry 4.0. Following on from this is a case study of a pharmaceutical company based in Ireland which discusses the pressure points on this industry as it competes globally. The Irish government has developed policies and a strategy for the digitisation of manufacturing which then are briefly introduced.

The company Irish Manufacturing Research was established in 2010 to pilot a new type of research model in Ireland, one which is independent, creates applied-research centres, and acts as a bridge between Academia and Industry. IMR shared data from a Cobot survey which they conducted in 2019 with the researcher. The objective of the survey was understanding the current state of collaborative robotics applications in Irish manufacturing and to identify the major concerns. The results proved to offer an insight into the current position, albeit with a small sample size and a limited number of questions.

The next section looked at the literature around robotics in modern manufacturing including the characteristics of modern robotics, the associated opportunities, and risks, Cobots, and robotics in conjunction the human workforce.

The section on work and its organisation was comprised of a study of the following: sociology and the economy, work and society, the evolution of work in factories and Fordism and post Fordism eras. This gave an insight into how work has evolved over the decades and its importance to humans.

Systems and models are then investigated. Mike Cooley's Human centered Systems and Edith Mumford's Social Technical Design look at bringing humans back into the center of the design of work by ensuring their needs are equal to the requirements of technology. Mumford also states that humans that use the systems should be involved fundamentally in the design of the system.

The next section spans workplace culture and values and investigates values through the lens of an organisation. There is discussion then on how values influence the organisations and how company values, culture, ideology, and strategies play a role in how employees view the company.

Following on from this the external influences on an organisation are investigated. These influences include external factors and the influence of the factors on the company strategy. Twenty first century threats are looked into from an angle of how these can be additional and have a strong influence on manufacturing.

The Literature Review looks at societal questions such as opportunities presented for manufacturing if it becomes a more diverse and inclusive workplace. Finally, the social and ethical opportunities are presented.

Chapter 5. Collection of Data

5.1 Introduction

In chapter three, the methodology chapter, an explanation of what research methods would be used and a rationale for why they would be used was outlined.

"An *important feature of qualitative design is that it is 'emergent'. Although a researcher may set off with some provisional ideas about design, these may change during the research process – often as a result of the analysis of data providing new directions (Patton, 2005). Qualitative research design, then, should be seen less as a linear, sequential pathway, but rather as a series of iterations involving design, data collection, preliminary analysis and re-design." (Gray, 2018)*

Many months were focused on consulting the journal and conference literature to uncover the latest discoveries and theories in the areas of Industry 4.0 and 5.0, and, as a result, it was found that there was very little written on Industry 5.0 and the role that the human would take in this advanced manufacturing scenario. A limited number of internet articles and blogs were uncovered at this time in this area and they raised more questions than they answered.

As a result of this secondary research, an academic paper was written to summarise the literature on Industry 5.0 and this paper was presented in Vienna (July 2019) at the International Symposium of Production Research (ISPR2019). The title of the paper was *"Industry 5.0: Is the Manufacturing Industry on the Cusp of a New Revolution?"* The result of the paper was that a series of questions were outlined.

These questions were seen as important if researchers were to move forward in this area. They range from how do we educate our workforce, to how we prepare them for this new high-tech environment that they will find themselves in, to how can we reform educational methods to ensure that the knowledge the students receive is delivered in a manner that prepares them for the environment in which they will work?

The second set of questions that arose were in the area of the working environment. Industry 4.0 and 5.0 are highly automated environments, with great emphasis on robotics and automation. Historically, we saw in chapter 4 that the introduction of automation has had a negative effect on the skills of the workforce in the past. In addition, the employee tends to feel less valued as work becomes more monotonous. Important questions here are how can we ensure a safe working environment for employees in Industry 5.0 as well as ensuring that they are engaged in a manner that they feel valued and motivated? A complete list of areas and questions can be seen in Table 5.

Table 5 showing the questions raised from the literature reviewed for this thesis and published in ISPR 2019. (Doyle Kent, M.; Kopacek, P., 2019)

Question 1 - Education and Skills

How to ensure that humans have a place in the highly automated workplace of the future optimizing human capital?

Can the traditional education provider supply these skills?

Question 2 - Working Environment

How can the work of the employee become more interesting and fulfilling into the future?

Can the workspace of the employee be safe and comfortable with the new technologies surrounding them?

Question 3 - Relationship between Productivity and Wages

How can the rise of inequality be addressed in the workplace?

How can wages keep in line with productivity into the future?

Question 4 - Ensuring the Best Technologies are used without making Humans redundant

How can we ensure humans are not made redundant in this new environment?

How can optimised decisions be made to ensure the newest and optimised technologies are used in manufacturing?

Question 5 - Optimum Product Characteristics

The customer demands optimised quality, cost and delivery and how can this be ensured in an agile and connected factory?

How can the customer be guaranteed product that is personalised and eco-friendly?

Question 6 - Protection of the Environment

Is the factory working in a sustainable manner meeting environmental targets set out for them?

How can the company continuously make improvement to its environmental footprint?

Question 7 - Governance and Ethics

How do we ensure that governance on new and future technologies will meet the requirements of an equitable society?

Can moral and ethical standards be part of an engineering education and a working career, ensuring moral responsibility in future decision making?

A number of these far-reaching questions were beyond the scope of this research. For this thesis it was decided to focus on the following research questions with the agreement of the researchers' supervisor:

The following research questions were established.

Question 1.0 What would an Industry 5.0 conceptual framework look like?

Question 2.0 Can collaborative technology play a role by enabling humans and robots to work together in Industry 5.0?

Question 3.0 Can a set of guiding principles be developed to aid with the introduction of human centred automation in modern manufacturing companies?

Question 4.0 In Industry 5.0, can a highly skilled creative workforce be established to work in a human centred workplace, which generates personalised high-value and high-quality products**?**

In the interest of gathering qualitative information to answer questions 2, 3, and 4 above, a series of case studies were set up in the spring of 2020. These took the format of a number of informal interviews with Cobot specialists in Ireland, and these interviews were subsequently transcribed. Case studies 1-3 were the result of these interviews.

Gray describes that plans can change at any time during the collection of data. This is because of the evolving nature of qualitative research. *"Gathering data using a variety of these types will contribute to the construction of the kind of 'thick descriptions' upon which qualitative research depends."* (Gray, 2018) Often it is a case of collecting multiple types of data and combining them.

"Having a thorough knowledge of the data enables researchers to capitalise on opportunities to broaden and diversify the sample. It allows follow-up on emerging ideas and enables building in new questions that arise during the course of research, rather than mulling over missed opportunities after the interviews have been conducted. This is entirely appropriate, indeed central, to a research method that is, by its very nature,

interpretive and where analysis is anchored in the ideas that are located in the data themselves." (Gray, 2018)

The researcher was signposted from these initial interviews to Cobot blogs, Cobot manufacturer's websites, YouTube clips showcasing Cobot users and applications, and to other resources including a survey that had been previously carried out on industrial Cobot usage in Ireland. This led to case studies 4-10 and proved to be a significant turning point and gave direction and focus to the research. Case study 1-10 transcripts and other materials can be found in the appendices.

5.2 Case Studies

As described by Patton in 2005, purposive, or expert sampling is the important difference between quantitative and quantitative research, as well as the sampling size. Qualitative sampling uses small and sometimes even single samples whereas quantitative relies on a large number of samples. The qualitative samples are selected purposefully on the basis that they are information-rich cases.

Purposive samples, then, are used when particular people, events or settings are chosen because they are known to provide important information that could not be gained from other sampling designs (Maxwell, 2012).

"In this kind of approach, the researcher exercises a degree of judgement about who will provide the best perspectives on the phenomenon of interest and then invites these participants into the study. However, a disadvantage of purposive sampling is that the researcher may inadvertently omit a vital characteristic on which to select the sample or may be subconsciously biased in selecting the sample." (Gray, 2018)

Informal interviews were undertaken as case studies at the start of this research with a number of experts in the collaborative robotics sector in Ireland. The first case study was with a sales director of a Cobot company, the second interview was with an industrial solutions architect in a research centre in Ireland, and, finally the third interview was with two postdoctoral researcher engineers specialising in a collaborative robotics working group in the same Irish research centre. The transcripts of these interviews are located in appendices. A number of Cobot user videos from a Cobot website were transcribed as additional case study material. These are also stored in the appendices. Table 6 summarises the 10 case studies undertaken in this research.

Table 6 The case study matrix

Case Study Number	Case Study Code	Company
Case study 1	**R1CA**	Company A (Cobot manufacturing company)
Case study 2	**R2CB**	Company B (Research Institute)
Case study 3	**R3CB & R4CB**	Company B (Research Institute)
Case study 4	**RNB**	Online
Case study 5	**Thyssenkrupp Bilstein**	Online
Case study 6	**Saint Gobain**	Online
Case study 7, 8, 9, & 10	**Universal Robots blogs**	Online

Once the case studies were completed, the next step was to analyse the data. Braun et al. in 2006 describe in Table 7 the processes and steps required to effectively extract themes from the studies. This six-step methodology was used in this research to add validity to the thematic results of the case studies.

Table 7 Phases of thematic analysis (Braun et al., 2006)

Phase	Description of the Process
1. Familiarising yourself with your data:	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
2. Generating initial codes:	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
3. Searching for themes:	Collating codes into potential themes, gathering all data relevant to each potential theme.
4. Reviewing themes:	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
5. Defining and naming themes:	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
6. Producing the report:	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

5.2.1 Preliminary case studies through interviews

<u>Preliminary case study 1: Respondent 1. Company A. [30.03.2020]</u>

The first case study was undertaken with the Irish National Sales Director of a Danish-based Collaborate Robotics company in March 2020. This company is based in Co. Cork on the south coast of Ireland and globally the company has sold over 46,000 collaborative robots which are used in several thousand production environments every day around the world. Founded in 2005, the company describes themselves as being at the forefront of innovation and their mission is to make robot technology accessible to small and medium-sized enterprises globally. (Universal Robots, 2020)

A number of questions were put to the respondent with a view to broadly gathering general information about how Cobots are used in Ireland in the manufacturing industry. Phone calls and emails were used over a two-month period to gather information. A transcription was produced putting all the information together and this is available in the appendix section. The results of the thematic analysis can be seen in the following chapter. This was how all the case studies were analysed.

<u>Preliminary case study 2: Respondent 2. Company B. [25.05.2020]</u>

The phone interview was set up with an industrial solutions architect specialising in Cobots and automation. The phone interview was then transcribed and can be found in the appendix. The interviewee asked for their anonymity to be respected so there will not be any identifying information in the transcription in the appendix or in the thematic review of this interview.

It must be noted that this expert was extremely knowledgeable in the field of automation in the Irish industry and has a very balanced approach to the advantages and disadvantages of using Cobots going forward.

<u>Preliminary case study 3: Respondents 3 and 4. Company B. [02.06.2020]</u>

The informal interview took place on a videoconference TEAMS call on Tuesday 2nd of June 2020. Both research engineers have doctorates in the area of robotics. The company that they work for is seen as the leading national research institute in the area of robotics in Ireland. This company works with several multinational manufacturing companies that have sites in Ireland. They are also involved at a European level in developing new international standards in the area of robotics and collaborative robotics. They are recognised as experts in this field. It can be noted that these researchers focused on the technical, skills, education, training and health and safety aspects of Cobots, as would be expected.

In addition to the interview on June 2nd, the respondents 3 and 4 shared an industry survey that they had conducted with a view to understanding why Cobots are not being used in a more widespread manner in Irish industry. The idea behind this survey was to take the results and use them to inform their future activities as well as getting industry to consider Cobot applications. The researchers explained: *"the objective of the survey is to understand the current state of collaborative robotics applications in manufacturing (in Ireland) and to identify the major concerns that engineering managers and manufacturing directors have, which prevent the wider adoption of collaborative robotics applications. The collaborative robotics adoption survey was disseminated as a paper form and as an online questionnaire between July 2019 and October 2019. Engineers and managers from manufacturing companies and technology providers were invited to fill-in the paper survey when visiting." … "This industry survey indicates that while most of the surveyed have starting or have deployed collaborative robotics applications (73% of the participants), the level of human-robot collaboration is mostly limited to sequential collaboration and below (12 participants over 16 who have started/already deployed HRC applications). The lack of a clear and methodical process for Health & Safety sign-off and the lack of definitive reference documents/standards are the most prevalent concerns across the 23 surveyed individuals and have been the most frequently rated as preventing a meaningful engagement with human robot collaborative applications at this time."* (IMR, 2020)

Even though the sample size was small (23 respondents), the information gathered is an important element for this research as it is Irish, recent, and industry relevant. The respondents 3 and 4 from Company B also made recommendations for the questionnaire that were subsequently developed for this research and, in addition, they tested the survey before it was released.

5.2.2 Preliminary case studies through online information

Additional online case studies were made from watching recommended videos online and transcribing them. The full transcription can be found in the appendix. This accounts for case studies 4-6. Case studies 7-10 were taken from a recommended blog and gives an insight into how Cobot technology and integration plays a crucial role, both in the Covid-19 pandemic and in the introduction of Industry 5.0 into manufacturing companies worldwide. All of the case studies were deemed relevant even though the sources are non-academic in nature. It highlights how in the modern era, information is accessed.

Preliminary case study 4 RNB [12.06.2020]

RNB is a company dedicated to manufacturing and marketing skincare and fragrance products. They state their four key pillars are:

- People and professionals
- Image and design
- Excellence in technology
- Care for the environment

They have six Cobots in the packaging and preparation areas working with the centre pack palletising cell teams.

Preliminary case study 5: Thyssenkrupp Bilstein [14.06.2020]

Thyssenkrupp Bilstein is an industry leader in high tech suspension solutions for the automotive industry. The plant in Ohio now has nine Universal Cobots. They are used for tending to machines, assembly operations and inspection tasks. The Operations Manager views the introduction of Cobots into their plant as revolutionary.

Preliminary case study 6: Saint Gobain [16.06.2020]

Saint-Gobain's plant in Sully-sur-Loire, France, focuses on glass production for the armoured and aeronautical industries, and the civil market. In their shift towards Industry 4.0, management has deployed collaborative robot cells to free employees from tedious, repetitive tasks. Human labour provides high-value work to the finished product, but some tasks are more tedious than others. This is why the Sully-sur-Loire factory, like many other Saint-Gobain plants, began to deploy collaborative robot cells into their process about a year ago.

Preliminary case study 7: Universal Robots [08.06.2020]

The role of Cobots in the Covid-19 era

This is a blog of the role of Cobots in the Covid-19 era. It describes the role of Cobots in the Conquer manufacturing plant. The highlights are plant closures; partial layoffs; staggered shifts; labour shortages; stringent hygiene measures and restrictions on the number of people working together at the same time. The mandatory guidelines include increased testing, following social distancing norms, and limiting the total number of workers at a physical location. These initiatives themselves give rise to a host of issues for manufacturing firms to tackle. Some of the automation barriers faced by manufacturing include an abundance of unskilled labour, a lack of space on the shop floor, or the lack of technical expertise to operate the complex new technology.

By using automation in their plants and assembly lines, manufacturers overcome these issues. Cobots, in particular, are a niche automation solution which are the most efficient, flexible, and cost-effective way forward for factories looking to automate and reduce external dependence, especially to get on track to achieve ambitious 'Make in India' plans. This article introduces the undeniably important role of Cobots in manufacturing and how they can easily adapt a new working model to improve output and efficiency, especially in the post-Covid-19 world. (Universal Robots, 2020)

Preliminary case study 8: Universal Robots [10.07.2020]

Making personal protective equipment (PPE) and other vital equipment with Cobots

As Covid-19 began its spread in the United States, Hurco in North America (a machine tool supplier headquartered in Indiana) set its employees a challenge – to adapt a machine tool into a system for making N95 masks. The employees chose to deploy a UR5 Cobot to make high tech masks for its employees and customers and distributers. Revtech Systems in Canada launched an internal competition to design and manufacture makes for the staff. Once the final design was chosen, the team quickly set up a cell with a human operator and two UR10 Cobots. Hannafin Automation and Industrial Controls used Cobots also to manufacture face shields from an automated 3d printing process. Gamber-Johnson in the USA joined a collaboration with local partners to create a temporary facility for face shield production. EinsRobotics in Mexico also produces face shields using Cobots.

In China, researchers at Tsinghua University have created a mobile medical Cobot system that performs ultrasounds, takes mouth swabs, performs temperature checks, and can operate a stethoscope. This system has been deployed in Wuhan Union hospital.

Preliminary case study 9: Universal Robots [20.05.2020]

Manufacturing in the age of Covid-19 continued

Endutec Maschinenbau Systemtechnik gmbh is a specialist equipment manufacturer. It states that it now operates 24 hours a day and Cobots facilitate this. They say that two years ago they introduced Cobots because finding suitably skilled operators had become a huge challenge. They now use Cobots for the less complicated tasks and use their skilled operators for more high value work. *"In spite of COVID-19, our production runs almost as usual - with the difference that before the pandemic our full team was physically present at the company. Some of the employees wrote CNC programs on site while the others worked on the machines on the shop floor. Currently, half of the employees write the programs from home, upload them to the company server, where after employees on-site retrieve the programs and run them on the machines via the Cobot."*

Several other changes were easily implemented by the company and the result is that they are even more competitive now. *"For us, the crisis has shown that the time and money we invested in automation has more than paid off. I am convinced that other small and medium-sized companies will now also increasingly rely on robot technology to prepare themselves for the future."* A full transcript can be found in the appendix.

Preliminary case study 10: Universal Robots [17.10.2017]

Collaborative robots ushering in Industry 5.0.

This blog describes the differences between Industry 4.0 and 5.0. It states, *"Industry 5.0 is about highly skilled people and robots working side by side to create individualised products, services and experiences."* It gives examples of where it already is in operation such as Aurolab and has resulted in a 15% increase of productivity. Other examples include Linaset, SWEM and more.

This blog describes how the new revolution is about the convergence of human and robot capabilities. The customer no longer wants mass produced products. New market expectations can be met with the collaboration of Cobots and humans which result in personalised and customised high value products. Staff enjoy working side by side with the Cobots. They are freed up to develop new skills which makes work more interesting and rewarding. A full transcript can be found in the appendix.

5.3 Questionnaire Survey

The next step was to develop a survey questionnaire which would test certain ideas and concepts previously gathered from the literature and case studies. This questionnaire was distributed using SurveyMonkey™, an online survey tool. (Survey Monkey, 2020) Considerable effort was put into the design of the survey, testing, and refining the survey and then distributing the survey. In all, 111 respondents filled out the survey over a three-month period.

The survey looked at the classification of the company, the product type, the areas where collaborative robotics are currently working, the type of work being performed by the collaborative robotics, what the advantages and disadvantages are, how easy they are to install and use, education of the operators, automation of business process in the company and so on.

An important element of the survey was the introductory paragraphs. They frame the work and explain its significance. In addition, the introduction communicates that the responses will be kept confidentially in line with GDPR protocol which is especially important for the respondents. The full survey can be found in the appendix but following is an explanation of the introductory paragraphs and questions asked.

5.3.1 Introduction:

Title of the survey: *"Case study profiling emerging Collaborative Technology in Manufacturing Companies in Ireland."*

Reason behind the survey: *"Thank you for agreeing to participate in this survey which is part of a research project for an on-going Doctoral Program in Engineering Science in Vienna University of Technology, Austria."*

Background: "*We are moving into the fourth industrial revolution, or Industry 4.0, currently, where manufacturing takes place in an information intensive environment. This 'connected' environment consists of data, people, processes, service, and systems with Internet of Things (IoT) enabled industrial assets. This new smart way of manufacturing is facilitated by increasing levels of automation, cyber physical systems, digital-twins, and the intensive use of data analytics. It is driven by modern industrial and societal challenges and evolutions, as well as the integration of information and operational technology."*

Definition of Industry 4.0: *"Industry 4.0* consists of the following core elements:
ICT – IoT, cyber security, cloud computing, big data artificial intelligence and wireless systems. Connectedness – simulation, digital twin and systems integration. Sensors – built in intelligence, real time capability, traceability and completeness. Robotics – High flexibility, intuitive operation, human robot cooperation and intelligent control. Innovative

production systems – complete cross linkage, augmented reality, cyber physical systems, self-configuration and additive manufacturing.”

Industry 5.0: *“This research looks at the social impact of the fifth industrial revolution, Industry 5.0, and focuses on automation in human centred systems. It investigates how, in a new futuristic age of manufacturing, robotics and humans will work together seamlessly. Collaborative robots (Cobots) and their operators, (Coboters) will play important roles in future manufacturing environments which will be agile, flexible, environmentally friendly, safe, and efficient. Industry 5.0 will combine the technological breakthroughs of Industry 4.0 and combine them with the unique capabilities of humans*.”

Aim of the survey: *“The aim of this 15-minute survey is to provide an important insight into the experiences of companies on their use of automation and we hope that it will help influence future policy and education programmes.”*

Confidentiality*: “All data will be treated confidentially, and individuals will not be identifiable in any reports generated from this study. The general findings may be presented to academic conferences and journals, as well as enterprise agencies, in order to help understand the particular situation in Ireland when compared to other regions. All responses will be treated with the utmost confidentiality and the name of the company will not be associated with any particular response. Company names will appear in an appendix at the end of any publication in order to illustrate the profiles of the companies who participated.”*

Researcher and supervisor’s details: “*This study is being conducted under the supervision of Peter Kopacek Professor Emeritus, Vienna University of Technology (kopacek@ihrt.tuwien.ac.at). The researcher is a member of INSYTE, the Centre for INformation SYstems and Techno culture (INSYTE) which is an interdisciplinary research centre located in the south east of Ireland. She can be contacted at marydoylekent@gmail.com. Thank you in advance.”*

5.3.2 Survey questions and their rationale

There are 37 questions in the survey. Each question was chosen carefully, and it related either to the Literature Review or the case studies (1-10) in the previous sections. Following is a brief outline of each question.

Question 1. What sector does your company belong to? (www.EnterpriseIreland, 2020) This is a categorical question and the categories offered come from an Enterprise Ireland list. Twenty different categories are offered as well as an option for "other" which is open ended.

Examples of the categories are:
Bio Pharma Engineering
Consumer Retail Products (Furniture, Textiles, Giftware, Jewellery, Apparel)
Construction
Consultancy

Question 2. Which of the following is closest to your actual job title? *(Preliminary case study Universal Robots SCB) This is a categorical question and the categories offered come from the first case study. The 16 options that were offered can be from the database of the case study 1. This can be seen in the appendix. In addition,* there is an option for "other" which is open-ended.

Examples of the categories are:
Engineering Manager
Production Engineer
R&D Manager
Maintenance Technician

Question 3. What type of enterprise are you working in? *(Official journal of the European Union 2003, 20.05.2003)* This is a categorical question and the categories offered come from the Journal of the European Union 2003. Five categories are offered together with an option for "other" which is open-ended.

An example of one of the categories is: microenterprise (enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million).

Question 4. *Describe your company's products/services.* An open box was left for this answer. Here the respondent has an opportunity to explain what their company does.

Question 5. ***How would you describe your company's products/services in terms of unitary market value?*** Here the respondent was offered a sliding scale ranging from low value to medium value to high value.

Question 6. ***In your view what are the top priorities in your area? [Rank in order]*** The list offered 21 plus an additional 'other' option. This is seen as an especially important question and is based on a textbook titled "Management for Engineers, Scientists and Technologists Chelsom", by Payne & Reavill.

Examples of categories are follows:
Maximising the health and safety of the employee
Ensuring workforce stability and continuity
Minimising the environmental footprint of the company
Minimising the special footprint of the manufacturing space
Ensuring product ingenuity and innovation of design
Optimising product cost and competitive pricing
Maintaining the high reputation of the brand
Maintaining a position of the latest cutting-edge technology and automation
Maintaining an excellent relationship with the company's suppliers

Question 7. ***In your opinion what level of experience does your company have with robotics and automation?*** Here the respondent was offered a sliding scale ranging from low to medium to high. The rationale for adding this question came from the case studies. It was stated that if a company has already a high level of automation and experience it would be easier for them to successfully integrate Cobots.

Question 8. ***Have you heard of collaborative robotics [Cobot]?*** The options offered were simply yes or no. A definition of a Collaborative Robot (Cobot) was given as it was thought that respondents would find it very difficult to fill out the rest of the survey without a clear definition. *"A Cobot is a robot that works in collaboration with humans without guards due to high sensitivity of its sensors. It is light weight and easily programmed, has a low payload and is generally low cost."*

Question 9. ***Do you currently have Cobots in your manufacturing plant?*** The options offered were simply yes or no.

Note: At this point the questionnaire breaks into streams, one where the respondent answers no and the other yes to question 9.

Question 10. ***If no, what are your top three concerns? (Choose multiple answers if appropriate)*** The answers offered here are based on the preliminary study by IMR and feedback from an initial test of the questionnaire. Ten options were offered including Not Applicable and other examples of categories are as follows:

Prohibitive costs?
Require more information on how they can be integrated into your factory?
Need more highly trained technical staff?
Worried about Health and Safety?
Think they will not suit your type of product?
Worried about redundancies?
Worried about turnaround time and flexibility?
Worried about the environmental footprint?
No time to investigate?
Not Applicable and Other (please specify)

Question 11. ***If yes, in what areas are they working in? (Choose multiple answers if appropriate)*** The answers offered here are based on the preliminary study Universal Robots SCB. 18 options were offered including Not Applicable and Other.

Examples of categories are as follows:
Packaging and Palletising
Industrial Assembly
Dispensing and Welding
New Product Development
Prototyping

Question 12. ***What level of involvement does the Cobot operator [Coboter] have with the Cobots?*** The answers offered here are based on the preliminary study by IMR. Here the respondent was offered a sliding scale of the percentage of hours.

Question 13. ***What type of work does the 'Coboter' do with the Cobots?*** The answers offered here are based on the preliminary study by IMR.

Programming

Working side by side

Working in collaboration

Undertaking a risk assessment

Other

Question 14. ***What level of involvement does the Maintenance Technician have with the Cobots?*** The answers offered here are based on the preliminary study by IMR. Here the respondent was offered a sliding scale of the percentage of hours.

Question 15. ***What type of work does the Maintenance Technician do with the Cobot?*** The answers offered here are based on the preliminary study by IMR and are the same as Q13.

Question 16. ***What level of involvement does the Automation Engineer have with the Cobots?*** The answers offered here are based on the preliminary study by IMR. Scale with then be a sliding scale of the percentage of hours.

Question 17. ***What type of work does the Automation Engineer do with the Cobot*?** The answers offered here are based on the preliminary study by IMR and are the same as Q13.

Question 18. ***Has your experience with your Cobots met your goals and expectations so far***? It was important to understand the level of satisfaction with existing users.

An assessment was made using a Likert scale.

1 - Has not met goals and expectations

2 - Has met some goals and expectations

3 – Yes, moderately met goals and expectations

4 – Yes, to a large extent met goals and expectations

5 – Yes, exceeded goals and expectations.

Question 19. *In your opinion how has your company changed due to the introduction of Cobots? [Rank in order]* This question is based on the preliminary study Universal Robots SCB. Most of the 14 categories were discovered in the case studies and some extra categories were added as well as Other.

Examples include the following:
Increased autonomy and decision making
Improved communication with other employees [Technicians, Engineers etc.]
Improved social interaction with work colleagues and less isolation
Improved job security because of working with Cobots
Improved employment opportunities because of working with Cobots

Question 20. Have your business processes needed to be redesigned due to the introduction of Cobots? The answers offered here are based on the preliminary study by IMR.

An assessment was made using a Likert scale.
1 - No, not at all
2 - Yes, some minor or minimal changes
3 - Yes, a rationalisation for improved efficiency
4 - Yes, a moderate redesign
5 - Yes, a complete shift in thinking [paradigm]

Question 21. *To what extent have your engineering tasks needed to be redesigned to facilitate the introduction of Cobots?* The answers offered here are based on the preliminary study by IMR.

An assessment was made using a Likert scale.
1 – No, not at all
2 – Yes, minor or minimal changes
3 - Yes, a rationalisation of tasks
4 - Yes, a moderate redesign
5 - Yes, a complete shift in thinking [paradigm]

Question 22. *Who redesigned the engineering tasks to facilitate the implementation of the Cobots?* *The answers offered here are based on the preliminary study by IMR. Five options were given including Not Applicable and Other.*

Examples are as follows:

External Systems Integrator

Internal Engineer

Internal Technician

Internal Cobot Operator [Coboter].

Question 23. ***To what extent did the Cobot need to be customised for your company?*** The answers offered here are based on the preliminary study by IMR.

An assessment was made using a Likert scale.

1 – No, not at all

2 – Yes, minor or minimal

3 – Yes, some customisation

4 – Yes, moderate amounts of customisation

5 – Yes, a large amount of customisation

Question 24. ***How long did the set-up of your Cobot take?*** The answers offered here are based on the preliminary study by UR and IMR. Some Cobot vendors state that it only takes a number of hours turnaround to get the Cobot up and running. Three options were given including Other.

Question 25. ***What tasks were undertaken during this set up-time?*** The answers offered here are based on the preliminary study by IMR and it was recommended that this was an important piece of information. Four options were given including Other.

Doing risk assessment

Programming

Interacting with Coboter

Training

Other (please specify)

Question 26. Who installs, programs, calibrates, and maintains Cobots in your company? The answers offered here are based on the preliminary study by UR and IMR. Four options were given including Other.

External Systems Integrator

Internal Engineer

Internal Technician

Internal Cobot Operator [Coboter]

Other (please specify)

Question 27. To what extent, in your opinion, do Coboters require post Leaving Certificate education to successfully operate a Cobot? This question was asked to assess the educational level of the Coboter and five options were given.

Question 28. What other abilities should a Coboter have to successfully operate a Cobot? A profile of the Coboter was assessed here.

Question 29. In your opinion do third level Institutions currently prepare students to work in this collaborative environment? This question was asked to assess if Collaborative Robotics was part of the respondent's education.

***Question 30. What additional education/information would benefit the Coboter to successfully operate a Cobot*?** This question was asked to assess what training would benefit the Coboter.

Question 31. How could this additional education/knowledge be accessed? This question was asked to understand how best to offer training to the Coboter.

Question 32. In your opinion would your company be interested in obtaining more value from Cobots by higher task optimisation? This question was asked to see if there was potential to reassess how tasks are allocated in the business and to see if training or a Consultant could increase the value of the work undertaken by Cobots in the plant. Yes, No or Please Specify were the options given.

Note: Here both streams (yes and no) joined together again.

Question 33. In your opinion, would your company be interested in accessing training in the automation of business processes? Both streams of respondents were asked if they would like training and the options were Yes, No or Please Specify.

Question 34. What would be the best way, from your perspective, to access this training based on current company scheduling and workload commitments? Continuing on in the training for automation of business process the respondents were asked to choose how this training could be delivered. Six options including Other were offered.

Question 35. In your opinion what would the most important outcomes of this training be? This question was asked to understand the requirements of the training in the previous question. An open box was left to gather this information.

Question 36. ***The current Covid-19 global pandemic makes physical distancing a requirement in the workplace, does this influence your opinion on using Cobots in a manufacturing?*** This question was asked due to the global Covid-19 pandemic at the time of the research being undertaken. The option of yes, No or Please Specify were offered.

Question 37. Please enter your contact details: This was the final question in the survey and optional. The following were requested: Name, Job title, Company, Email Address and Contact Number.

5.4 Chapter 5 Summary

Chapter 5 begins with an explanation of how the initial questions (table 5) which emerged from the literature review, and published in a conference paper, were reviewed and refined to produce the final four research questions. This was achieved with the advice of the thesis supervisor, as the original questions were beyond the scope of a doctorate thesis.

The collection of primary data was undertaken by a series of case studies and a comprehensive survey distributed by SurveyMonkey™ over a number of months. Details of the case studies are outlined in this chapter, but the more detailed transcripts are available in the Appendix A.

The survey was carefully constructed and comprised of 37 questions. The actual survey as it appeared on SurveyMonkey™ is available in Appendix B. A summary of the questions is given in chapter 5, but Appendix C gives the complete results of the questions. The data were gathered and analysed, and the results can be seen in the following chapter.

Chapter 6. Results

6.1 Introduction and General Comments

Payne and Williams (2005) suggest that in attempting to formulate generalisations, qualitative researchers will achieve more plausibility if they are: cautious, moderating the range of generalising conclusions. Being too ambitious in conclusions merely undermines the credibility of otherwise competent research. If the sample is specialised in some way, be clear that the results may only be applicable to a limited type of site or category of person – and say what they are. Be careful in recognising the limitations of time periods. Claims are more believable if made for current conditions than about some period in the future. Be meticulous in demonstrating clear linkages between generalising conclusions and the specific data that provide its foundation. Be honest and transparent about findings from sub-groups, the views or behaviours of which differ from or are similar to those of the population being reported. Be modest by making claims for basic patterns or tendencies, so that other studies may find similar but not identical findings. Be diligent in reporting alternative explanations or the constraints on generalisations. The constraints on generalisations need to become a standard element of the analysis. (Gray, 2018)

6.2 Results Case Studies

6.2.1 Case studies:

As outlined in chapter 5, 10 cases studies were undertaken, and Thematic Analysis was used to analyse this data. The phases of Thematic Analysis, as outlined in Table 6, were rigorously used. After the data collection, interview recording and transcription by the researcher, the generation of codes and search for universal themes were aided by using a paper-based system.

- The researcher read and reread the interviews several times to become familiar with the data.
- Then, the interesting statements were highlighted by transcribing them onto coloured notepaper. They were then stuck onto a large A1 sheet. The colour of the note paper was significant. The five colours used identified the codes.
  - Ease of use (green paper note)
  - Cost (yellow)
  - Technical (blue)

➢ Skills, education, and training (pink)
➢ Health and safety (orange)

- The coloured notes were collated and ordered according to the colour. A photo was taken to record this step and can be seen in Figure 28.

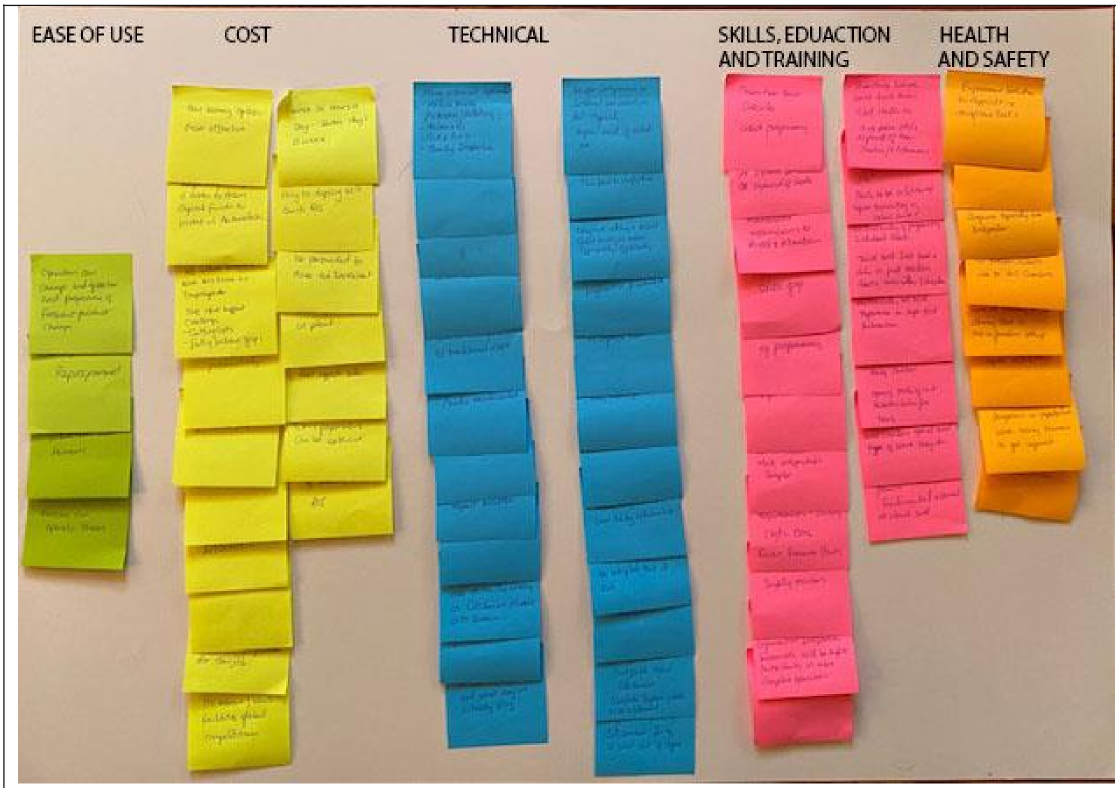

Figure 26 A photograph showing the collation of the coded information.

- Next the codes were collated into preliminary themes.
- The common preliminary themes were checked against the dataset.
- A thematic map using the note paper was developed and this can be seen in Figure 29.

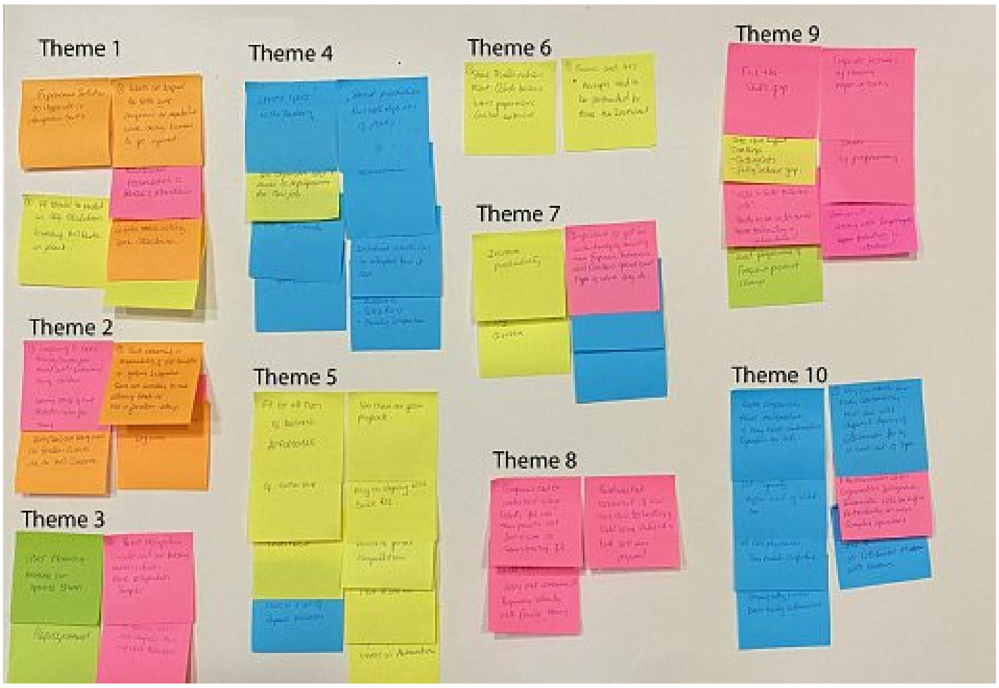

Figure 27 A photograph showing the collation of the thematic information.

- The themes were refined, and a clear definition of each theme was established. A list of the themes can be seen in Table 7.
- A summary table was developed for the final themes which helped with the reporting of the results.
- This summary table can be seen in Table 8.

Table 8 Themes from the qualitative case studies

Theme 1. Health and Safety of the workforce is enhanced by introducing collaborative robots.
Theme 2. There are uncertainties about meeting the statuary health and safety requirements **by using Collaborative Robots unguarded.**
Theme 3. Collaborative Robots are easy to install, to use and to maintain and do not require a robotics expert on site.
Theme 4. The versatility of Collaborative Robots makes them uniquely applicable to most environments.
Theme 5. The relatively low cost of a Collaborative Robot ensures it is within the range of small to medium enterprises.
Theme 6. Collaborative Robots may not be fanatically viable to all business.
Theme 7. Collaborative Robots improve productivity.
Theme 8. Collaborative Robots can fill the skills gaps in industry and operators will have a more rewarding and interesting work environment due to increased skills and varied work practices.
Theme 9. Most Collaborative robots are not working to their full potential in Irish industry and larger companies have an advantage over smaller ones.

Table 9 has positive themes on the left-hand side and negative themes on the right-hand side. The fact that there were negative themes meant that important areas to investigate further had been highlighted from the initial case studies.

Table 9 The results of a thematic analysis undertaken on the case studies. (Doyle-Kent, 2020)

Advantages	Disadvantages
Theme 1. Health and Safety of the workforce is enhanced by introducing collaborative robots.	**Theme 2. There are uncertainties about meeting the statuary Health and Safety requirements by using Collaborative Robots unguarded.**
✓ *Ergonomic solution to difficult or dangerous tasks* ✓ *Decrease workers injuries* ✓ *Cobots lower H&S risks to the operators in the plant so Human Resources should be involved* ✓ *Complete system needs to be assessed rather than the Cobot in standalone decision making* ✓ *They can do dangerous or repetitive work therefore avoiding humans getting injured* ✓ *For the service and maintenance aspects, some companies train, and up-skill technicians* ✓ *Lack of clarity of safety requirements of the Cobots is one of the areas holding back Cobot introduction*	• *Company A's Cobots are extremely easy to program but are often put into cages for safety reasons.* • *Most Cobots in Ireland are used as a fenceless robot to meet with health and safety regulations.* • *These safety standards come from the industrial robot's safety standards and are evolving continuously.* • *Comprehensive H&S risk assessment must be implemented before the Cobot can be installed.* • *The risk assessment is the responsibility of either the machine builder or systems integrator and some are unwilling to take the risk of allowing the Cobot to run in a fenceless setup.*
Theme 3. Collaborative Robots are easy to install, use and maintain and do not require a robotics expert on site.	
✓ *Cobots are user-friendly so that anyone can operate them.* ✓ *They can be easily reprogrammed.* ✓ *For the service and maintenance aspects, some companies train, and up-skill technicians.* ✓ *Cobot manufactures are making the integration much simpler (easier to program and risk assess).*	
Theme 4. The versatility of Collaborative Robots makes them uniquely applicable to most environments.	
✓ *Can have frequent interactions with humans in a shared space.* ✓ *Cobot is easy to use and if they need to change the application it is far less expensive and easier to programme.* ✓ *When there is a big variety, flexible automation is the quickest solution as changes can be programmed into the software.* ✓ *Relocatable in the workplace.* ✓ *Operates in a fenceless area of the factory.* ✓ *Modular and can be easily moved and reallocated*	

✓ *Applications include: Packaging and Palletising, Machine Tending, Industrial Assembly, Pick and Place etc.* ✓ *Cobots are suitable for small production runs and a high mix of parts*	
Theme 5. The relatively low cost of a Collaborative Robot ensures it is within the range of small to medium enterprises.	**Theme 6. Collaborative Robots may not be fanatically viable to all business.**
✓ *Cobots are perfect for all sizes of business* ✓ *Cobots are affordable* ✓ *They have a low total cost of ownership* ✓ *They have a short return in investment* ✓ *Cost-effective alternative which, in turn, facilitates global competitiveness* ✓ *Less than a one-year payback on Cobots* ✓ *Designed for all sizes of business and with the leasing option* ✓ *Cobot shows its efficiency and effectiveness, we get a lot of repeat business.* ✓ *Companies with established automation have access to capital expenditure more easily* ✓ *Cobots suit this area (SME) perfectly and are made for fast, easy and flexible deployment with a quick ROI* ✓ *Using Cobots is often cheaper and saves space*	✓ Some multinationals in Ireland resist Cobots because the internal EH&S paperwork involved can be extensive ✓ Financial and H&S managers need to be convinced to invest in Cobots
Theme 7. Collaborative Robots improve productivity	**Theme 8. To achieve maximum value from Collaborative Robots, redesign of engineering and business process is required.**
✓ *Increase productivity* ✓ *Operate 24 hours seven days a week* ✓ *Low speed low volume are the zones that the Cobots excel in* ✓ *Understanding of the scope of the Cobots currently available in terms of payload, speed, dimensions, volume, variety of tasks and so on* ✓ *Need to understand the amount of time an Engineer, Technician and Operator spends with the Cobot and what type of work they do [programming, working side by side, working in collaboration, undertaking a risk assessment…]*	✓ *Companies need to understand where Cobots fit in their plants. It is not just a case of substituting industrial robots with Cobots* ✓ *A fundamental assessment of how this new technology could bring value at a task level was required* ✓ *What tasks are undertaken - doing risk assessment, programming, Interacting with Coboter, training*
Theme 9. Collaborative Robots can fill the skills gaps in industry and operators will have a more rewarding and interesting work environment due to increased skills and varied work practices	**Theme 10. Most Collaborative robots are not working to their full potential in Irish industry and larger companies have an advantage over smaller ones.**
✓ *Fill the skills shortage gap in a modern industrial environment where there can be high employee turnover* ✓ *SMEs in Ireland have the biggest challenges going forward to cut costs and fill labour gaps and account for 70% of factories* ✓ *Human factors will be critical going forward, working with operators before the technology is introduced*	✓ *Companies with established automation trust automation faster* ✓ *Larger companies will change the criteria so that they can use a Cobot or even add a second Cobot to help to do the job more efficiently and effectively*

✓ *The operator (Coboter) would be required to change possibly the end effector or to programme when products change over* ✓ *Cobots empower the workers by removing them from repetitive tasks* ✓ *They give additional skills such as programming to workers*	✓ *Larger companies using the Cobots here in Ireland typically use the Cobot to its full capacity which can make the programming and installation at the higher end of Cobots use* ✓ *Smaller companies starting to investigate and use our Cobots now for simple pick and place at CNC machines* ✓ *Currently Cobots are being used in sequential applications rather than in a truly collaborative manner* ✓ *A very small percentage of the Cobots in industry are actually running in a truly collaborative manner* ✓ *When there are experienced automation engineers and mechanisation in an organisation, the integration success rate will be higher, particularly for the more complex operations*

The advantages of using Collaborative Robotics are replicated in the literature reviewed but the disadvantages were not. To investigate further, a comprehensive survey was carried out with managers, engineers and technicians working in manufacturing. It is beyond the scope of this chapter to share the complete results.

6.3 Results from Questionnaire Survey

Ivanov et al. in 2020 undertook a large-scale, cross-disciplinary, and global survey on Industry 4.0 topics with researchers in the areas of industrial engineering, operations management, operations research, control, and data science at the 9th IFAC MIM 2019 Conference in Berlin in August 2019. They then went on to use both the literature survey results and the survey findings to establish structural and conceptual frameworks to propose future research opportunities for operations management researchers. (Ivanov, D., et al., 2020)

Similarly, the results of the collaborative robotics survey carried out as part of this research, provide the researcher a snapshot of the current trends and opinions on the use of this new technology in the workplace in Ireland.

The Cobot survey had 111 respondents in total and of the 111 there was an 87% completion rate. There were 37 questions in total. The average time to complete the survey was 10 minutes and 55 seconds. It ran over a period of 3 months from early June to late August 2020. The complete set of results including graphs can be found in the appendix section. Following is a brief description of the highlights.

Question 1. What sector does your company belong to?

A list of Irish manufacturing sectors from Enterprise Ireland was used to form a list of typical companies in Ireland. (www.Enterprise Ireland, 2020)

Medical Devices, Pharmaceuticals and Lifesciences accounted for 48 of the respondents, Engineering 19, Bio Pharma Engineering 10 and Food and Drink 7.

Four each from Education, Construction, and Electronics.

Two each from Environmental and Cleantech Products and Services, and Automotive.

One each from Consultancy, Lithography Semiconductor, Design and Build of special purpose equipment (mostly Medical Device), Aerospace, Semiconductor and Research and Technology Organisation (Advanced Manufacturing).

Question 2. Which of the following is closest to your actual job title?

The initial list was based on information from the preliminary study Universal Robots case study.

The 'Other' category accounted for 28 here. This was broken down into a list of individual job titles which can be found in the appendix.

Manufacturing Engineers accounted for 19 respondents, Engineering Managers 13, Design Engineers and New Products Engineers both 9, Maintenance Technician 6, R&D Manager 5 and Junior Project Engineer 4.

Three of each the following Plant Manager, Production Manager, Maintenance Manager.

Two Manufacturing Technicians and Quality Engineers.

In terms of seniority:

Directors and Managers	33
Specialists	5
Engineers	53
Technicians	11
Educationalists	4

Question 3. What type of enterprise are you working in?

The categories refer to the company size with and an additional Other option.

The results show that the largest category was large multinational enterprise with 68 of the respondents working in this type of enterprise. Small enterprise was selected by 15 of the respondents and medium enterprise by 11. Large indigenous enterprise was selected by 9 of the respondents, micro enterprise 4 and university and technological university both 1 each.

Question 4. Describe your company's products/services.

A vast range of replies was given, and the complete list can be found in the appendix. A small sample is shown here:

Medical devices

Provide products to monitor environmental conditions in cleanroom manufacturing

Automotive

Medical device contractor

Surgical instruments

Pharmaceutical solid dose

Manufacturing of microprocessors

Drug and pharma products

Surgical instruments and implants

Contract medical/pharma device manufacturers

Food products, both branded and for industry

Question 5. How would you describe your company's products/services in terms of unitary market value in %?

Total Number	N	26
Standard Deviation	δ	26.06
Mean	M	70.52

Question 6. In your view what are the top priorities in your area? (Average score in %)

The top 12 results are given here, and the full range can be found in the appendix.

Maximising the health and safety of the employee	14.97
Optimising product cost and competitive pricing	12.13
Ensuring workforce stability and continuity	11.72
Maximising workforce motivation with highly skilled teams	11.24
Maintaining the high reputation of the brand	11.23
Maximising workforce wellbeing	10.90
Ensuring product ingenuity and innovation of design	10.60
Maximising the career opportunities of the workforce	10.22
Minimising the environmental footprint of the company	9.62
Maintaining a position of the latest cutting-edge technology and automation	9.60
Providing customer service excellence	9.32
Satisfying regulation requirements	9.32

Question 7. In your opinion what level of experience does your company have with robotics and automation in %?

Total Number	N	103
Standard Deviation	δ	16.26
Mean	M	55.17

Question 8. Have you heard of collaborative robotics [Cobot]?

Yes	77
No	31

Question 9. Do you currently have Cobots in your manufacturing plant?

Yes	31
No	76

Note:

Question 10. is answered by companies that answered NO to Question 9.

Question 10. What are your three top concerns?

The top seven results areas are as follows:

Prohibitive costs?	36
Require more information on how they can be integrated into your factory?	35
Think they will not suit your type of product?	31
No time to investigate?	22
Need more highly trained technical staff?	21
Worried about Health and Safety?	17
Worried about turnaround time and flexibility?	11

There are other replies that can be seen in the appendix, but the above answers are the most common replies.

Note:

Question 11. is answered by companies that answered YES to Question 9, that is companies that have Cobots working in the plant.

Question 11. In what areas are they working in?

There were 18 options including Other from respondents. The most common replies to the applications were as follows:

Pick and Place	15
Packaging and Palletizing	9
Prototyping	9
Machine Tending	7
Quality Inspection	5
Assembly	5
New Product Development	5
Testing	5
Concept Generation	5
Industrial Assembly	4

Question 12. What level of involvement does the Cobot operator [Coboter] have with the Cobots?

Total Number	N	26
Standard Deviation	δ	21.91
Mean	M	29.92

Question 13. What type of work does the Coboter do with the Cobots?

Working side by side	15
Working in collaboration	12
Programming	7
Undertaking a risk assessment	4

One "other" category was filled out and the answer was "Cobot is fully guarded. Cobot is stopped to load/unload machine. No collaboration."

Question 14. What level of involvement does the Maintenance Technician have with the Cobots?

Total Number	N	26
Standard Deviation	δ	20.55
Mean	M	22.23

Question 15. What type of work does the Maintenance Technician do with the Cobot?

Other	13

This was the most common answer and the details of this were as follows: None, unless a new product is introduced, Preventative maintenance, Unblocks jams and recover from crashes, Very little work with Maintenance Tech to date, Planned preventive maintenance, Maintenance, Maintenance/tending to breakdowns, Periodic maintenance, Preventative maintenance and repairs, Interventions with the tended equipment, Maintenance, Preventative maintenance and No maintenance technician per se as Cobot not used in production.

Programming	8
Working in collaboration	7
Working side by side	3
Undertaking a risk assessment	3

Question 16. What level of involvement does the Automaton Engineer have with the Cobots?

Total Number	N	26
Standard deviation	δ	27.62
Mean	M	48.31

Question 17. What type of work does the Automation Engineer do with the Cobot?

Programming	20
Undertaking a risk assessment	7
Other	6

Other included Machine design, Optimising workflow, Looking for ways to improve interaction between Cobots and operators to make the Making the process more efficient, Fault finding, Cell Development and No dedicated automation engineer.

Working in collaboration	4
Working side by side	2

Question 18. Has your experience with your Cobots met your goals and expectations so far?

Yes, to a large extent met goals and expectations	9
Yes, moderately met goals and expectations	7
Has met some goals and expectations	5
Has not met goals and expectations	2
Other	2

The other category had two answers; Too new to tell and We have unclear goals around Cobots.

Yes, exceeded goals and expectations.	1

Question 19. In your opinion how has your company changed due to the introduction of Cobots?

Some of the highest scoring results are shown here:

Increased autonomy and decision making	8.54
Monotony of human work is reduced as the Cobot taking over these boring tasks	7.33
More interesting work because of working with cobots	7.25
Reduction to health and safety risks as the Cobot taking over these tasks with higher risks	6.88
Improvement of ergonomics in the workplace due to the Cobot versatility	6.83
Improved job satisfaction because of newly acquired technical skills	6.54
Expanded educational opportunities because of working with Cobots	6.25
Improved communication with other employees [Technicians, Engineers, etc.]	6.08

Question 20. Have your business processes needed to be redesigned due to the introduction of Cobots?

The results are as follows:

Yes, some minor or minimal changes	10
No, not at all	6
Yes, a complete shift in thinking [paradigm]	3
Yes, a rationalisation for improved efficiency	3
Yes, moderate redesign	3
Other	1

Other categories were: Current application was new so new design was required and Will be incorporating into existing processes on the next process and expect some process redesign.

Question 21. To what extent have your engineering tasks needed to be redesigned to facilitate the introduction of Cobots?

Yes, minor or minimal changes	9
Yes, a moderate redesign	6
Yes, a rationalisation of tasks	3
No, not at all	3

Other	3

Other categories were: Too new to tell, We are at an early stage, Long term I would expect that we would be looking at a significant change in engineering tasks and Still at very early stage but major change is coming.

Yes, a complete shift in thinking [paradigm] 2

Question 22. Who redesigned the engineering tasks to facilitate the implementation of the Cobots?

Internal Engineer	19
External Systems Integrator	10
Internal Technician	5
Internal Cobot Operator [Coboter]	5
Not Applicable	3
Other	2

Other categories were: Planning to develop internal skills and Research Engineers.

Question 23. To what extent did the Cobot need to be customised for your company?

Yes, minor or minimal	7
Yes, some customisation	5
Yes, a large amount of customisation	5
Yes, moderate amounts of customisation	5
No, not at all	3
Other	1

Other categories are No customisation on the Cobot, but specialised tooling needed on the arm.

Question 24. How long did the set-up of your Cobot take?

Greater than one working day	17
5-9 hours	4
Other	3

Other categories in detail were: Greater than 2 months, new line had to be built, Maybe I misunderstood but the turnkey system took 6 months to build and commission and over a year including operation qualitification.

1-4 hours 2

Question 25. What tasks were undertaken during this set up-time?

Programming	23
Doing risk assessment	19
Training	17
Interacting with Coboter	12
Other	4

Other categories in detail were; Design of tool and machine frame, fabrication, wiring, Designing fixtures, safeties, end of arm tooling, Validation and implementation of safety devices.

Question 26. Who installs, programs, calibrates, and maintains Cobots in your company?

Internal Engineer	19
External Systems Integrator	14
Internal Technician	12
Internal Cobot Operator [Coboter]	3
Other	1

Other category was Research Engineers.

Question 27. To what extent, in your opinion, do Coboters require post Leaving Certificate education to successfully operate a Cobot?

An advantage	11
Instrumental	5
Moderately beneficial	4
Slightly beneficial	4
Not at all	2
Other	1

Other category was Too early to make an assessment of this.

Question 28. What other abilities should a Coboter have to successfully operate a Cobot?

Sound technical aptitude	23
Good attention to detail	18
Facility to pass on knowledge to others	12
Self-motivation	11
Tenacity	6
Other (please specify)	0

Question 29. In your opinion do third level Institutions currently prepare students to work in this collaborative environment?

They teach the basics	12
The education is adequate	10
Not at all	4
The education is good	1

Question 30. What additional education/information would benefit the Coboter to successfully operate a Cobot?

Mechatronics basics	20
Health and Safety	11
Quality control introduction	5
Communications	5
Teamwork	4
Programming for automation	0
Other (please specify)	0

Question 31. How could this additional education/knowledge be accessed?

Hybrid of above options	18
In-house hands-on training	15
Traditional class-based module in a third level Institute	14
Third party online from Robotics company	12
Remote module in a third level Institute	12
In-house digital training	6
Other (please specify)	0

Question 32. In your opinion would your company be interested in obtaining more value from Cobots by higher task optimisation?

Yes	24
No	3

Question 33. In your opinion, would your company be interested in accessing training in the automation of business processes?

Yes	69
No	23

Question 34. What would be the best way, from your perspective, to access this training based on current company scheduling and workload commitments?

In-house hands-on training	51
Hybrid of above options	31
Third party online from the Robotics company	29
In house digital training	20
Traditional class-based module in a third level Institute	17
Remote module in a third level Institute	16
Other (please specify)	0

Question 35. In your opinion what would the most important outcomes of this training be?

Over 100 suggestions were shared here and a small example of these are as follows:

Skillset to install and program cobot

To promote autonomy amongst engineering staff

Give us confidence in our abilities to harness Robotics and to develop core skill-set's with machine use

To be fully up to speed in programming and operation of the robot

Wish to use Robotics that are interchangeable for other various work duties

Skill level

Increased knowledge base

Return of investment and confidence that continual PM costs will not be required

Applications to suit company automation

Better understanding

Hands on troubleshooting

Question 36. The current Covid-19 global pandemic makes physical distancing a requirement in the workplace, does this influence your opinion on using Cobots in manufacturing?

Yes	39
No	52

Question 37. Please enter your contact details:These will be held in strict compliance with General Data Protection Regulation (GDPR)

Note: 83 respondents completed this section. This data will not appear in the research due to GDPR.

6.4 Chapter 6 Summary

Chapter 6 reports the results of the qualitative case studies and the quantitative survey. It does not attempt to draw conclusions from these results. This will be undertaken in chapter 7. A thematic review of the case studies resulted in Table 9 which itemises the final 10 themes. Results from the questionnaire were listed in this chapter for further analysis.

Chapter 7. Findings and Discussion

In this chapter an analysis of the results of the mixed model approach is undertaken with a view to answering the four research questions highlighted in chapter 5.

Question 1.0 **What would an Industry 5.0 conceptual framework look like?**
Informed by the Review of Literature undertaken in chapter 2, 'Vision of Industry 5.0 and the state-of-the-art model', a conceptual framework encompassing four key areas was developed. Figure 6, a schematic of these areas, can be seen in chapter 3. In summary, the areas that are of critical importance for this research are:

- Work and Tasks
- Automation and Cobots
- Knowledge and Skills
- Human and Values

Industry 4.0 had extensive literature covering the areas of new value chains, data and smart manufacturing, technology and automation, but little on where the human fits and what skills they will need to become, and remain, useful in the high-tech working environment.

Work and Tasks. It is predicted by Hirsch-Kreinsen, that *"smart products can actively direct the production process."* However, it is not predicted what the future workplace will look like or what tasks will be required from the employees working in this environment. He continues by saying that the new technologies, patterns of work, corporate organisation including new models of business and ever-changing digital ecosystems have "*the potential to have all-encompassing social impact which is, as yet, difficult to grasp in its entirety".* Also, he states that the cyber-physical systems (CPS) will play a key role in this transformation. (Hirsch-Kreinsen, 2019) In the future, the manufacturing plant workers will be connected to the cyber physical systems by smart phones, or tablets.

Automation and Cobots. Personalisation and customisation are seen as an important element of Industry 5.0. The synchronisation, symbiosis, and harmony of the human and robot is the key to unlocking this potential going forward. Cobots can produce these customised, high value products whilst working seamlessly with humans. Gausemeier et al. in 2016 stated that in Europe the main challenge is to balance digitisation opportunities with the human centric world of employment. This is seen as a socio-technological challenge, the preservation of sustainable careers. (Gausemeier et al., 2016) Human-machine collaboration is one of the major challenges in the literature and is mentioned by Hermann, also, in 2016.

Knowledge and Skills. An emerging theme in the future of industry is the shortage of suitably qualified highly skilled staff. From the literature this is a critical problem for all companies going forward. Cyber-physical systems are more complex, and the human must become the flexible problem solver and strategic decision maker. Caldarola et al. state that in order for European industry to flourish, the workforce needs to have the correct skills and the development of human competencies must be in step with technological developments. The worker is responsible for maintaining the cyber physical systems and resolving extraordinary problems, as required. Thus, the worker needs to be more digitally skilled.

Human and Values. An investigation into the younger generation's needs and requirements in the workplace leads to the idea that the culture and values of the company are increasingly important. To attract the top talent, the workplace needs to be an inclusive environment. The point was made that workplaces that promoted diversity and inclusion were more successful at not only hiring but retaining these highly skilled individuals.

A research paper by the author was published in Vienna in 2019 at the ISPR conference titled "Industry 5.0: Is the Manufacturing Industry on the cusp of a new revolution?" Here, the authors investigated the history of manufacturing from the first industrial revolution to the fourth. They projected forward as to what the fifth industrial revolution might look like. They stated that *"science and technological innovations, training, and capital, were the key elements in evolving how products are conceived, designed and manufactured. Looking forward to the fifth industrial revolution it is likely that there will be a paradigm change in how industry will evolve given the tools of industry 4.0; the internet of things, digitisation, blockchain, advanced materials, additive manufacture, artificial intelligence and robotics, drones, energy technology, biotechnology, neurotechnology and virtual and augmented reality."*

In summary, the findings stated that currently Industry 5.0 has not been defined in the literature available at that time, nor do we have a vision of what this industrial revolution will bring in terms of technology. Nonetheless, the workforce of this new revolution will be vastly different. Governments worldwide will have to invest in human capital to make the workers of the future relevant and useful in Industry 5.0. Governance and ethics will be increasingly important so that the correct decisions for mankind will be made. (Doyle-Kent, M.; Kopacek, P., 2019) The full text of this paper can be seen in the appendix.

Question 2.0 **Can collaborative technology play a role by enabling humans and robots to work together in Industry 5.0?**

Firstly, looking at the literature available on Industry 5.0 initially, it can be said that Industry 5.0 will be built on the pillars of previous industrial revolutions. Chapter 4.3 looked at robotics in the modern manufacturing industry. New technology is continuously being developed and one emerging technology which has taken the human-machine symbiosis brought about by Collaborative robotics.

Doyle-Kent et al. stated that Cobots are designed to work alongside and in cooperation with humans. If it comes in contact with a human, it is designed not to hurt or injure them. Elprama et al. stated that Cobots are designed to be safe and this leads to new opportunities where factory workers and Cobots can work closely together in manufacturing. The International Federation of Robotics stated that Cobots are designed to be used in proximity to humans and are safe but a safe robot does not guarantee a safe collaborative application in practice. However, the interpretation of the safety requirements could be the most important influence on the uptake on Cobots in industry and requires further investigation (IFR, 2019).

The versatility of Cobots also emerged from the literature. One example is that IFR state that Cobots are lightweight and can be easily moved from one task to another. They are easy to implement and staff do not need to have much robotic programming experience. IFR state that the level of *"human-industrial robot collaboration can range from a shared workspace with no direct human-robot contact or task synchronisation, to a robot that adjusts its motion in real-time to the motion of an individual human worker."* The most common application is a shared workplace with tasks being completed sequentially. The importance of "how" humans and Cobots work together cannot be underestimated as responsive collaboration which builds on *"precision and repeatability to achieve productivity*" is where Cobots become economically viable in robotic automation. (IFR, 2019)

The literature raises the question of how to ensure staff are suitably skilled for the new high-tech environment? This was covered in question 1 previously. In chapter 4.3.5, in a MIT study, it was stated that Cobots enhance and are complementary to the human worker and recommend that it will be necessary to study, observe, and evaluate real life case studies to make assessments.

Another important question raised in the literature is does the level of automation in a company, and the type of industry, play a part in the success of the introduction of Cobots? It was noted that this type of automation has not been explored to its full potential but has the ability to bring widespread change to certain industries. Elprama et al. in 2016 stated even if there is a very high expected growth of Cobots, there is very little research available which focuses on Cobots and their interaction with factory workers. They asked do we know if these workers are willing to work with these Cobots and what will be the impact on their working practices?

ABI Research undertook an assessment of Cobot manufacturers and ranked the leading 12 in a study in 2019. They stated that there are currently over 50 manufacturers worldwide, but most do not have a product that is available on a meaningful scale. Secondly, the case studies investigated show that the advantages of using Cobots greatly outweighed the disadvantages and this can be seen in case study table 9. It was found that the 'health and safety' of the workforce was greatly enhanced by using this technology. Examples of how Cobots improve the work for humans is evident in the following comments taken from the case studies.
Cobots:

- *Ergonomic solution to difficult or dangerous tasks*
- *Decrease workers injuries*
- *Cobots lower H&S risks to the operators in the plant so Human Resources should be involved*
- *They can do dangerous or repetitive work therefore avoiding humans getting injured*
- *Can have frequent interactions with humans in a shared space*

However, the case studies reinforce the concerns that the literature raised about 'interpretation and adoption of the current health and safety legislation', and the resultant effect on how Cobots are being used in industry at the moment.

- *Lack of clarity of safety requirements of the Cobots is one of the areas holding back Cobot introduction*
- *Comprehensive H&S risk assessment must be implemented before the Cobot can be installed*
- *Company A's Cobots are extremely easy to program but are often put into cages for safety reasons*
- *Most Cobots in Ireland are used as a fenceless robot to meet with health and safety regulations*
- *These safety standards come from the industrial robot's safety standards and are evolving continuously*

In addition, the case study mentioned that it is the 'individuals installing the Cobots' that undertake the health and safety assessments and associated risk. As a result, Cobots are often put behind fences.

- *The risk assessment is the responsibility of either the machine builder or systems integrator and some are unwilling to take the risk of allowing the Cobot to run in a fenceless setup.*

The 'versatility' of Cobots in the workplace was an especially important theme in the case studies and examples shared were:

- *When there is a big variety, flexible automation is the quickest solution as changes can be programmed into the software*
- *Operate in a fenceless area of the factory*
- *Relocatable in the workplace and modular, and can be easily moved and reallocated*
- *Applications include: Packaging and Palletising, Machine Tending, Industrial Assembly, Pick and Place, etc.*
- *Cobots are suitable for small production runs and a high mix of parts*

In addition to 'versatility', the case studies reinforced the 'ease of use' of the robots and the fact that robotics experts were not required to install, operate, and maintain the Cobots.

- *Cobot is easy to use and if the application needs to be changed, it is far less expensive and easier to programme*
- *Cobots are user-friendly so that anyone can operate them*
- *They can be easily reprogrammed*
- *For the service and maintenance aspects, some companies train, and up-skill technicians*
- *Cobot manufacturers are making the integration much simpler (easier to program and risk assess)*

From the literature, 'how the Cobots operates with humans' was deemed important - from shared workspace to synchronisation. Also, the extent to which the 'Cobot must be integrated with other machines' in a process was highlighted. 'How to gain maximum value' from Cobots was under theme 8 in the case studies.

- *Companies need to understand where Cobots fit in their plants. It is not just a case of substituting Industrial robots with Cobots.*
- *A fundamental assessment of how this new technology could bring value at a task level was required.*
- *What tasks are undertaken - doing risk assessment, programming, Interacting with Coboter, training.*

In the case studies, the theme of 'productivity' was raised. Both positive and negative comments were made under this theme.

For example, on the positive side:

- *Operate 24 hours seven days a week.*
- On the negative side:
- *Low speed low volume are the zones that the Cobots excel in.*
- *Understanding of the scope of the Cobots currently available in terms of payload, speed, dimensions, volume, and variety of tasks and so on.*
- *Need to understand the amount of time an Engineer, Technician and Operator spends with the Cobot and what type of work they do [programming, working side by side, working in collaboration, undertaking a risk assessment…]*

‘Costs’ were not highlighted in the literature but were in the case studies. How to justify the investment in different size companies became critical to uptake in this technology. Both positives and negative comments were expressed here.
On the positive side the case studies stated:

- *Cobots are perfect for all sizes of business*
- *Cobots are affordable*
- *They have a low total cost of ownership*
- *They have a short return in investment*
- *Cost-effective alternative which, in turn, facilitates global competitiveness*
- *Less than a one-year payback on Cobots*
- *Designed for all sizes of business and with the leasing option*
- *Cobot shows its efficiency and effectiveness, we get a lot of repeat business*
- *Companies with established automation can access capital expenditure more easily*
- *Cobots suit this area (SME) perfectly and are made for fast and easy and flexible deployment with a quick ROI*
- *Using Cobots is often cheaper and saves space*

On the negative side the case studies stated:

- Some multinationals in Ireland resist Cobots because the internal EH&S paperwork involved can be extensive
- Financial and H&S managers need to be convinced to invest in Cobots

Neither sides of the cost arguments were found in the literature.
How Cobots could ‘fill the skills gap in industry’ was an important theme in the literature. In addition to filling the gaps, the Coboter would have a ‘more interesting and rewarding job’. This comes across in the following comments.

Firstly, in general:

- *Fill the skills shortage gap in a modern industrial environment where there can be high employee turnover*
- *SMEs in Ireland have the biggest challenges going forward to cut costs and fill labour gaps and they account for 70% of factories*
- *Human factors will be critical going forward, working with operators before the technology is introduced*

Secondly, how the Coboter would gain advantage by improving their work.

- *The operator (Coboter) would be required to change possibly the end effector or to programme when products change over*
- *Cobots empower the workers by removing them from repetitive tasks*
- *They give additional skills such as programming to the worker*

The literature raised the question does the 'existing level of automation in a company' predict the success or failure of introducing Cobots into the plant? This is very thoroughly discussed in the case studies and these are the points raised:

- *Companies with established automation trust automation faster*
- *Larger companies will change the criteria so that they can use a Cobot or even add a second Cobot to help to do the job more efficiently and effectively*
- *Larger companies using the Cobots here in Ireland typically use the Cobot to its full capacity which can make the programming and installation at the higher end of Cobots use*
- *Smaller companies starting to investigate and use our Cobots now for simple pick and place at CNC machines*
- *Currently Cobots are being used in sequential applications rather than in a truly collaborative manner*
- *A very small percentage of the Cobots in industry are actually running in a truly collaborative manner*
- *When there are experienced automation engineers and mechanisation in an organisation, the integration success rate will be higher, particularly for the more complex operations*

Thirdly, the industry questionnaire was analysed in the areas highlighted in the literature review and case studies. Out of a total of 111 respondents that started it, 96 completed

the questionnaire fully. To explain the background of the respondents, the following details were established:
When asked 'what their current role was', out of 108 replies 53 (49.07%) were Engineers, 33 (30.56%) were Directors and Managers, 11 (10.19%) Technicians, 5 (4.63%) described themselves as Specialists, and 4 (3.7%) were Educationalists.

The type of company that the respondents were working in was interesting. Out of a total of 109 replies, 68 (62.39%) stated that they were working in a multinational enterprise. Figure 16 in chapter 4 showed that in 2018 in Ireland 48.6% of manufacturing companies were classed as large enterprises and 51.4% were classed as small and medium sized enterprises. In survey 15, (13.76%) stated that they worked in a small enterprise and 11 (10.09%) in a medium sized enterprise. Nine (8.26%) of the respondents worked in a large indigenous enterprise while 4 (3.67%) worked in a micro enterprise and 2 (1.83%) in universities.

There was a vast range of industries represented (question 1) and also a vast range of products being produced by the companies (question 4). This included a range from medical devices to food products. Some more detail on the value of the product was asked in question 5, and the average value of the products was rated at 70.52%, with a standard deviation 26.06, out of a sample size of n=26.

In terms of all the company's priorities (question 6), the respondents were asked what the top priorities of the company were. 'Maximising the health and safety of the employee' (14.97 %) and 'maximising workforce wellbeing' (10.90 %) were particularly important to the companies. This reflects the case studies top priorities.

'Cost optimisation' and 'competitive pricing' were the second highest priority. This echoes the case studies in relation to the importance of costs. The case studies pointed to the relevance of costs when trying to justify the capital costs of investing in Cobots. Capital investment affects the cost of the product in terms of overhead costing.

The third area that was highlighted was ensuring 'workforce stability and continuity' (11.72%), 'maximising workforce motivation with highly skilled teams' (11.24%) and 'maximising the career opportunities of the workforce' (10.22%). In the literature, the stability of the workforce is a key priority of companies now, as it is difficult to replace highly trained staff. One motivating factor for the young modern workforce in relation to retention is by providing upskilling and career opportunities and this was highlighted in the responses to this question.

Another important priority in the survey (question 6) was ‘maintaining the high reputation of the brand’ (11.23%). This was not mentioned in either the case studies or the literature. In addition, a priority signalled in the survey was ‘ensuring product ingenuity and innovation of design’ (10.60%). It could be said that Cobots have the possibility of doing both of these. The high-quality work produced by the robots ensures low variability which will maintain the reputation of the brand. Products can be customisable and client specific which facilitates the ingenuity and design innovation requirement. This correlated also with ‘providing customer service excellence’ (9.32%) and ‘satisfying regulation requirements’ (9.32%).

Minimising the environmental footprint of the company had a high priority rating (9.62%) which was not mentioned either in the literature or the case studies to much extent.
The survey found that ‘maintaining a position of the latest cutting-edge technology and automation’ had significant importance also for the companies (9.6%). This means that they are open to new technologies such as Cobots and other types of automation.

In questions 8 and 9, when asked have you heard of Cobots, 77 out of n=108 said yes. When asked do you have Cobots in your plant, 31 out of n=107 said yes.

Question 10 was answered by the respondents whose companies do not have Cobots currently in their plants. They were asked to list their top three concerns about Cobots, and the following answers were recorded. ‘Prohibitive costs’ was the most popular answer. This correlated with the case study and question 6. ‘Lack of information’ was the second highest area. The respondents ‘required more information’, they thought that ‘Cobots will not suit our product’, and, had ‘no time to investigate’. All three of these require more information. The next concerns were ‘do we need more highly trained staff’ and ‘are there H&S risks’? Then they were ‘worried about turnaround and flexibility of the Cobot’. Both of these could be addressed easily again with more information.

Question 11 was answered by the respondents whose companies do have Cobots currently in their plants. It asks what areas the Cobots are currently working in, relating to the versatility and flexibility potential, raised both in the Literature Review and the case studies. The replies pointed to a number of areas. 51 companies used Cobots for pick and place operations which was by far the most common. Nine companies used the

Cobots in the areas of packaging, pelletising, and prototyping. Seven companies used the robot for machine tending. Five companies used Cobots for quality inspection, assembly, new product development, testing and concept generation. Finally, four companies used the Cobots for industrial assembly. Overall, 18 different options were offered in the question including an option of 'Other'. 84 replies were given. A total of 260 Cobots were operating in the respondent's plants undertaking different tasks in different production scenarios.

In the case studies, IMR requested that the following question should be raised in the questionnaire: "In reality who works with the Cobots in manufacturing, what do they do and what was their level of involvement?" The questionnaire addressed this by asking it in relation to three different employees: the Coboter, the Maintenance Technician and the Automation Engineer (questions 12-17). Table 10 illustrates the results.

Table 10 A summary of the results for questions 12-17

Employee	**What tasks do they carry out**	**Level of Involvement**		
		N	δ	M
Coboter	Working side by side (15) Working in collaboration (12) Programming (7) Undertaking a risk assessment (4) Other: Cobot is fully guarded. Cobot is stopped to load/unload machine. No collaboration.	26	21.91	29.92
Maintenance Technician	Working side by side (15) Working in collaboration (12) Programming (7) Undertaking a risk assessment (4) Other: None unless a new product is introduced, Preventative maintenance, Unblocks jams and recover from crashes, Very little work with Maintenance Tech to date, Planned preventive maintenance, Maintenance, Maintenance/tending to breakdowns, Periodic maintenance, Preventative maintenance and repairs, Interventions with the tended equipment, Maintenance, Preventative maintenance and No maintenance technician per say as Cobot not used in production.	26	20.55	22.23
Robotics Engineer	Working side by side (2) Working in collaboration (4) Programming (20) Undertaking a risk assessment (7) Other: Machine Design, optimising workflow, Looking for ways to improve interaction Between Cobots and operators to make the Making the process more efficient, Fault finding, Cell Development and No dedicated automation engineer.	26	27.62	48.31

From the data, with a sample size n=26, it is clear that it is the Automation Engineer who has the most interaction with Cobots in the plant. On average, 48.31% of their time is spent with the Cobots, programming, undertaking risk assessments, working in collaboration and side by side. They also undertake many other high-level technical duties such as cell and machine design, optimising workflow and efficiencies, improving human-machine interactions, as well as fault finding.

The Coboter spends on average 29.92% of their time interacting with the Cobot. The main work that the Coboter undertakes is working side by side, closely followed by working in collaboration. Four of the respondents said that the Coboters undertake risk assessments. It was noted that in some cases the Cobot is behind a guard and it is stopped only to load and unload raw materials and finished products. Finally, in some cases there is no collaboration between the Coboter and the Cobot. It can be said that in the majority of these cases, the Cobot is not being used to its full potential.

The Maintenance Technician only spends on average 22.23% of their time with the Cobot. The main duties undertaken are working side by side, closely followed by working in collaboration. They also undertake risk assessment and programming duties. In addition, the respondents added the following duties in the 'Other' section: The Technician works with the Cobot if a new product is introduced. They undertake planned and unplanned maintenance including preventative maintenance, unblocking jams and recovery from crashes. Another noted that there is no Maintenance Technician as the Cobot is not used in production and finally, one respondent wrote that there was very little work with Maintenance Technician to date.

Customer satisfaction was not a specific theme in the case studies apart from one remark which was that "Cobot shows its efficiency and effectiveness, we get a lot of repeat business". This illustrated a serious lack of feedback in terms of whether the Cobot is performing to its expectations.

Questions 18 and 19 investigate if the respondents are satisfied with this technology and pose the question how has their company changed due to the introduction of this collaborative technology? Out of the 26 responses, only one company states that the Cobots have exceeded the goals and expectations set down. This is a low number. Nine companies stated that to a large extent they have met their goals and expectations, seven said moderately, and five have met some goals and expectations. Two respondents state that this technology has not met their expectations. In addition, one company has only recently introduced Cobots and they state that it is too early to judge, and finally, another respondent states that its goals around Cobots are unclear. There seems to be an opening here to look at key performance indicators and metrics to help companies establish how to judge the performance of Cobots, as well as how to improve performance if they are not living up to expectations.

In summary, collaborative technology does play a role by enabling humans and robots to work together in Industry 5.0. The literature, the case studies and the survey reinforce this strongly but there is a scope to improve how this is enabled.

A research paper was published at the ISPR 2020 conference investigating the wider social, ethical, and legal aspects of modern automation. This paper was titled "The Social and Ethical Aspects of Automation" by Mary Doyle Kent and Peter Kopacek. Special emphasis in this paper was given to new types of automation, like the new generation of collaborative robots. This yields to new questions in ethical and social sciences like how to best educate the Coboters? For the first time, legal aspects of robots in manufacturing automation and their influences on ethics and social issues are introduced and discussed with special emphasis to SME`s.

To conclude, future technology development should definitely go hand in hand with an adequate legal framework. This framework should readily transform the progressive nature of technology. It should also bring legal certainty, both for innovators and end users of the technology. However, it should not have a deceleration effect on the technology and should develop standards that would encourage progress.

Also, with regards to the education of the Coboters, adequate education possibilities should be offered. This includes both how they are educated, and what knowledge they require in the ever-changing highly technical work environment. Companies and governments must work at investing in appropriate education programmes to support the acquisition of skills necessary to secure and thrive in jobs that are being created or changed by the deployment of robots and automation. (Doyle-Kent, M., Kopacek, P., 2020) The full text of this paper can be seen in the appendix.

Question 3.0 Can a set of guiding principles be developed to aid with the introduction of human centred automation in modern manufacturing companies? Question three focuses on the introduction of the collaborative technology into the workplace. As was previously highlighted, there is an opportunity to help companies introduce Cobots in a manner to gain greater value from their investment. The following builds on themes 8 and 10 from the case studies, asking in a practical manner, can engineering and business processes be redesigned to lend greater value?

According to the interviewees in the case studies, there is scope to enable companies to introduce this technology in a more effective manner, as up to this point, companies have not optimised the role of the Cobot in the plant. The following narrative from the case studies illustrate this:

- Companies need to understand where Cobots fit in their plants. It is not just a case of substituting industrial robots with Cobots

- A fundamental assessment of how this new technology could bring value at a task level was required

- Currently Cobots are being used in sequential applications rather than in a truly collaborative manner

- A very small percentage of the Cobots in industry are actually running in a truly collaborative manner

In the questionnaire, the companies were asked about their experience in robotics (question 7). They were asked to rate the level of experience their company had with robotics and automation. The result out of a sample n=103 gave a mean of 55.17% and standard deviation of 16.26. This can be interpreted that there is a lack of automation expertise in the respondents.

The case studies highlighted that the larger companies with experience in automation have a better success rate.

- When there are experienced automation engineers and mechanisation in an organisation the integration success rate will be higher, particularly for the more complex operations

- Larger companies using the Cobots here in Ireland typically use the Cobot to its full capacity which can make the programming and installation at the higher end of Cobots use

Additionally, the interviewees in the case study mentioned that smaller companies were looking at collaborative robotics but not for collaborative work.

- Smaller companies starting to investigate and use our Cobots now for simple pick and place at CNC machines

Question 20 asks have business processes been redesigned for the introduction of this new technology. Minimal or minor changes followed by not at all were the top answers given. This leads to the conclusion that Cobots are not being used to their full potential and root and branch redesign of business processes were not made before their introduction to add value. Only three out of 26 said that there was a complete shift in thinking. Three further answered that there was a rationalisation for improved efficiency and three further stated a moderate redesign. In addition, one respondent said that it was too early to judge, and changes may need to be made in the future.

Likewise, question 21 posed the question to what extent have your engineering tasks needed to be redesigned. The results echoed the results of question 20. The most popular answer was that minor or minimum changes were necessarily followed by moderate redesign. Two stated that there was a complete shift of thinking. Three respondents stated that there was a rationalisation of tasks. On the surprising side, three said that there was no change to the engineering tasks and stated that it was too early to say but it may be necessary in the future.

In terms of who redesigned the engineering tasks to facilitate the implementation of the Cobots, this was asked in question 22. The majority chose an Internal Engineer followed by an External Systems Integrator. Five respondents stated an Internal Technician, and five others stated a Coboter. Finally, two others were planning to develop internal expertise in the future.

Question 23 investigated whether the Cobot was customised for the company? Five respondents stated that there was a large amount of customisation and five stated that there was a moderate amount. The majority said that there was minor, minimal and some customisation. Three stated not at all and one stated that specialised grippers needed to be developed.

Asking in question 24 how long it took to set up the Cobot out of n=26, the majority (17) stated greater than a working day. Four stated 5-9 hours and two chose 1-4 hours. This compares to less than a working day, which is what some of the Cobot manufacturers state in the literature. The make or type of Cobot was not specified here so this could be the reason for the variety of answers. In addition, question 25 asked about the type of tasks undertaken during the Cobot set up. Programming (23), risk assessment (19) and training (17) were the top tasks followed by interacting with the Coboter (4) and the design of tool and machine frame, fabrication, wiring, designing fixtures, safeties, end of arm tooling, validation and implementation of safety devices. Question 26 asked who installs, programs, calibrates, and maintains Cobots in your company? Internal Engineer (19), External Systems Integrator (14) and Internal Technician (12) were the most popular. This was followed by Coboter (3) and Research Engineer.

Following the feedback from both the case studies and questionnaire, an academic paper was written to present a set of guiding principles that would aid with the introduction of human centred automation in modern manufacturing companies. These principles can be found in the appendix in a paper titled “Do we need synchronization of the human and robotics to make Industry 5.0 a success story?” It was presented virtually in the ISPR 2020 conference in Turkey. This paper asked the following questions: Can we ensure that humans have a place in the highly automated workplace of the future (Industry 5.0) by optimising human capital? Can the traditional educational provider supply the skills required to educate this modern worker or do we require an innovative educational system?

In conclusion, the paper looked at how the relationship between humans and robotics can be optimised and enhanced in an Industry 5.0 setting. It focused on SMEs where the introduction of automation and robotics is traditionally more of a challenge for various reasons. It found that by systemically analysing the work tasks it was possible to find the optimum compromise between humans and robotics, building on the positives of both. In addition, focusing on, and enhancing the work and skills of the operators, ensures a long-term engagement of staff, which are a critical resource in the modern factory.

Theory based practical guidelines and a framework were proposed which was aimed at enabling businesses to embrace human centred systems. The next step is to apply the proposals to practical applications in SMEs and to assess the outcomes and to think about Production 6.0." (Doyle-Kent, M., Kopacek, P., 2020) The full text of this paper can be seen in the appendix.

Question 4.0 **In Industry 5.0 can a highly skilled creative workforce be established to work in a human centred workplace, which generates personalised high-value and high-quality products?**

Over the various industrial revolutions changes to work practices have been profound. In chapter 4, a review of work and society was undertaken in the Literature Review. In the 1900s, according to Giddens and Sutton, 35% of the workforce held skilled jobs and 10% unskilled. He states that over the decades, the numbers of people working in manufacturing are decreasing and the nature of work itself has greatly changed while the security of work, or job security, has been greatly diminished. (Giddens et al., 2017)

Taylorism and Scientific Management were described as a system of maximising work output through optimum layout in factories. The concept of time-and-motion studies transformed fundamentally work practices and improved efficiencies and is the foundation of modern work practices in industry. It has a negative effect on the skills and the autonomy of the workforce as work is broken down into small tasks. The result is the deskilling of the worker.

In the 1980's, various economists put forward the idea that work and economics should not be seen as a profit-making entity only but embedded into social networks.

Since 1970s, in what is described as a "high trust system", employees can take control of their work within specific guidelines. The result is team building, problem solving, working groups, gain sharing and is known as 'post Fordism'. This facilitated customisation of products. As a result of changing from mass production to flexible specialisation the skills of the factory operators, technicians and engineers had to change. (Cappelli, 1993)

With the advent of Industry 4.0, manufacturing industries have, once again, changed. The trend of offshoring manufacturing to low cost countries is well documented followed by recent trends of onshoring, where highly automated manufacturing plants can be cost effective, returning work to the mainland. This high tech, highly efficient automation leads to a reduction in the level of employment. Examples were given in the Literature Review where high levels of automation have resulted in low levels of employment - 140 employees instead of 2,000, for the equivalent volume of product without automation. (Ford, M., 2015)

In this highly automated world where do the humans fit in? What skills do they need and how do they obtain these skills? Jobs of the future will involve human collaboration with machines. Andrew McAfee from MIT says humans should learn “to race with machines not against them.” (Ford, 2015).

In 2019, the paper “Integrating Education into Maintenance Operations: An Irish case study” was co-authored by the author of this thesis. This paper was presented at an IFAC TC9.5 conference in Sozopol, Bulgaria. It investigated the skills and knowledge required for the modern manufacturing workplace and how this might be implemented into the technician workforce. It was an actual case study based on a high-tech medical device company in Ireland. The conclusion of the paper was that there was a requirement for several educational training modes to be introduced. *“One size definitely does not fit all when it comes to technician training and several options must be available for any training given need.”* (Costello, O., et al., 2019) The full text of this paper can be seen in the appendix.

Shortage of suitably skilled workers in manufacturing plants is a common theme internationally. Ireland also has this challenge, and this was highlighted in the case studies, particularly in SMEs.

- SMEs in Ireland have the biggest challenges going forward to cut costs and fill labour gaps and account for 70% of factories
- The Cobot has the capacity to fill this gap
- Fill the skills shortage gap in a modern industrial environment where there can be high employee turnover

Industry 5.0 builds on the Industry 4.0 advantages and improvements. Collaborative robots are an integral element of Industry 5.0, they are not replacement robots. Cobots assist workers rather than replacing them, resulting in a customisation of a product that is built to the highest quality standard by agile, versatile human-robot collaborative technology. Performance is maximised by minimising human idle time and by improving the health and safety and motivation of the worker.

Questions 27-35 focused on skills, knowledge, and training in the collaborative human-robot space. Initially, looking at the basic education of the Coboter, moving on to what are the key abilities that would make an ideal Coboter. Then, asking if third level Institutions could facilitate with upskilling and in what format.

The case studies highlighted the need to train the Coboters and also suggested how this would enhance the work of the Coboter.

- They give additional skills such as programming to workers
- Cobots empower the workers by removing them from repetitive tasks

The top skills and abilities needed by a Coboter to successfully do their work were recorded in the survey as sound technical ability (23) and good attention to detail (18). In addition, the facility to pass on knowledge to others (12) and self-motivation (11) were highly valued and to a lesser extent, tenacity (6). Following on from this, the respondents were asked what additional skills and education should be given to the Coboter (question 30)? Mechatronics basics (20) and health and safety (11) were the two front runners. Then, quality control introduction (5), communications (5) and teamwork (4) were selected but surprisingly, nobody selected programming for automation. How should the training be delivered was asked in question 31. Hybrid training was the most popular answer (18), followed by inhouse hands on training (15), traditional class-based module in a third level Institute (14), third party online from robotics company and the option of a remote module in a third level Institute both received 12 votes and finally, in-house digital training was the least favourite (6).

The opinions of the respondents in relation to the current training given by third level Institutions to students to operate in this collaborative environment were also investigated (question 29). Overall, they did not think that the institutions were performing well in this area. They teach the basics (12) and the education is adequate (10) were by far the most common responses. Four said that the Institutions do not prepare students at all to work in this collaborative environment and one said that the education currently offered is good. This is obviously an area that requires intervention in Irish education system.

Following on from this, the respondents were asked about higher-level skills and training in the area of automation of business process and training to extract higher value for the introduction of Cobots. Question 32 asked, in your opinion would your company be interested in obtaining more value from Cobots by higher task optimisation? This was asked to the group that had Cobots in the plant and 27 replies were given. An outstanding 24 (85.2%) said yes and three said no.

Moving back to the larger group, a question asking would your company be interested in accessing training in the automation of business processes was asked. Ninety-two of the respondents answered this question, 69 said yes and 23 no. This was a positive affirmation for the research in that 74% of the respondents were interested in this training.

Again, the respondents were asked to pick the optimum mode of training. In-house hands-on training (51) was by far the most popular, followed by hybrid training (31), third party online from the robotics company (29), in-house digital training (20), traditional class-based module in a third level Institute (17) and finally, the least popular was the remote module in a third level Institute (16). Later on, in the questionnaire (question 35) a list of over 100 important outcomes of this training were listed by the respondents.

The review of literature uncovered what the modern worker's needs and values were. Mumford expressed this as highly skilled knowledge-based work and predicts that this will be the largest growth area going forward. Modern highly skilled workers or knowledge workers value an acceptable income, job satisfaction, and job security. Mumford states *that "the rights and needs of the employees must be given as high a priority as those of the non-human system"*. (Mumford, 2003)

The World Economic Forum in 2014 discuss how modern employees now expect more collaborative, sustainable and inclusive ways of working. (World Economic Forum (a), 2014) Giddens et al. in 2017 state that work that generates income is the key to generating the wealth required to sustain a varied and fulfilling life. (Giddens et al., 2017, p. 285)

The companies values and culture are significant also. Organisations and individuals can share the same values and this is an important and defining factor of the institution. From the literature the modern worker expects the inclusion of minorities in a diverse working environment. Not only is this fair but it leads to better business outcomes. Inclusion in the workplace is one where there is a collaborative, supportive, and respectful environment that increases the participation and contribution of all employees. True inclusion removes all barriers, discrimination, and intolerances. When these principles are applied properly in the workplace, it is natural for everyone to feel included and supported. One minority group in engineering is women. The questions asked how can companies access the top talent if only 50% of the population are available?

In 2018, the author presented a paper in Baku, Azerbaijan at the IFAC TC9.5 conference. The title of this co-authored paper was “Where are all the Irish women engineers: a case study”. The paper investigates the reasons as to why there are a small percentage of female Irish engineers working in the profession. It also asks the question Is gender diversity needed in engineering? A qualitative and quantitative study was carried out and the results discussed.

In conclusion, it was established that the shortage of females working in engineering roles is a global challenge and Ireland reflects this shortfall. It is extremely important, going forward, that young women in Ireland recognise engineering as a possible and very worthwhile career.

In another co-authored paper “Diversity and Inclusion in Automation”, a case was put forward as to why inclusion of minority groups into a diverse working environment was not only fair and morally right, but made excellent business sense. When diversity and inclusion are a company’s mission, it requires strategies and practices to support a diverse workplace and leverage the effects of diversity to achieve a competitive business advantage. Companies that create diverse and inclusive work environments are more adaptable, creative, and become magnets that attract top talent. (Bula et al., 2020)

The question was raised how do we get minority groups interested in automation and engineering? A working group was formed in IFAC’s technical committee 9.5. The aims and objectives of this group are outlined in the author’s co-authored paper “TECIS Inclusion and Diversity working group vision”. The objective of this paper is threefold, to outline the future direction of the inclusion and diversity working group in TECIS, to support and foster greater knowledge of gender diversity in engineering education and to outline future research activities that could make a substantial contribution to our understanding of diversity issues in engineering in addition to making best practice recommendations that can be used in the engineering industry. In summary, the aims of the working group are:

- “We will work as a cohesive multicultural group listening to all and appreciating all contributions.

- Data gathering is an essential element of this process as understanding sociological, cultural and educational influences are key to unlocking trends and paradoxes.
- Investigating the role of the engineer in modern society is necessary so as to attract diverse communities into modern techno-engineering fields.
- It is strongly felt that engineering education needs to be remodeled to attract diverse communities at third level.
- Expression of the core values of our youth needs to be incorporated into engineering disciplines so that the value of this education is more highly appreciated.
- This working group will promote careers and education in engineering by highlighting positive role models and communicating the good news stories through diverse digital mediums and through IFAC and TECIS.
- Networking and mentoring are vital for people working in and considering STEM careers.
- Publishing academic papers and present at conferences, symposiums and workshops in TECIS and elsewhere.
- Investigation of funding opportunities to support future cross-cultural projects.
- We will work as a cohesive multicultural group listening to all and appreciating all contributions.
- Data gathering is an essential element of this process as understanding sociological, cultural and educational influences are key to unlocking trends and paradoxes.
- Investigating the role of the engineer in modern society is necessary so as to attract diverse communities into a modern techno-engineering field.
- It is strongly felt that engineering education needs to be remodeled to attract diverse communities at third level.
- Expression of the core values of our youth needs to be incorporated into engineering disciplines so that the value of this education is more highly appreciated.

In summary, all four research questions were analysed in this chapter. Each question was looked at individually and the information from the Literature Review was debated by comparing and contrasting the new findings from the results of the Irish case studies and questionnaire. This mixed model approach discovered that many aspects that were discovered in the qualitative and quantitative research were not written about in the literature to date. Important contributions have been made to understand how human-centred systems could be optimised in manufacturing. Seven conference papers were presented at ISPR and IFAC TC9.5 conferences throughout the duration of this research. This adds to the quality of this research as these papers have been peer reviewed by international specialists.

Chapter 8. Conclusions and Recommendations

The findings of this research are of value to engineers and engineering managers as well as the manufacturers and distributers of the collaborative robots and the automation specialists. It brings insights into the future of human centred automation through data gathered from case studies and a questionnaire distributed to employees working in a technical capacity in the Irish industry.

This solid research can be used to inform future policy makers, educationalists, and the research community in general. Some of the findings have been published in academic papers and presented in conferences. The unpublished data will be presented at future conferences and made available to the general public.

The validity and reliability of the research was strengthened through adoption of the chosen research methodology. Careful structuring, preparation, and data analysis contributed to the internal validity, whilst strong representative samples, extensive literature review and mixed method research served to strengthen the external validity. Reliability was obtained through the acknowledgement of limitations, recognition and mitigation of bias, piloting to reduce errors and any ambiguity, and via rigorous scoping. Looking forward to the fifth industrial revolution, it was established that there was little literature available in the area of manufacturing. This research focuses on human-centred automation, specifically in manufacturing. In terms of academic scholarship, it has developed a conceptual framework to encompass the main elements of Industry 5.0. The aim of this framework was to illustrate that multiple factors need to be considered in an Industry 5.0 human centred systems approach. These factors are intertwined and influence the adoption of the overall system.

The ideology used in this research was pragmatism which facilitates improvements in living standards, technology, and democracy. This research helps improve the integration of human-centred technology into manufacturing, hence improving the opportunities for humans, thus generating positive outcomes for society. There is a focus also on the inclusion of all, including minority groups, and this has the potential to expand the workforce ensuring the top talent in automation and manufacturing. It has been emphasised that if industry continues to only attract the traditional cohort that opportunities will be missed, and companies will struggle to attract and keep the best talent. Our youth expects an inclusive and dynamic working environment. These ideas have been expressed in three published papers.

Gray stated that pragmatism views the mixing of quantitative and qualitative data in a single study not only as legitimate, but in some cases, necessary. (Gray, 2018) A mixed model approach has been used in this research. Initially, a comprehensive literature review on the vision of Industry 5.0 and the state-of-the-art model was undertaken and four research questions were constructed.

A conceptual framework (Figure 6) was established, and a further in-depth review of relevant literature undertaken. The scope of this comprehensive review was defined by the conceptual framework.

This Literature Review led the author to discover that there was a significant gap in the area of human-centred systems in Industry 5.0. In pursuit of this knowledge, the author went about setting up case studies to undertake qualitative research in the area of collaborative robotics working with humans. As the author lives and works in Ireland, she used the contacts from the manufacturing industry in Ireland to conduct her research.

A number of case studies revealed an extensive array of findings that are novel. Full transcriptions of the interviews are available in the appendices. A thematic review was undertaken to analyse the case study outcomes and a summary of these themes was tabulated in Table 9. The themes led to unexpected contributions that were not highlighted in the literature. These were extensively discussed in chapter 6.

A questionnaire was designed to build on the Literature Review findings along with the findings from the case studies. Out of 111 respondents, 96 completed the in-depth questionnaire. Out of these, 77 had heard of Cobot technology, and 31 had Cobots working in their plants. The questionnaire findings were of substantial interest and illuminated how this technology was not reaching its potential currently in manufacturing plants all over Ireland.

The research hypothesis was found to be positive based on the outcomes for the four research questions in the previous chapter. Industry 5.0 will be a symbiosis of the technological advances of Industry 4.0 and a highly skilled creative workforce to create a human centered workplace which generates personalised high-value and high-quality products.

Many discoveries were made during this research and one outcome was that the seven academic papers were written and presented up to this point in time. Some of the important discoveries are outlined below.

The definition of Industry 5.0: Industry 5.0 has not been well defined in the literature. There is a lack of peer reviewed articles published so the information accessed is coming mainly from other sources. As mentioned previously, the German Research Council stated that Industry 4.0 and digitalisation of manufacturing is now a reality and these new technologies, associated value networks, patterns of work and dynamic digital ecosystems have the potential to have an important social impact into the future. They state that cyber physical systems are the basis for future transformation. (Hirsch-Kreinsen, 2019) Hermann, in 2016, stated that in the connected world of smart manufacturing, the role of the operator, technician, engineer, and manager changes. Cyber-physical systems are more complex, and the human must become the flexible problem solver and strategic decision maker. (Hermann, 2016) As with previous industrial revolutions, the next will incorporate the pillars of the last so that it is highly likely that Industry 5.0 will have the highly technical elements of 4.0.

A definition of Industry 5.0 has been proposed:

Industry 5.0 is the human-centred industrial revolution which consolidates the agile, data driven digital tools of Industry 4.0 and synchronises them with highly trained humans working with collaborative technology resulting in innovative, personalised, customised, high value, environmentally optimized, high quality products with a lot size one.

The critical elements of Industry 5.0: To establish what Industry 5.0 would potentially look like, research question one was developed. *"What would an Industry 5.0 conceptual framework look like?"*

This framework is a chronicle of the key factors to be studied and the presumed relationship between them. A model was developed (Figure 6) incorporating the following: *work and tasks, automation and Cobots, knowledge and skills and human and values.* The definition of Industry 5.0 is the symbiosis and harmony of these elements to produce a product which is customised and personalised.

The result of this framework was to signpost the Literature Review to discover the requirements of each of these in a modern manufacturing plant. The literature has revealed many important findings and a summary of some of these are listed here:

- The role of the human in manufacturing has changed dramatically over the decades and industrial revolutions. This has often been to the detriment of the white and blue-collar workers.
- Tasks carried out by workers changed from being complex, craft-type tasks to the Scientific Management era of dissected deskilled tasks to, once again, in the post Fordism era, a 'high trust system' which allows workers to take control of their work.
- Automation in Industry 4.0 takes away work from humans making them redundant on the factory floor. The result is very high-quality goods mass produced.
- Industry 5.0 required the personalisation and customisation of products and this required the more highly skilled human with creativity and agility.
- Robotics and automation are on the cusp of a new era.
- Open source robot operating systems will make robotics more available to all.
- The connection of human to robots communicating using IoT.
- Cyber physical systems and digital twins enrich digital factory models.
- Decisions are now being made by machines with the decentralisation of decision making. Humans can intervene as required.
- Cloud robotics means that the migration of intelligence is now centralised in cloud computing hubs. This gives mobile devices the opportunity to access the processing power of the cloud computing infrastructure.
- Individual robots can use the network for resources. Instant software updates are possible across multiple machines.
- Cobots are designed to work safely beside, and with, humans.
- Cobots enhance and are complementary to the human worker.
- The International Organization for Standardisation (ISO) has developed standards for robots operating in four types of collaborative mode.
- End-users must conduct a risk assessment of the intended application to be certain they meet the legally binding standards for health and safety at work in their country.
- Cobots offer considerable advantages to companies.

- Real value creation in Industry 5.0 is through the adoption of human-centred technology.
- For industry to flourish, the workforce needs to have the correct skills.
- In the “Factories of the Future 18-19-20 Work Program”, the focus is on human factors.
- The development of human competences must be in synergy with technological progress.
- The worker is responsible for maintaining the cyber physical system and resolving extraordinary problems that may arise.
- This requires the worker to be more digitally skilled.
- Learning factories are an essential means of educating students and professionals using practical pedagogy and using problem-based scenario learning.
- Socio technical system is where the human’s rights and needs are of the same importance as the technology’s needs.
- Socio-technical design has an important democratic component where employees who used the new systems should be involved in determining the required quality of working-life improvements.
- Change in organisations is difficult and can lead to social breakdown if not introduced in a cohesive manner. This includes introducing new technology.
- Recent economic crises have damaged trust, and many are disillusioned with the way our organisations operate.
- The social contract between business, government and society seems to be broken.
- Employees now expect more collaborative, sustainable and inclusive ways of working.
- In the workplace, employers are required to create new social covenants which are made up with moral values and commitments.
- Relationships between employer and employees can be known as ‘personal compacts’, and corporate change initiatives require the changing the terms of these compacts to align personal and corporate values.
- Employees look to see if the employer respects the values proclaimed by the company by checking to see if there is consistency between what it does and what it has set out to do.
- The modern worker’s commitment to a particular job is different to the employees of bygone years and they often move from company to company with little loyalty.

- A defining characteristic of a social institution is its values and the modern works looks to see if the company's values align with their personal values and, in addition, look for evidence that the company 'practices what it preaches'.
- Values influence communication, conflict, and group behaviour in an organisation.
- An employee was more likely to move up the promotion ladder if they had the same set of values as the manager in the company.
- A system of shared beliefs and values which develop within an organisation and guides the behaviours of its members.

The symbiosis of humans and robots work together: Research question 2 asked *"Can collaborative technology play a role by enabling humans and robots working together in Industry 5.0?"*

Automation and robotics excel in the manufacture of standardised products using manufacturing processes in high volumes to an excellent quality level. When creativity or customisation is expected, the human being is key. The solution is collaboration of robots and the human. Traditional robots cannot work side by side with humans but collaborative robots or "Cobots" are designed to work in synchronisation with human employees. The robot prepares the product in a rigorous manner, meeting specification requirements to a high standard, and the human then takes over to add the finishing touches to the product.

From the literature it was emphasised that humans need to be put back into the loop but, to do this, new and differently skilled employees are required to fill new job specifications. To this end, the employees need to expand both their digital and soft skills, so that they can maximise the benefits from the digital toolbox available from Industry 4.0.

In Industry 5.0, the collaboration between Cobots and humans will mean an increase of productivity, quality, output level and, most importantly, innovation. Safety will be increased, and workers will experience more personal satisfaction because the work that they undertake will be more interesting and motivating. Because of the 'connected' workforce of human and machine working together, there will be a knock-on benefit of agility. This means that the company will stay ahead of its competitors in terms of diverse product offerings, operational efficiency and keeping labour costs down in an increasingly competitive market.

These points were reinforced by the case studies and the questionnaire but in some cases the results from both of these differed to the literature. From the case studies, the health, safety and wellbeing of the workforce were critical. They emphasised that Cobots could help with these.

- Cobots reduce H&S risks to the workers by taking over the arduous tasks
- They can decrease workers injuries.

The questionnaire highlighted that the health and safety of the company's employees and maximising employee wellbeing were the top priorities of the companies.

However, it was also emphasised in the case studies that the lack of clarity of the safety requirements of Cobots at the moment is a negative factor for their introduction into factories.

- A comprehensive H&S risk assessment must be implemented before the Cobot can be installed
- Cobots are extremely easy to programme but are often put into cages for safety reasons
- The risk assessment is the responsibility of either the machine builder or systems integrator. Because of this they can be unwilling to take the risk of allowing the Cobot to run in a fenceless setup.

The questionnaire also mentioned that one of the reasons that Cobots were not already introduced into their plants was because of perceived health and safety risks, even though this was low in the replies ranking of question 10.

When considering Cobots, there are many more factors that need to be evaluated. The versatility and ease of use of Cobots was highlighted as important factors in the case studies.

- Cobots can be easily moved and are modular.
- They are suitable for low volume high variety.
- They are easy to reprogramme when moving from one application to another.
- Anyone can operate a Cobot as they are user friendly.
- Integration is getting easier and easier. Easier programming and risk assessment help with this.

Improvements in productivity were discussed in the case studies but there were positive and negative points made here.

- Yes, Cobots can operate 24 hours a day
- However, they are limited to low speed low volume automation applications

In addition to versatility and increased productivity, it was considered especially important that companies needed to understand where Cobots fitted into their plants and how they can bring value at task level to the business. Also, another factor that was considered important was how much time do engineers, technicians and operators spend with the Cobot and what work they are undertaking is also important.

The case studies highlighted the importance of understanding the costs associated with the Cobot. There are many positives here in that they are cost effective to buy and run but, nonetheless, as is often the case with new technology introduction, sometimes it is difficult to justify. Also, the amount of paperwork required in the larger multinationals in terms of health and safety, can be off-putting. In the questionnaire, costs optimisation and competitive pricing were the second highest priority of the firms.

The case studies interviewees believed that Cobots have the potential to fill the skills shortages in Ireland in the manufacturing industry. They stressed that it was essential to do this in a manner that would bring the staff ‘onboard’ with the changes. Working with the operators before the technology was introduced would be essential for it to be accepted. The questionnaire highlighted that in terms of company priorities, ensuring workforce stability and continuity was the third highest priority, as was maximising workforce motivation and careers opportunities. This was echoed in the literature. The stability of the workforce was a key priority of companies as it is difficult to replace staff.

Another important factor which needs to be considered is that the level of automation already in a company will predict the success or failure of the introduction of the collaborative robotics into a particular company. The more comfortable the company is with automation, the more easily this technology can be introduced. It is also true to state that the larger, more highly automated companies have more staff trained to work with robotics and automation. Some statements from the case studies that illustrate this are:

- Companies with established automation trust automation faster
- Larger companies using the Cobots here in Ireland typically use the Cobot to its full capacity which can make the programming and installation at the higher end of Cobots use
- When there are experienced automation engineers and mechanisation in an organisation the integration success rate will be higher, particularly for the more complex operations

In the questionnaire, the companies that had Cobots currently in their companies stated that the automation engineers worked the most with Cobots. They worked almost half of their hours with the Cobots. This was followed closely by the Coboters and finally, the maintenance technicians. The robotics engineers spent the majority of their time programming the Cobot and then doing risk assessments. The Coboters mainly worked side by side and in collaboration with the Cobot, as did the technician.

The survey found that maintaining a position at the latest cutting-edge of technology and automation was a significant priority for the companies, which in turn, leads to the idea that companies are open to Cobots.

However, from the survey there is a significant opportunity for Cobot distributers to share information to companies as they seem to be inadequately informed at the moment. The reasons given as to why these companies do not have Cobots currently were given in the following order:

- Prohibitive costs
- Require more information on how they can be integrated into your factory
- Think they will not suit your type of product
- No time to investigate
- Need more highly trained technical staff
- Worried about Health and Safety
- Worried about turnaround time and flexibility
- Not Applicable
- Worried about redundancies
- Worried about the environmental footprint
- Set up cost and space

- They are not currently safe enough to work alongside humans in the large majority of cases has been our experience
- Floor space requirements
- Regulatory requirements - CQV
- How they are validated/qualified in a regulated environment

In summary, the Cobot does play a significant role by enabling humans and robots working together in Industry 5.0, but the questionnaire exposed how this technology has more potential, especially when it comes to customer satisfaction.

From the questionnaire, only one company stated that Cobot introduction had exceeded their goals when asked if they were satisfied with this technology. At the other end of the scale, two companies stated that Cobots had not met their expectations. The case studies said that they did not ask for feedback but that they do get a lot of repeat business which they interpret as positive feedback. Question 4 attempts to understand this outcome. Additionally, there is a need for adequate legal framework when introducing this new type of progressive technology. This was discussed in chapter 6. This legal certainty is important for technology innovators and end user. The type of legal framework should not decelerate this type of technology either in the development or adoption phases. Standards in this area would encourage progress as well as adoption.

Companies and governments must provide adequate education to Coboters and others working with this high-tech industry. Investment must be made to support the development of relevant skills. This is critical for employees to thrive in this rapidly evolving environment.

Introduction of collaborative technology to maximise effectiveness: Research question 3 *asked "Can a set of guiding principles be developed to aid with the introduction of human- centred automation in modern manufacturing companies"?*
Feedback from both the case studies and questionnaire highlighted the need for companies to obtain cost-effective, cutting-edge returns on their investments in Collaborative technology.

The case studies highlighted that in general, to date, companies have not been able to optimise the introduction of the Cobot into their plant. Comments such as the following highlight this:

- Companies need to understand where Cobots fit in their plants. It is not just a case of substituting Industrial robots with Cobots
- A fundamental assessment of how this new technology could bring value at a task level was required
- A very small percentage of the Cobots in Industry are actually running in a truly collaborative manner

The questionnaire delved into the possible reasons for this. Previously highlighted was the theory that the more experience the company had in automation and robotics before the introduction of Cobots, the more likely they were to succeed. Following on from this it was investigated ‘how’ the technology was introduced and what changes were made, both in the areas of the redesign of business processes, and the redesign of the engineering tasks.

The idea here is to understand how much thought went into the introduction of the technology into the company. One extreme was that it replaced a human operator with little thought given to the potential of the Cobot, the other being the business was redesigned based on the potential of this new technology.

From the results the majority of companies underwent minimum or minor changes to the business processes, followed by none at all. Likewise, when it came to redesigning the engineering tasks the most popular answer was minor or minimum changes then followed by moderate redesign. The question of ‘who’ redesigned the engineering tasks was asked and the respondents replied it was an internal engineer, followed by an external systems integrator. The length of time to set up the Cobots was asked in the questionnaire and the majority said greater than a working day. The work undertaken during this set-up was listed as programming, undertaking risk assessment and training. Finally, to the question of who installs, programmes, calibrates, and maintains the Cobots the answers given were internal engineer, external systems integrator and internal technician in that order.

A novel set of guiding principles was developed based on the information gathered from the qualitative and quantitative data. Two of the principles were adapted from other authors but the complete proposal can be seen in the appendix. In summary, a three-step approach was conceptualised for to optimise the Collaborative robotics adoption in manufacturing industries in Ireland.

Principle 1. The Socio-Technical Methodology: (Adapted from Mumford)

Background:

- *When introducing the new technology all employees who will use the new system will be involved in determining how it will be introduced.*
- *Skills required to develop the successful system are:* ***Capability*** *this is "the power, capacity and knowledge to achieve the desired objectives".* ***Competence*** *this is "the problem-solving ability of the individuals" or the "know-how".* ***Coordination*** *is "the ability to work closely, democratically and creatively with other groups".*
- *Problems need to be solved as they occur in real time.*
- *Consensus with the wider groups can lead to better problem solving.*
- *Knowledge of the nature and scope of the problem, together with the means to solving this problem are the essential elements.*

The four stages in the problem-solving process are:

- **Seeing the total picture** - seeing the complex systems design as a unified holistic process including technical, economic, organisational and social issues at every stage of the design process.

- **Developing strategies** - they need to be developed at each stage of the design process including technical, economic, organisational and social issues. In volatile situations these strategies may need to be continually adjusted and reviewed.

- **Taking action** – a mission statement can start the process. A risk analysis is required.

- Use a design methodology to successfully **implement the changes**. This facilitates the team to move from problem analysis to the successful implementation of the solution.

Principle 2. A design method: Reinventing Jobs: (Adapted from Jesuthasan and Boudreau)

Background:

Jobs can be deconstructed into work tasks and then the compatibility of these tasks for automation can be assessed. There are three elements that determine the compatibility of the task with its automation. The simple classification system is:

- *Repetitive Vs Variable*
- *Independent Vs Interactive*
- *Physical Vs Mental*
- *Each job can be deconstructed into tasks and there are on-line programmes and databases available to help with this process.*
- *When a job has been deconstructed into tasks, the organisation can clearly identify how to optimise the application of automation and to understand how to transform the activities.*
- *By using this procedure, it is noted that automation can shift elements of work into other roles and augment, eliminate and create new activities.*
- *Automation and reinventing jobs are critical to connecting work to the strategic goals of an organisation.*
- *Finally, the tasks that are difficult to automate will be carried out by humans.*
- *When Cobots are introduced into the workplace, the Coboter will play a key role in setting up and working side by side with the Cobots.*
- *They are involved in redistributing tasks and redefining their roles.*
- *Thus robotics, automation and humans have a valuable role in the manufacturing plant which can be adjusted over time and optimised.*

Principle 3. Synchronising Cobots and Coboters. (Adapted from ETHICS)

Background:

To define the new higher value roles of the Coboters, a methodology such as the ETHICS is used. This facilitates groups unused to being involved in participative system design by giving simple design tools to assist logical thinking. This 11 step by step approach is used with the design group which are the direct users of the system. The steps are:

- *Step1. Why change?*
- *Step 2. Definition of system boundaries*
- *Step 3. Description of the existing system*
- *Step 4. Definition of key objectives*

- *Step 5. Efficiency needs analysis of variances*
- *Step 6. Analysis of job satisfaction needs*
- *Step 7. Future analysis*
- *Step 8. Setting the system objectives*
- *Step 9. Organisational, educational and technical design*
- *Step 10. Implementation*
- *Step 11. Evaluation*

An industrial proposal

To test this proposal, it will be necessary to do a trial run in SME settings. It is an important step and will require collaboration with both robotics companies and manufacturing plants. The important elements of the strategy are Organisation (management), Technology (Cobots), People (Coboter) and the Tasks (job specification). Each type of industry and individual manufacturing company will have its own hierarchy of needs and priorities and the methodology will be bespoke for each application.

- *The first step will be to discuss the socio-techno methodology with management and put together a team with the core skills of capability, competence and co-ordination.*
- *The next step is to put together a plan, looking at the total picture, developing strategies, taking action and using a design methodology*.
- *The design methodology is the deconstructing of jobs into their work elements, looking at the return of improved performance, the role of automation for each task and then choosing the best type of automation for each task.*
- *Finally, the focus will be on redesigning and upskilling the Coboters. These workers will have higher value and higher skilled jobs that are more comfortable and safer in the modern Industry 5.0 factory.*

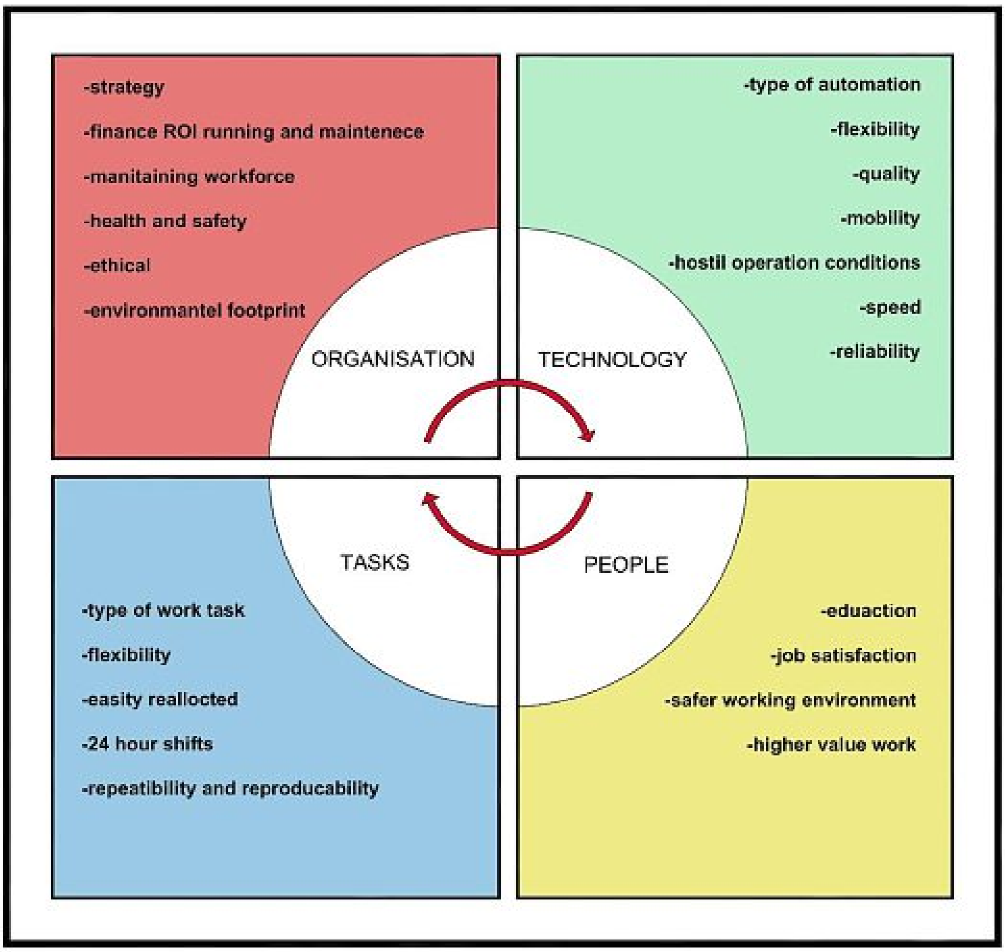

Figure 28 The Key Stakeholder for Industry 5.0

Figure 28 above shows the key stakeholder when designing an optimised Industry 5.0 framework for SMEs. Each SME will have a bespoke framework based on its specific requirement.

The education of workers for this new era: Research question 4 asked “In Industry 5.0 can a highly skilled creative workforce be established to work in a human-centred workplace, which generates personalised high-value and high-quality products?”

Discussion on the upskilling of employees has been made previously in this research. In Ireland, there needs to be a shift in how we educate our students at all levels to equip them for Industry 4.0 and 5.0. Industries are aware of this and there is an imminent need to fulfil this requirement. The Irish government has disseminated its visions and goals for 2025 in publications described in chapter 4.

The case studies and questionnaire in this research highlight the need for change, especially the educational requirements in the collaborative technology sphere. The respondents to the questionnaire, in particular, outlined the skills they deemed necessary for the Coboter.

Sound technical ability was the highest-ranking response. This was followed by good attention to detail, facility to pass on knowledge to others and self-motivation. They also ranked the skills that could be taught to the worker. The manner in which these skills could be best delivered to the workers was described and a hybrid approach was the most popular followed on by in-house, hands-on training. This approach mirrors the literature which describes 'Learning Factories described in the second chapter. These leaning environments use practical pedagogy and problem-based scenario for learning and teaching. These are not used in Irish education at the moment and these centres of excellence are recommended to facilitate the upskilling for Industry 4.0 and 5.0.

One of the most exciting outcomes of this research was the level of detail given to question 35 where the respondents were asked what the most important outcomes of the training would be. Two and a half pages of suggestions were detailed, and these can be found in the appendix. In summary, the respondents had particularly insightful proposals for the researcher which would help design a module, or set of modules, which would help introduce human centred systems and Cobots into their factories in Ireland.

Chapter 9. Summary and Outlook

According to the existing literature, this is the first trial to describe Cobots in an interdisciplinary manner including the technological, social, ethical, Industrial, and educational aspects. Individual concepts can be found but the idea of gathering together these themes in a cohesive manner is the essence of this research.

The current body of literature looks mainly at the technological aspects and alludes to the inclusion of humans. The health and safety and legal requirements of this new technology have not been sufficiently defined to enable its widespread adoption. There is a significant omission in third level education to incorporate collaborative technology. Radical and sustained change will not come about until these themes are brought together in symbiosis.

There is a need for a straightforward definition of Industry 5.0 to help with the conceptualisation of this new era. There are definitions offered but they are not succinct, are only available online, and do not appear in the existing academic literature. A definition of Industry 5.0 has been put forward which is easy to understand and to use and can be developed over time.

This research is the first study to introduce the idea of socio-technical design in the area of manufacturing engineering and collaborative technology. It brings together three separate concepts to facilitate the best possible outcome for the introduction of Cobots into a manufacturing plant. It maximises value, teamwork, and upskilling. It has the potential to bring a fundamental cultural change when introducing this technology.

Cobots have the potential to build upon the positive aspects of Industry 4.0. The human-machine interaction can only reach its potential if both humans and machines are given equal consideration. The rights and needs of the workers are equally important to that of the technology if the system is to be accepted in the workplace. If important changes are to be accepted in a plant, a collaborative community should be established in the company to aid the introduction of the socio-technical design. This includes everyone that is involved with the Cobot from the Coboter to the Technician to the Automation Engineer and the External Integrator. A culture of inclusion needs to be established and the novel set of guiding principles that have been developed in this research is one way in which this can be accomplished.

Introducing Cobots by adding value and optimising business processes was a topic which is not addressed in the current literature. The in-depth questionnaire in this research highlighted, for the first time, that companies are open and willing to undergo training in these areas. The respondents were from a wide cross section of the manufacturing community in Ireland. They replied with two and a half pages of suggestions of learning outcomes which shows a considerable potential for training in these two areas.

The lack of inclusion of minority groups in engineering, especially women, is not new. What is new in this research is the idea that Cobots have the potential to bring a unique solution to this. In fact, by building on both the Cobots and humans' positive traits, the result is an overall 'system' that can allow diverse humans to be included in this new high-tech working environment. The result is a more inclusive and diverse workplace which brings many positives to both the employer and employee. This, in turn, will attract the top talent and meet the requirements of the younger generations, a more inclusive working environment that values all the employees equally.

There is a clear gap in engineering education in Ireland, as automation education still takes a traditional approach in terms of contents and how it is taught. It has been seen by this research that there is an appetite to introduce hybrid training into the workplace. The researcher suggests that a third level module, or set of modules, be developed for Industry to aid the introduction of human-centred systems and Cobots into factories, whilst maximising value and optimising the return on investment. The Cobot manufacturer UR has, a result of this thesis, started to train third level robotics lecturers in Ireland. The first of these webinars took place on the week this thesis was submitted, Thursday 28th January 2021. The webinar was called "Educate and Inspire Learners with Universal Robots' Collaborative Training Tools".

Further research is necessary in the area of Industry standards, and a legal framework for collaborative technology which is continually evolving needs to be established. Without these, the ability of companies to introduce Cobots in a truly collaborative sense is reduced. In practice, it was seen from the data gathered that this is restraining the potential of Cobots as companies are unwilling to invest in a technology where they are unsure of the associated risks.

It is recommended that the conceptual guiding principles developed in this research be tested in a real case study in Industry. Originally, this was to be a part of this research but because of the global pandemic it was not possible to gain access to a company to undertake this study. Further research is required to test the concept mentioned here and an MSc student has opted to continue this work in academic year 2021 in Waterford Institute of Technology.

In addition, from the case study, it was suggested that enforced social distancing due to the current global pandemic would help companies justify the more rapid introduction of this technology and several examples of this can be found in the appendix. In fact, out of 91 respondents that answered this question, 52 (57.14%) replied no and 39 (42.86%) replied yes. This will also form part of the MSc thesis. More data will be available in 2021 to test this theory.

The results gathered in the case studies and industrial questionnaire in this research have not been analysed to the fullest extent. They will provide material for publication in conferences and journals over the coming years. Significant insights into Irish industries approach to automation can be extracted and this will prove beneficial to benchmark as governmental Industry 4.0 strategies are implemented. It also could be used to do international comparative studies in the future.

There are a number of companies that have asked the researcher to publish the outcomes of this research. The researcher is considering the ways in which the information can be made easily available to Industry. It is envisaged that this will be done over the coming year. One manner under consideration to initiate this is through Engineers Ireland as the researcher has been asked to present her findings in a webinar and to write articles for their national journal.

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Appendices

Appendix A

Preliminary case studies 1, 2 and 3

Appendix B

Industrial Questionnaire using SurveyMonkey™

Appendix C

Results of the Industrial Questionnaire

Appendix A

Preliminary case studies 1, 2 and 3

Preliminary case study 1: Respondent 1. Company A. [30.05.2020]

A link with the collaborative Company A was established in March 2020. In a preliminary study a number of questions were put to Respondent 1 to broadly gather general information. This information would help with the design of a more detailed questionnaire which was distributed afterwards.

MDK: What are the advantages of Company A's collaborative robots (Cobots)?

R1CA: *Company A design and build revolutionary collaborative robots. They are perfect for all sizes of business and are so user-friendly that anyone can operate them. Their products are so affordable that it is worthwhile for any manufacturing company to invest in them, meaning a low total cost of ownership. The traditional industrial robotics solutions are fixed installations without human interaction. They require a separation between the human and the robot for safety reasons. The industrial robot is a specialist at repetitive work with low variability. The return on investment for the industrial robot is long term. In contrast, Cobots are relocatable in the workplace as required and can have frequent interactions with humans in a shared space. They can be easily reprogrammed to suit a task and in terms of costs have a short return in investment.*

In terms of manufacturing, Cobots can fill the skills shortage gap in a modern industrial environment where there can be high employee turnover. Where there are rising minimum wages and training costs, Cobots can be a cost-effective alternative which, in turn, facilitates global competitiveness.

The business drivers include the following:

- *there is more than a 50% emissions reduction in comparison to traditional robot solutions. In general, there is less than a one-year payback on Cobots.*
- *They can operate in a fenceless area of the factory; they are modular and can be easily moved and reallocated.*
- *They can operate 24 hours, seven days a week.*
- *They are an ergonomic solution to difficult or dangerous tasks; they can decrease workers injuries and increase productivity.*

Cobots empower the workers by removing them from repetitive tasks and giving them additional skills such as programming.

MDK: How affordable are Cobots?

R1CA: *Cobots are designed for all sizes of business and with the leasing option they are now more attractive than ever. 70% of companies in Ireland are SMEs, based on a figure of 60 employees in the company. SMEs have the biggest challenges going forward to cut costs and fill labour gaps.*

MDK: Can you give me an idea of the type of applications that currently exist for your Collaborative robots?

R1CA: *There are many applications that our robots can be used for including: Packaging and Palletizing, Machine Tending, Industrial Assembly, Pick and Place, Quality Inspection, Injection Molding, CNC Tending, Assembly, Polishing, Screw driving, Gluing, Dispensing and Welding.*

MDK: How can I get a basic understanding of how a Company A's Cobot is programmed?

R1CA: *Company A offer a free online training course at our e-Learning center which starts from a basic to an overall understanding of the programming of the robots. As discussed yesterday, it is a great tool for anyone who wants to learn some more about using the robot and, of course, it is free which means it is open to everyone once they register and you get a certificate at the end of the course once all modules are completed in full. The eight new e-Series modules make up the core track and use the same pick-and-place scenario as the CB3 training Cobot which is our original robot. The new modules are more in-depth, more simulation-based, less paint-by-numbers and allow the users to make common mistakes and see what happens! A module on using threads to control the conveyors has been added, as well as a module on optimizing. In addition, the module on safety settings also covers the functionality of the dedicated safety inputs as well as the new tool sphere.*

The eight new modules are called "Core track". In addition to this, we also added a "Pro track" that teaches more advanced topics such as using features and conditional statements. We will also be added an "Application track" with application-focused *modules (e.g. palletizing) and, as far as possible, seek to align these modules with the application builder. Here is the link to the application builder: https://www.universal-robots.com/builder/*

MDK: Is the type of product being manufactured an important factor when adopting Cobots?

R1CA: *The product being made can range from a simple part to be loaded into a process or a complete assembly where more value is added. The product type can be both discreet and continuous production. Traditionally, automation has suited large volumes and a small mix of parts but because Cobots are flexible it is possible to set up for small production runs and a high mix of parts. When products have a big variety, flexible automation is the quickest solution as changes can be programmed into the software.*

MDK: What level of involvement does the Operator, Maintenance Tech and Automation Engineer have with the Cobots?

R1CA: *It really depends on the application. For example, we have a Cobot that went into production in Cork almost five years ago that has never even been serviced. In addition, the product that the Cobot is manufacturing has not changed so besides turning it on, there is little or no involvement with the operator. However, this is not always the case, many companies change the products being manufactured hourly, daily, weekly, or monthly. In this scenario, an operator would be required to change possibly the end effector or to programme depending on the application and part.*

Then, you have the service and maintenance aspect. Some companies train and up-skill to do this themselves and others would employ an outside company to assist with all their needs around this. A "one fit" for all certainly does not exist and I guess that is what makes Cobots special.

Some companies will be trained up and from then will take complete ownership from programming new applications, to the changeover of products, to maintenance and service and even develop new application cells. Other companies will look for a systems integration company to do it all and then you have the companies in between that have the systems integrator set up, the new designs and applications set up, but core internal staff will be trained to use the robot for internal program changes.

The list is endless on how different companies approach it, however, we do see that in certain countries like Germany and France that they use external system integrators less and less. There is a correlation between the more a country becomes aware of Cobots in automation, the more the company takes ownership of the technology, which is really where Cobots show their true value in my opinion. This helps minimises costs and helps to up-skill internally.

MDK: Who programmes the Cobots and who makes the decision on where to use them in manufacturing?

R1CA: *This is pretty much the same as above, it depends on the application and the customer. If the application is complex and the customer is new to Cobots they would usually employ an external systems integrator but may later take the training themselves to up-skill on the Cobot. By doing this they can have more control over their application.*

At Company A we strongly recommend this as it gives a greater payback to the company and helps to up-skill internal workers. However, a lot of companies, even if they have never used Cobots, will take control from the start. These companies tend to take ownership and only need a small amount of training and then, from start to finish, design the Cobot application and take care of it in its entirety.

Of course, we even have companies in Ireland and across the globe that have never taken any training at all and have bought a Cobot, fully installed and programmed it, and, just from online information from our website, manuals and the occasional tech support question, they do it all themselves.

In terms of who are the decision makers, this can vary from the Managing Director to the CEO to the automation engineer. The following is a list taken from my personal database of the contacts that I deal with regularly for Cobots:

Table X.

Plant Manager	Quality Engineer
Engineering Manager	Continuous Improvement Engineer
Production Manager	Manufacturing Engineer
Projects Manager	New Products Engineer
R&D Manager	Design Engineer
Maintenance Manager	Maintenance Technician
Energy Manager	Manufacturing Technician
Finance Manager	Quality Control Technician
	Junior Project Engineer

MDK: Can you tell me what the numbers of Cobots in Irish companies are?

R1CA: *I would only have the numbers for Company A's robots that were bought in Ireland, but there are other companies that sell Cobots here. We see a lot of Irish companies would already have certain companies for their automation requirements from across Europe and they also bring in UR and other cobots into Ireland. Flexlink in Sweden would be an example of this. They make fully automated lines that they put into Irish companies and I would see Company A's Cobots as part of the line. At a guess I would say there are approximately 400 to 500 Cobots in Ireland in 2020.*

MDK: Is there a connection between the number of Cobots and how efficiently/effectively they are used?

R1CA: *In my own opinion when a company installs a Cobot and can see their "pains" eased in a short space of time it then spikes their interest to getting the next Cobot project under way. So yes, when the Cobot shows its efficiency and effectiveness, we get a lot of repeat business.*

MDK: Do larger companies find it easier to invest in Cobots and if so, why, do you think?

R1CA: *Yes, because predominantly they would already be using some sort of automation and would not be as nervous in investing in automation. Also, they would usually trust automation faster as they would already have engineers on-site using automation so would feel like they can easily skill up on Cobots faster. They can, of course, access capital expenditure easier which has a knock-on effect. If you spend the money in automation the return on investment is typical positive, therefore, easier to* *justify spending more money! Whereas smaller companies would be more nervous of the investment, especially if they have no automation already or if they have no one with experience in this area.*

The advantage of Cobots is they suit this area (SME) perfectly and are made for fast and easy and flexible deployment with a quick ROI. We see the take up across Europe much faster than Ireland and the UK although smaller companies are now starting to look at Cobots as an way to ease the difficulties that they are facing.

MDK: Is there a relationship between the number of Engineers and Technicians in the company and how successful is the implementation of Cobots in these companies do you think?

R1CA: *In Ireland yes – across Europe this is less so. We face a difficult task here with health and safety and typically companies implementing the Cobots as "Cobots" therefore, the need for safety guarding usually requires an integrator. In addition, the larger companies using the Cobots here in Ireland typically use the Cobot to its full capacity which can make the programming and installation at the higher end of Cobots use. However, we are seeing smaller companies starting to investigate and use our Cobots now for simple pick and place at CNC machines. These types of applications are which are easy for Cobots and will build confidence in the medium and long term.*

MDK: Are more highly automated companies (industrial robots) more readily able to change to Cobots?

R1CA: *Industrial robots will always have a use. Weight, speed, height and reach to name just a few features would always require companies to have industrial robots but when the job is within the Cobot specification, we see a large amount of highly automated companies now enquiring if a Cobot could do the job. Often the company will change the criteria so that they can use a Cobot or even add a second Cobot to help to do the job more efficiently and effectively. Using Cobots is often cheaper and saves space. In addition, they can control the application in-house themselves because the Cobot is easy to use and if they need to change the application it is far less expensive and easier to do so when compared to traditional automation.*

MDK: Whilst trying to establish the level on involvement of Automation Engineers and Technicians in Cobots, what would be the typical number of hours per day (or % of their working day) that they would work with the Cobot?

R1CA: *Is this for installation or day-to-day use? Either way it would depend on the application. One example is we have a UR10 in Cork for 5 years now which has never even been serviced and the operator just turns it on and off every day. We have another company in Cork that would change their parts regularly, so the end of arm tooling is changed daily / weekly and the program switched from one to another.*

MDK: The same question as above for the Coboter (Cobot Operator)?

R1CA: *Again, this is very hard to answer as it would be application specific.*

MDK: How can third level Institutes work with Cobot manufacturers/distributors to ensure better understanding of Cobots and their functions?

R1CA: *Company A's academy should be a module in all relevant courses. I would go as far as to say that the academy should be a requirement for all students in secondary school as part of the IT lesson or in some way for it to be incorporated into their studies. One opportunity might be for it to be part of the transition year curricula as it would give our secondary level students the chance to become familiar with this technology and this comfort factor would be a great advantage in the future.*

MDK: If a company hasn't invested/committed do you get feedback on why?

R1CA: *Typically, what are the top three concerns? Safety, cost – when ROI is not fully understood or believed or too risky (for small businesses a Cobot is still a large capital expense, whereas worker's salary would come from a monthly / yearly budget and this is easy to pay out and or cancel.)*

MDK: Have you feedback information on pros and cons from clients on their Cobots that I could look at?

R1CA: *I don't really have any written feedback for this I'm afraid. If I am to be honest, the feedback is usually exceptionally good and this is evident from the fact that traditionally every customer I have dealt with is a repeat customer!*
End.

Preliminary case study 2: Respondent 2. Company B. [25.05.2020]

Company B's funding comes partially from the Irish Development Authority and Enterprise Ireland who are both state bodies, and the rest of the money comes from companies. Company B's has established a new Robotics Executive Committee in the past 18 months and are currently kitting out a state-of-the-art robotics lab in Ireland. The members of this Executive Committee are both technology providers and end users. Johnson & Johnson DuPuy in Cork are an example of a company that are involved in this project. The aim of the project at this initial stage is to select areas to research. One important area is Collaborative Robotics, or Cobots.

Company B has a team of approximately 12 engineers. They have several industrial projects ongoing. Respondent 2 stated that "one of our services of Robotics and automation group within Company B is that if the machine builder doesn't want the challenge or perhaps doesn't have expertise for a specific application then Company B can do the groundwork and then hand it back to the end user or Machine Builder for implementation."

Respondent 2 stated that the main drivers in industry is the financial implication of committing to technology and specifically the Return on Investment (ROI). Companies insist on a ROI varies between organisations but typically a specific company's target must be met before they are deemed commercially viable.

Another point is that, of the 200 or so Cobots sold last year in Ireland, only four or five are actually used in industry in a truly collaborative manner, with humans when in operation. Most are used as a fenceless robot to meet with health and safety regulations.

Company A's products are known to be very easy to program but are often put into cages for safety reasons. There are four methods of assessing health and safety requirements of a robotics system following ISO/TS 15066 and the most common is assessment of force and pressure points. These safety standards come from the industrial robot's safety standards and are evolving continuously.

With regards to the implementation of Cobots, a comprehensive H&S risk assessment must be implemented before the Cobot can be installed. This often results in the installation of light curtains and cages which ensure the safety of the Cobot. This is an area that must be reviewed going forward to allow the Cobot to be used in a fenceless setup and collaboratively with humans. Cobots were designed to be a third or fourth hand in industry and to help humans, not to replace them completely. They are designed to take over dangerous or repetitive work, therefore, avoiding humans getting injured. They are not a replacement for industrial robots because they are typically slower, and their payload is very limited. The payload can be higher, but speed will be greatly reduced if they are using force feedback as the only safety feature. They are outstanding when the product volume is relatively low, and the variability is high.

From Respondent 2's extensive experience in industry, Cobots are being used in a sequential rather that truly collaborative manner. Most currents applications are for fenceless robots. Industrial robots can be adapted to become collaborative but it's rare when this happens. Denmark is the country of origin for Company A's robots. Company A's Cobots are the largest player in the Cobot market but a small player in the robot industry on the whole. Denmark are early adopters of this type of technology. They have a high percentage of Cobots working in a collaborative manner in industry. Anecdotally, most Cobots are not being used correctly internationally. The risk assessment is the responsibility of either the machine builder or systems integrator and some are unwilling to take the risk of allowing the Cobot to run in a fenceless setup. Respondent 2 stated that "it is all subject to a correct risk assessment. Fenceless can be achieved with combined safety functions e.g. a laser scanner and force feedback. The Cobot speed could slow down when an operator is detected by the scanner, the force feedback would perform the safety function at the slow speed. Again, all subject to a risk assessment."

Cobot sales in general are about 4-5% of all robot's sales internationally at the moment. One of the main reasons for this is the cost. For example, a Company C's Cobot can cost 80k. The Cobot is in fact a third hand so if they are to be commercially viable in this sector then costs should be under 10k.

Also, some multinationals resist Cobots because the internal EH&S paperwork involved can be extensive.

Respondent 2 stated that "when there are experienced automation engineers and mechanisation in an organisation the integration success rate will be higher particularly for the more complex operations. However, I do believe robot manufactures should, and are breaking these barriers by making the integration much simpler (easier to program and risk assess)."

Main drivers:

Who is going to pay for it? Financial and H&S Managers need to be persuaded to make the investment.

ROI environmental should be seen not only in terms of purely financial but also in terms of lowering H&S risks to the operators in the plant. Human Resources should be involved in the decision making.
Low speed low volume are the zones that the Cobots excel in.

The decision of whether to run them as collaborative or simply fenceless is important. Fenceless are more justifiable than collaborative.

Complete system needs to be assessed rather than the Cobot in standalone. (What is the end gripper?)

Human factors will be critical going forward. Employees often ask the question “will the robot take our jobs?” This needs to be addressed before the introduction of this new technology.
End

Preliminary case study 3: Respondents 3 and 4. Company B. [02.06.2020]

The informal interview took place on a videoconference TEAMS call on Tuesday 2nd of June 2020. Respondent C explained how Company B was funded by Entreprise Ireland, Competitive funding, and Industrial partners. Company B chairs the Cobotic's National Steering Committee and are involved in the ISO Standards International group.

One driving question that this steering group is asking is why Collaborative Robotic technology is not spreading both in Ireland and worldwide as it should? Why is there such a gap between what these robots CAN do and what they are currently DOING? It was highlighted that Company B looks also at industrial robots with relevant sensors as augmented robots that also occupy the collaborative space.

An interesting point to note is that the lack of clarity of safety requirements of the Cobots is one of the areas holding back Cobot introduction. The safety norms for Cobots have evolved from the industrial robotics safety norms but the question arises, are they apt for this new technology? IMR and Systems Integrators are actively working in this area. Two further specialists were mentioned in Dublin.

Another interesting point that Respondents C and D made was that in Ireland only a very small percentage of the Cobots in industry are actually running in a truly collaborative manner. Most run with different degrees of collaboration, for example, in and out of sync.

The researchers stated that it was important that staff working with Cobots needed to have a basic understanding of the programming of industrial robots. They said the third level Institutes had a duty to implement modern robotics tools and education.

Nonetheless, there are significant roadblocks to the implementation of this technology worldwide. In their opinion, for example, even though France has a rich history of expertise in automation, it is still struggling to implement this type of technology (specifically, collaborative modes) nationally. Ireland is further behind as historically we are not a country with high tech automation experience in industry due to the absence of the automotive industry.

In their opinion, the USA is also struggling with the implementation of Cobots and have moved towards endowing industrial robots with sophisticated sensors to allow humans and robots to share a workspace. They need to be keyed into understanding how to look at collaborative opportunities at the factory floor and process level, rather than redeployment of current robots doing current tasks.

MDK asked about the origin of the Automation Assessment Tool that was available on their website [https://imr.ie/2020/04/09/automation-assessment-tool/]. This tool originated from a challenge statement identified by Company B and the Robotics Executive Committee (formed of 13 industrial partners, both end-users and technology providers) on the lack of clarity of where each automation paradigms fit. From the same committee, a questionnaire has been circulated previous to the current AATool. MDK asked if this could be forwarded on to me as I was undertaking a similar study? The main findings from the original questionnaire focused on the concerns around the adoption of Collaborative Robotics application was that companies didn't have clarity on the safety requirements of Cobots and, in addition, they were not comfortable with the financial investment required.

The outcome for Company B was that the Manufacturing Industry needed some direction in the area of Cobots. They needed to understand where Cobots fit in their plants. It is not just a case of substituting Industrial robots with Cobots, A fundamental assessment of how this new technology could bring value at a task level was required. Also, it was important to consider the scope of the Cobots currently available in terms of payload, speed, dimensions, volume and variety of tasks and so on.

A state-of-the-art Robotics lab is currently being set up in Company B. It will consist of demonstration cells, cells that can be used in industrial training, and private project cells. Non-IP-sensitive project cells will be open access. Company B has run automation training courses in 2019 with a third level Institution which included a 2-day hands-on lab through a company called ICBE (https://icbe.ie/). They have also run courses with industry. They also use Universal Robots to run activity programmes for children together with I-FORM [https://www.sfi.ie/sfi-research-centres/i-form/], the additive manufacturing group.

Finally, I asked had they any recommendations on changes to my questionnaire?
The following points were made by Respondent C:

Questions 12, 13 and 14:
-It is important to get an understanding of the amount of time an Engineer, Technician and Operator spends with the Cobot and what type of work they do? Add specifics to the

questions [programming, working side by side, and working in collaboration, undertaking a risk assessment…]

Question 21:

-Regarding the time spent on setting up the Cobot – it would be helpful to understand how the time was spent: doing risk assessment, programming, interacting with Coboter, training…. Put an open box underneath to specify.

End

Preliminary case study 4: RNB [12.06.2020]

RNB is a company dedicated to manufacturing and marketing skincare and fragrance products:

According to Aureilo Turnero, the Industrial General Manager, "this plant has 600 employees and generates 90 million euro in revenue each year and ships between 70-75 million units of cosmetics and fragrances.
At RNB, they have four key pillars:

- People and professionals
- Image and design
- Excellence in technology
- Care for the environment

Cobots are used mainly because they are a great fit with people and professionals. We assign them to a task so staff will not have to perform many repetitive movements especially at end of line areas (packaging) or areas that involve unfavourable ergonomic impacts".

Cristina Jimenez, Production Engineers says, "we are in the packaging and preparation area of RNB cosmetics where we currently have six collaborative center pack palletizing cell teams working".
The traditional robots required experts to handle them. With Cobots, after a week of training, operators from the factory can work side by side with the robots.

Gregorio Camacho is a robotics and automation technician. He says that "we have opted for Collaborative robots firstly, because our plant is small and secondly, given that our plant is a smaller space, we need the robot to work directly with the operator." The operator would no longer have to handle 7kg packages which caused a significant number of problems.

Cobotors said that when they realised that they were going to introduce Collaborative robots to their lines they were fearful. Perhaps they would be no longer needed and become redundant? They say that after a while they realised that this is not the case and the complete opposite is true. Their work has improved greatly. Physically, they are no longer under pressure. In fact, Cobots free up operators from ergonomically unfriendly tasks. In addition, the safety of the employees is an important factor for RNB. Due to the highly sensitive sensors, the robots can sense when there is an obstacle in their route and stop automatically and as a result, the risk analysis conducted recommended that no safety guarding was required. The older traditional industrial robots had several safety issues and required clearly safely guarded areas. According to Aureilo Turnero, “People entering the area to gain access to the robot had to be much more experienced in terms of safety and the production process and the robots had to be stopped before people could enter their work envelope. The absence of safety guards simplifies the maintenance of the palletizing cell.”

Another advantage is that they can be easily reprogrammed for other tasks. The palletizing format can change from one customer to another. It only takes a minute to swap from one programme to another. Touch the screen and select the new programme. It is as simple as that. This can be implemented by operators. According to Maria del Prado Ocana, a Coboter, “everything is explained on its screen. Start and stop and it is a really simple interface. We are all capable of using the robot which means we can collaborate with it”.

Management feel that the most important point is that you can really see your Coboter integrated with the Cobots and are managing them. They don’t hire top experts to manage a state-of-the art Cobot, instead, the operators that were previously working on the production line are now the ones managing the Cobot. As a result, Cobots improve professional competences. The operators are now taking training to become experts in this area of automation.

It is agreed that Cobots improve production efficiency working conditions. The fear of the Cobots ‘taking over’ and workers losing their employment had not happened. In fact, the opposite is the case, the number of employees has increased, there is an increase in the volume of work and employment contracts have changed from seasonal to permanent in some cases. The Coboters refer to the Cobot as “one of us. A colleague. We have even given it a name!”

Preliminary case study 5: Thyssenkrupp Bilstein [14.06.2020]

Thyssenkrupp Bilstein Addresses Labour Shortage, Expands Production with Fleet of Universal Robots:

Thyssenkrupp Bilstein is an industry leader in high tech suspension solutions for the automotive industry. The plant in Ohio they now have nine Universal Cobots. They are used for tending to machines, assembly operations and inspection tasks. Operations Manager, Aldo Albiere, describes the introduction of Cobots into their plant as revolutionary. He says that he feels that they introduced the Cobots at the right time. They were always an attractive alternative as they avoided finding new resources but facilitated the expansion of the business. When he realised that the Cobots were mobile and didn't require protective fencing or barriers, they became an obvious choice for his company. Cobots' built in safety systems eliminate the need for fencing after risk assessment. To simplify the change to this technology, they decided to pick one supplier and one type of Cobot from the Universal range. Albiere says that Universal "had the most advanced solution and precise pick-and-place repetitive, easy to maintain, easy to program Cobot. The most important element is the speed of the Cobot and it has been a fantastic experience. We have nine plus projects implemented and another plus 40 to be implemented. Each Cobot has a name of an American President".

Doug Mcle is a Manufacturing Engineer and is part of the Industry 4.0 group. He says that "once the first Cobot project was completed it really spread very quickly. We started to notice different applications all around the plant". One application cell features two Universal Cobots working in tandem. For example, one Cobot forms an inner tube, punches a hole in it and places it on a transfer fixture. The second Cobot picks this part up and loads it into the marriage stations and grabs the outer tube, marries them together and forms them again and put it into the exit shoot. The Cobot also performs cleaning operations preparing them for welding. In the final assembly, the Cobot handles post crimp, fill and inspection. He says that they were previously doing inspection on two parts per hour but now the Cobots deliver 100% inspection.

Explaining the return on investment (ROI), some projects have short ROI and others longer ROI. They range between 10 and 14 months at the moment. RobotDK is Universal Robots software for offline programming and simulation. Thyssenkrupp Bilsteinuse both demo Cobots and RobotDK and this simulates the workflow and allows the Engineers to find out if the cycle time is accurate. This helps with troubleshooting and the finished program is ready to go.

One of the goals was to enhance the experience of the employees in the plant and make it a good place to go to work. The operators are part of the process improvement team. They have promised that no operator would lose their job due to Cobots being implemented. One operator, Quenna Quarles, states that her job used to be highly manual. She suffered from repetitive strain injury. As a result of installing the Cobots, the have eliminated this problem. A CNC operator states that his job is safer, cleaner and calmer due to the introduction of Cobots.

Preliminary case study 6: Saint Gobain [16.06.2020]

Saint Gobain, Sully-sur -Loire France Reduce Injuries and Increase Productivity with the FT 300 Force Torque Sensor

Saint-Gobain's plant in Sully-sur-Loire, France, focuses on glass production for the armoured and aeronautical industries, and the civil market. In their shift towards Industry 4.0, management has deployed collaborative robot cells to free employees from tedious, repetitive tasks. Robotiq's FT 300 Force Torque Sensor has proven essential to automate the gruelling glass polishing process. Saint-Gobain was founded in 1665 as a public society manufacturing luxury mirrors and glass under King Louis XIV's reign. The corporation kept high quality standards through the centuries, expanding its business throughout the whole housing industry. Now a global company, it employs more than 185,000 people worldwide. Near its original headquarters in the outskirts of Paris, Saint-Gobain still works on high-end glass production. Human labor provides high-value work to the finished product. But some tasks are more tedious than others. This is why the Sully-sur-Loire factory, like many other Saint-Gobain plants, began to deploy collaborative robot cells into their process about a year ago.

Building the factory of the future, freeing employees from those gruelling tasks begins with finding a technology that would do the job on their behalf. Saint-Gobain's Digital Manufacturing Manager, Ignacio Sanchez, had to find a solution for a difficult glass polishing process. The operation is painful, frequently causing musculoskeletal disorders for workers. "The operator had to polish all of the glass surface, repeating the same movement on and on," Sanchez explains. "He then does the surface preparation of the glass before it becomes one of many layers of an armoured glass. This second step is a lot easier. We wanted an automated solution for the polishing part of the process." "We naturally chose to work with Universal Robots on this project considering safety requirements, the ease of use that was required, all this in a small space." Saint-Gobain turned to local automation solutions provider, HMI-MBS engineering and services, for expert advice. Their representative, Nicolas Bouhet, quickly presented a first option. "Saint-Gobain's application had a very important diversity of reference points. There was also a problem of production space, since the cell had to be deployed in a small area in order to work in collaboration with the operators. We naturally chose to work with Universal Robots on this project considering safety requirements, the ease of use that was required, all this in a small space. We chose the UR10 model to be able to reach every area of every type of glass." A different path for each glass HMI-MBS performed many tests at their lab, which is about 15 minutes from Saint-Gobain's plant. The first proofs of concept did not deliver viable options. "We ended up in a dead-end," recalls Bouhet. "Then we had the idea to use the FT 300 module with the path recording function. We managed to integrate it into the robot and continued with tests at our offices. We then moved to Saint-Gobain and worked with the operator to see if the product met Saint-Gobain's expectations."

"Programming a robot movement that must follow a volume in space is a complicated thing to do. We were able to do it with the path recording function of the FT 300." Testing at HMI-MBS helped minimize the time needed to implement the robot into production. When everything was ready, the UR10 and FT 300 combo took part of the work over from the operator, and both started working together*. "Without the FT 300, this operation would have been quite complex since the programming of a robot movement that must follow a volume in space is a complicated thing to do," adds Bouhet. "With the path recording function of the FT 300, the operator can grab the device and make the movement; the Universal Robots UR10 then records and reproduces the operator's motion." "We're able to produce the same amount of work in two 8-hour shifts instead of three, before the robot arrived." For Christophe Legeay, Methods Technician at Saint-Gobain Sully-sur-Loire, automating the polishing process of each layer of armoured glass gave relief to operators who were previously assigned to this task. "It allowed them to no longer experience vibrations in their shoulders or perform repetitive movements. The installation of the robot was more than welcome," he explains.

From now on, all the operator has to do in the polishing process is program the proper path for the product and set the glass for polishing. "The robot asks us to place reference marks to check the positioning. You cannot run your application until you have validated your positions. As soon as the validation is done, you press start and the robot starts running." Human + machine collaboration increases productivity while polishing is in progress, the operator simultaneously washes the glass that was previously polished. Then it's time for surface preparation, a process in which human labour brings much more value into the product. "We assigned the robot to the hardest part of the polishing process," recalls Sanchez. "During this time, the operator can focus on surface preparation. We're able to produce the same amount of work in two 8-hour shifts instead of three, before the robot arrived. We've achieved ROI in less than a year." "By empowering the operator, allowing him to do the program himself, we avoid calling an integrator every time a product comes back into production." Capacity increased by 30%, allowing Saint-Gobain to deliver orders on top of those initially scheduled. "A product might come back once every one or two years. We often have to create a new program. By empowering the operator, allowing him to do the program himself, we avoid calling an integrator every time a product comes back into production. This is one of the goals of our digital manufacturing project, in which Cobots will play a huge role," Sanchez explains. In a factory where human labor delivering high-end quality has been a tradition over the last 350 years, robots are seen as a helping hand for human workers aiming for perfection. "We do not cut jobs like it's often perceived when a robot is installed somewhere," concludes Sanchez. "It's a collaboration between man and machine that allows us to remove gruelling tasks from the hands of operators. This is the goal and it's fairly well perceived here."

<u>Preliminary case study 7: Universal Robots [08.06.2020]</u>

[DOI: https://blog.universal-robots.com/in/role-of-cobots-in-covid19era]

THE ROLE OF COBOTS IN THE COVID-19 ERA: JUN 8, 2020 8:11:13 AM / BY PRADEEP DAVID

CONQUER MANUFACTURING IN THE COVID-19 ERA WITH COLLABORATIVE ROBOTS

Plant closures. Partial Layoffs. Staggered shifts. Labor shortages. Stringent hygiene measures. Restrictions on the number of people working together at the same time.

These are just some of the ground realities of the new normal facing manufacturers operating in the Covid-19 era. As per the World Bank, by the end of 2018, India was the world's sixth-largest manufacturer. The labor-intensive manufacturing sector has been one of the hardest-hit due to the Coronavirus. According to Business Insider, the seasonally adjusted IHS Markit India Manufacturing Purchasing Managers Index (PMI), a reflection of the health of the manufacturing economy, fell to 27.4 in April, from 51.8 in March this year. Make no mistake; it is the sharpest deterioration in business conditions in the last 15 years.

There are two primary reasons for this negative direction - first, most manufacturing jobs are primarily on-site, and second, slowed economic activity has decreased demand. Manufacturing is one of the rare industries where work-from-home, Zoom meetings and teleconferencing can only accomplish so much. While job functions involving marketing, sales, management, finance, and R&D can work virtually, execution at the assembly line needs to start rolling out at specific physical locations and on time.

The main question arising in the mind of every forward-thinking manufacturing executive is how to adapt to this new normal. All isn't lost, and according to Forrester analytics, we are now entering the second stage of the pandemic, which requires us all to 'Adapt & Overcome.' Accordingly, the Indian government is taking efforts to gradually bring the economy back on track and has put forth a slew of requirements for work in this Covid-19 landscape. These steps include allowing industries outside municipalities and corporations to restart their operations, a renewed focus on domestic manufacturing, and tax exemptions for manufacturers. However, strict compliance to COVID-19 based on current lockdown and guidelines will have to be adhered to.

AUTOMATION TO THE RESCUE

The mandatory guidelines include increased testing, following social distancing norms, and limiting the total number of workers at a physical location. These initiatives themselves give rise to a host of issues for manufacturing firms to tackle. Some of the automation barriers faced by manufacturing include an abundance of unskilled labor, a lack of space on the shop floor, or the lack of technical expertise to operate the complex new technology.

By using automation in their plants and assembly lines, manufacturers can overcome these issues. Cobots, in particular, are a niche automation solution which are the most efficient, flexible, and cost-effective way forward for factories looking to automate and reduce external dependence, especially to get on track to achieve ambitious Make in India plans.

This article introduces the undeniably important role of Cobots in manufacturing and how they can easily adapt a new working model to improve output and efficiency, especially in the post-Covid-19 world.

WHAT ARE COBOTS?

A Cobot, short for Collaborative robot, is a robot that is intended to physically interact or communicate with humans in a shared workspace. Built on the concept of Human Robot Collaboration, they are designed to work together with humans at the highest levels of truly collaborative applications, in any manufacturing environment.

In times of Covid-19, one of the key priorities for manufacturers is to protect their workforce with minimal loss in efficiency. Coronavirus is at its most lethal when it is allowed to spread through social contact. As a result, leading health advocates, including the World Health Organization (WHO) and eminent medical authorities in India have asked that strict social distancing norms be maintained, even when factories open up. The dependence on a migrant workforce in manufacturing belts across the country also needs to be mitigated.

Listed below are the major benefits and advantages of using Cobots during the pandemic and beyond.

SOCIAL DISTANCING

By enabling humans and machines to work simultaneously, Cobots reduce contact between human workers, allowing them to maintain safe social distancing standards. Manufacturers should allow social distancing practices in workplaces that are typically worker-dense (e.g., manufacturing plants, warehouses, etc.) by using Cobots. This would allow factories to continue being productive while keeping employees safe. The lack of space on a typical factory floor forces workers to come within close physical proximity, which abets the spread of the infection. Cobots can be used in crowded assembly lines to enable social distancing on the shop floor.

Additionally, an MIT Technology Review study found that there is an 85% reduction in idle time when humans and robots work together, which goes to show that Cobots are not only safe but also effective in driving efficiency. Cobots are designed to be able to work safely with humans, without the need for caging or fencing (with subject to risk assessment). By using Cobots in limited workspaces, factories can maintain the recommended distance between workers and increase safety, all while skyrocketing productivity and efficiency.

PARTIAL AUTOMATION

It is well said in the manufacturing industry, "Automate what can be automated and simplify the rest." There are various levels of complexity in manufacturing. Different sub-segments of existing manufacturing facilities can be partially automated using Cobots. By identifying specific applications or processes to deploy Cobots, instead of the whole plant, manufacturers can reduce capital expenditure significantly.

Manufactures can start small by deploying Cobots only in processes requiring repeated human interaction, extra precision, or in operations which can be dangerous or monotonous. For example, at Baxter Lab, we can see that the Cobots are placing bottles in boxes, but the man is manually holding the boxes open. Both are thus, working together and the process is only partially automated to optimize efficiency. Cobots bring safety, ergonomics, quality, and throughput - all crucial metrics for manufacturing management in an assembly plant.

QUICK DEPLOYMENT AND FLEXIBLE REDEPLOYMENT

Collaborative robots are one of the fastest automation solutions on the market to deploy and even redeploy for new applications, with setup often taking less than a day. In this uncertain environment, many manufacturers need to repurpose their assembly lines to focus on different products based on the urgency of requirements.

A key challenge is to be able to modify the assembly line to produce a larger number of units of products which have peaked in daily demands. The flexible redeployment of the Cobots is an especially useful feature, as Cobots are extremely easy to dismount and redeploy on different lines, depending upon the requirement. Traditional robots, in contrast, are often fixed installations, which are usually much too heavy and cumbersome to deploy and redeploy. Also, unskilled labor must be re-trained each time there is a small change in the assembly line, leading to cost and time over-runs.

A great example is how L'Oréal could shift Cobots to different applications at the click of a button, allowing them to become more flexible and agile in terms of serving the market in real-time. Furthermore, the Cobots could be easily reverted to the original assembly line, without affecting production output.

Cobots can be redeployed with ease for new applications. Repurposing assembly lines using Cobots allows manufacturers to keep production lines up and running in times of low demand, switching easily to produce high demand products, generate revenues, and positively impact their reputation.

DEMOCRATIZED AUTOMATION

Cobots help bridge the gap between large and small manufacturers in the world of automation. The biggest challenge in the minds of manufacturers on deploying Cobots is the perceived cost and technical difficulty of implementation. In truth, the sheer precision, cost-effectiveness, and competitiveness that Cobots provide are unmatched in a globally competitive environment.

SMEs are major building blocks in the Indian economy. Given the increased benefits to small manufacturers in India, especially in the COVID-19 economy, Cobots are incredibly easy to deploy and manage within the existing environment.

By lowering entry barriers for automation, like space requirements, ease of deployment, and flexible redeployment, Cobots make it easy for manufacturers of all sizes to take a step in the direction of Industry 4.0, whether they are a multinational, SME, or even an MSME.

SUMMARY

Covid-19 has taken the world by storm. With more than 6 million cases reported globally, the virus is showing no signs of stopping, and there isn't a cure or vaccine in near sight. Covid-19 has ushered in a host of challenges for Indian manufacturing, with many large organizations expecting that this pandemic will have serious financial implications in the coming future. What the Coronavirus has shown us is the unpredictability of life and the need to be prepared for the future. In starting a whole new chapter, manufacturers need to prepare for a prolonged recovery. Managing human capital and production capabilities becomes of paramount importance. Given the unknown variables of how the Covid-19 pandemic will play out and when containment will be achieved, industrial manufacturers should brace for a trying period and plan for a recovery that may not arrive for at least the next six months. By deploying Cobots where suitable, all manufacturers can tide the Covid-19 crisis, in both the short-term as well as the long-term. Cobots offer manufacturers unique solutions that traditional robots cannot provide.

Challenges caused by an acute shortage of labor, changes in assembly lines, and supply and demand level fluctuations can easily be overcome with Cobots. The whole world has seen the impact on global supply lines due to their dependence on China. With India being touted as the new destination for global manufacturing, Cobots will allow Indian manufacturers to take advantage of this shift and become future-ready.

<u>Preliminary case study 8: Universal Robots [10.07.2020]</u>

DOI: https://blog.universal-robots.com/cobots-vs.-covid-19-part-ii

COBOTS VS. COVID-19, PART II. 10. JULY 2020 / BY UNIVERSAL ROBOTS

In the second of our ongoing series of blog posts showing how Universal Robots, Cobots are being used in the battle against Covid-19, we look at some exceptional face shield and mask production set ups, meet a unique Cobot barista and admire a remote controlled mobile Cobot performing key medical tests in China.

MAKING PERSONAL PROTECTIVE EQUIPMENT (PPE) WITH COBOTS

As Covid-19 began its spread in the United States, Hurco North America (a machine tool supplier headquartered in Indiana) set its employees a challenge –to adapt a machine tool into a system for making N95 masks. The employees chose to deploy a UR5 Cobot integrated with the ProFeeder from UR Certified Systems Integrator ProCobots to tend a heated mould for shaping the mask. The UR5 loads a stack of four plies, two polymer outer layers and two spun-fiber filter layers, and these become a mask through a five-minute cycle involving moulding, welding and cutting. Thanks to the system, Hurco is able to produce masks for all its employees with enough left over to donate to customers and distributors.

Peter Zelinski, Editor-in-Chief at Modern Machine Shop visited Hurco's Indiana facility to find out more...
Revtech Systems, a Universal Robots CSI from Quebec, Canada, also launched an internal challenge that saw groups of 3-4 employees join forces to design a face shield that could be produced in high quantities, fast. Once the final design was chosen, the team quickly set up a cell with a human operator and two UR10 Cobots.

The process begins when one of the Cobots grabs a plastic sheet and places it on a station. The second Cobot then picks up a foam piece that's glued to cardboard and places it on the plastic sheet. The same Cobot then takes an elastic piece, pulls it over the foam to the other side, and a pneumatic mechanism staples the elastic to the cardboard and plastic. Then, the first Cobot takes the plastic sheet and moves it to the next stopper to be stapled and finally, places the completed face shield in a box. Within just four weeks, the production cell was producing an amazing 700+ face shields per day!

Meanwhile, Hannafin Automation and Industrial Controls, a UR CSI in Ontario, Canada, developed an automated 3D printing process that uses a UR Cobot (dubbed 'BOB'), a 2-finger gripper from UR+ partners at Robotiq, a vision system from Cognex and two Dremel DigiLab 3D printers to manufacture face shields to be used in the fight against Covid-19.

BOB handles the entire printing process autonomously from operating the 3D printer's touchscreen to start a new job, to checking on the status of the prints with its camera, to lifting the finished product and placing it in a bin. Capable of operating 24/7, the system can produce 50 face shields per day and the company has donated the equipment to police, fire and paramedic workers.

Gamber-Johnson, a supplier of mounting systems for mobile communication systems, computers and other electronic equipment located in Wisconsin, USA, joined a collaboration with local partners to create a temporary facility for face shield production. At the heart of the facility is a UR5 Cobot, which is used to cut out plastic sheets for face shields. Gamber-Johnson and partners crowdsourced funds and have raised thousands of dollars for producing face shields to donate to local area hospitals.

A UR5 Cobot used to create face shields by the team at Gamber-Johnson. Credit: Gamber-Johnson, South of the border, EinsRobotics, a UR distributor based in Monterrey, Mexico, is using a UR5 to tend to two 3D printers, resulting in the production of 40+ face shields per day. EinsRobotics is donating the face shields to public and private health institutions in the region.

Facing a sharp increase in demand for ventilator components, a Pennsylvania manufacturer had to quickly ramp up production. To meet this increased demand, UR CSI team quickly set up a UR5e equipped with the UR+ certified Wrist Camera and Hand-E gripper from Robotiq, and now use it to unload finished parts from a Tsugami Swiss Turn Lathe into a plastic tray that ships out for post-processing.

In China, researchers at Tsinghua University have created a mobile medical Cobot system that performs ultrasounds, takes mouth swabs, performs temperature checks and can operate a stethoscope. The system, which incorporates a UR5 on wheels, can be remotely controlled, protecting doctors and nurses against direct contact with Covid-19 patients. After being trialled by doctors at hospitals in Beijing, the remarkably versatile system has now been deployed at the Wuhan Union Hospital.

The medical Cobot system is designed to reduce workload and risks for frontline medical workers.
When Covid-19 reached Portland, USA, traffic at the popular In J Coffee coffee shop dropped by a whopping 50%. Owner Joe Yang understood that customers were concerned about human contact and viral spread so he decided to build a Cobot barista. The end result is a completely contact-free, Cobot-powered system for preparing specialty coffee. Dubbed 'Jarvis,' the Cobot is able to make coffee, froth milk and can even pour latte art.

“No PPE, no risk to spread Covid-19. No one really knows how long this ‘new normal’ will last. People need coffee and I hope they can enjoy a perfect cup of coffee safely at In J Coffee during this special time,” Yang told Daily Coffee News.

Preliminary case study 9: Universal Robots [20.05.2020]

https://blog.universal-robots.com/manufacturing-in-the-age-of-covid-3

MANUFACTURING IN THE AGE OF COVID-19 - PART 3. 20. MAY 2020 / BY UNIVERSAL ROBOTS

During uncertain times, humans turn to stories. We look for reassurance, for inspiration, and for a sense of community; to know we're not alone in our experience and to understand how others are coping. With that in mind, we have launched this series of blog posts to share the stories of manufacturers around the world who are figuring out how to address the Covid-19 pandemic; to keep employees safe and their businesses viable. Our hope is that we can all continue to collaborate—from a safe distance—to care for and learn from each other.

ENDUTEC MASCHINENBAU SYSTEMTECHNIK GMBH:

"OUR COBOT OPERATES AROUND THE CLOCK TO MEET TIGHTER DELIVERY SCHEDULES“

Endutec GmbH is a special machine manufacturer with its own design office and 14 employees. The company from Chieming am Chiemsee in Germany is also a Certified System Integrator of Universal Robots. Managing director Andreas Flieher talked to us about how Endutec is coping with the Covid-19 crisis.

Tell us how you run your production today vs. before the pandemic?

Two years ago we started to automate parts of our production with a UR10e Cobot. The main drivers for that decision were that we wanted to achieve the fullest possible utilization of our machine capacity while also addressing the shortage of skilled workers. We are always desperately looking for qualified employees. Therefore, we plan to automate as many simple tasks as possible in order to be able to use our staff for higher-value tasks. In spite of Covid-19, our production runs almost as usual - with the difference that before the pandemic our full team was physically present at the company. Some of the employees wrote CNC programs on site while the others worked on the machines on the shop floor. Currently, half of the employees write the programs from home, upload them to the company server, whereafter employees on-site retrieve the programs and run them on the machines via the Cobot.

How are you protecting your employees? What types of Personal Protective Equipment are they wearing (if deemed necessary)? Did you have to restructure your production line to minimize contagion risks?

We have already worked with face masks to some extent before, as certain production activities require this. In addition, we have provided several options for hand disinfection not only in the washrooms but also in our production. We address the social distancing guidelines by having only some of our employees on site and the rest working from home. About half of the employees are currently writing the CNC programs from home. This allows us to maintain the minimum distance in production," says Andreas Flieher, Managing Director, Endutec GmbH.

How do you communicate necessary production changes to your workforce?

Actually, there are no big changes in production - just a small thing: Before Covid-19, shop floor production orders from the ERP system were distributed around the company in paper form. Now the employees receive the production order as PDF in an e-mail.

How has your supply chain been impacted? What have you done to mitigate this? - e.g. have you had to re-engineer some of your products?

Fortunately, very little has changed for us. Sometimes we receive the parts necessary for our production from our suppliers in Austria slightly delayed, but this does not cause any difficulties. After all, we operate as a contract manufacturer, among other things, so we are naturally very agile and continue to receive product specifications from our customers and manufacture them according to their requirements.

Are you relying more on automation now than before? Or, is automation helping you in new and unexpected ways?

Even before Covid-19, it was clear to us that we needed to check each process step to determine if automating the step is possible. If yes, we want to automate it. In addition to the lack of skilled workers, the price pressure we are under as a contract manufacturer is also decisive. Every hour that we make better use of our facilities helps us to remain competitive.

Currently, automation helps us even more than before - even before Covid-19, delivery times were very spotty. This has now become even worse: Many of our customers work in their home offices or work reduced hours. As a result, they no longer have full and permanent access to their data and this can cause delays in their orders. Yet our delivery remains the same. Instead of a delivery time of three or four weeks, it is currently only two weeks in some cases. That is very tight, but thanks to the Cobot we make it as it runs through the night and also on weekends.

This case study documents how the UR10e Cobot enabled Endutec to set up a two-shift operation, utilizing its machines to full capacity.

How do you make sure your products reach the end customers on time?

The robot is used as much as possible to produce the same quantity of parts as before in less time.

How do you think this crisis will shape your company going forward? What are some of the lessons learned?

For us, the crisis has shown that the time and money we invested in automation has more than paid off. I am convinced that other small and medium-sized companies will now also increasingly rely on robot technology to prepare themselves for the future. As a system integrator of Universal Robots, we can already see this. One of our customers, for example, is using the free time he has available as a result of short-time work and lower capacity utilization to install an automation solution to be ready for the upcoming increase.

<u>Preliminary case study 10: Universal Robots [17.10.2017]</u>

https://blog-universal--robots-com.cdn.ampproject.org/c/s/blog.universal-robots.com/collaborative-robots-ushering-in-industry-5.0?hs_amp=true

Collaborative robots ushering in Industry 5.0. Written by Esben H. Østergaard | 17. October 2017

From Industry 4.0 to Industry 5.0

There's long been a global movement to create smart, automated production setups and make things communicate digitally – all jingoistically summed up as "Industry 4.0". But at Universal Robots, we reckon a new robotics development is even more interesting: We call this "Industry 5.0", simply to highlight the difference.

Whereas Industry 4.0 setups are largely about consistency of quality, consistency of flow and data collection – replacing functions in which lesser-skilled people had to carry out repetitive, burdensome tasks – Industry 5.0 is about highly skilled people and robots working side by side to create individualised products, services and experiences.

Having Cobots and human work together at Aurolab manufacturing cataract kits resulted in a massive 15% increase in the product output, with over 2,000,000 lenses per year.

CONVERGING TO COLLABORATIVE

Industry 5.0 is basically about robot capabilities and human skills converging to get the best of both. It's a state of development in which manufacturers pair the unique, cognitive skills of a craftsperson or other skilled human with a robot's ability to deal with requirements for heavy lifting, consistent quality and round-the-clock exactitude.

Industry 5.0 involves the transformation of modern manufacturing as well as a wide range of other processes – commercial and non-commercial – to enable man and machine to work side by side – collaboratively using collaborative robots (Cobots). At Linaset in the Czech Republic, manual blast molding was time and resource consuming, a UR5 now handles the task, freeing up labor to value-added tasks.

BRINGING BACK THE HUMAN TOUCH

This redeployment of human creativity into setups where skilled workers collaborate with robots is necessary because market requirements and consumer expectations are moving away from mass production, and end-user customers are demanding much more personalization and customization in the products they buy.

Robots are excellent at manufacturing standardized products using standardized processes that help ensure high speed and high production volume.

But adding a “special something” to each and every product is a challenge where robots require guidance and assistance, driving the need to bring the human touch back into a wide range of manufacturing, preparation and finishing processes.

Indian manufacturer of textile machine, SMEW, saw an increase in their production from 30 to 80-90 pieces per week; a 300% boost in production, with staff enjoying working alongside robots.

BEST OF BOTH WORLDS

Collaborative robots is where Universal Robots is doing exactly this, and really breaking new ground by enabling humans and robots to work side by side – literally – in the same workspace, be it fast food joint, hospital ward, specialist workshop or creative den.

Because Cobots are versatile, easily programmable and safe, expensive, space-guzzling safety caging can almost always be done away with. Robotic capabilities can then move out of closed factories and limited-access spaces, to work side-by-side with us humans. Robotic capabilities become a personal tool that members of any work force can use to apply their distinctive creative skills more effectively, to provide greater human value.

This then leaves human employees free to apply their intangible skills and difficult-to-program creativity to more complex projects – or to notch up a considerable boost in productivity for their existing craft or skill.

At Universal Robots, the Industry 5.0 moniker is simply a question of Cobots and skilled humans working closely together in myriads of different ways – many as yet unthought-of and unexplored – to create maximum human value by getting the best of both worlds and both types of capabilities.

Industry 5.0 – and the Cobots at its heart – is about combining people’s creativity and craftsmanship with the speed, productivity and consistency of robots, and exploring how to make the very best of the many possible overlaps to mould hitherto unseen commercial and societal capabilities. From more people-centric, individually customized products to craftsmanship and specialist skills made much more widely available.

Appendix B

Industrial Questionnaire using SurveyMonkey™

Industrial Questionnaire using SurveyMonkey and a list of the WIT graduates.

Case study profiling emerging Collaborative Technology in Manufacturing Companies in Ireland.

TECHNISCHE UNIVERSITÄT WIEN Vienna | Austria

INSYTE information for innovation Waterford, Ireland

Thank you for agreeing to participate in this survey which is part of a research project for an on-going Doctoral Program in Engineering Science in Vienna University of Technology, Austria.

Background: We are moving into the fourth industrial revolution, or ***Industry 4.0***, currently, where manufacturing takes place in an information intensive environment. This 'connected' environment consists of data, people, processes, service and systems with Internet of Things (IoT) enabled industrial assets. This new smart way of manufacturing is facilitated by increasing levels of automation, cyber physical systems, digital-twins and the intensive use of data analytics. It is driven by modern industrial and societal challenges and evolutions, as well as the integration of information and operational technology.

Industry 4.0 consists of the following core elements:

- ICT – IoT, cyber security, cloud computing, big data artificial intelligence and wireless systems.
- Connectedness – simulation, digital twin and systems integration.
- Sensors – built in intelligence, real time capability, traceability and completeness.
- Robotics – High flexibility, intuitive operation, human robot cooperation and intelligent control.
- Innovative production systems – complete cross linkage, augmented reality, cyber physical systems, self-configuration and additive manufacturing

This research looks at the social impact of the fifth industrial revolution, ***Industry 5.0***, and focuses on automation in human centred systems. It investigates how, in a new futuristic age of manufacturing, robotics and humans will work together seamlessly. Collaborative robots (Cobots) and their operators, (Coboters) will play important roles in future manufacturing environments which will be agile, flexible, environmentally friendly, safe and efficient. ***Industry 5.0*** will combine the technological breakthroughs of ***Industry 4.0*** and combine them with the unique capabilities of humans.

The aim of this fifteen-minute survey is to provide an important insight into the experiences of companies on their use of automation and we hope that it will help influence future policy and education programmes.

All data will be treated confidentially, and individuals will not be identifiable in any reports generated from this study. The general findings may be presented to academic conferences and journals, as well as enterprise agencies, in order to help understand the particular situation in Ireland when compared to other regions.

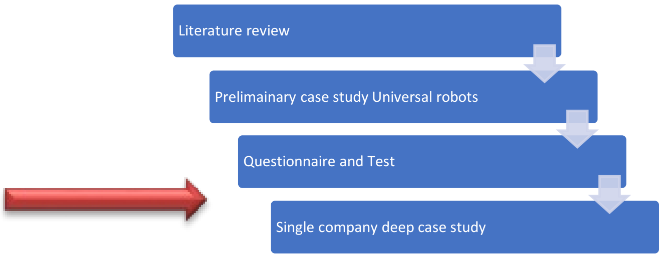
ALL RESPONSES WILL BE TREATED WITH THE UTMOST CONFIDENTIALITY AND THE NAME OF THE COMPANY WILL NOT BE ASSOCIATED WITH ANY PARTICULAR RESPONSE.

Company names will appear in an appendix at the end of any publication in order to illustrate the profiles of the companies who participated.
This study is being conducted under the supervision of Peter Kopacek Professor Emeritus, Vienna University of Technology (kopacek@ihrt.tuwien.ac.at).

The researcher is a member of INSYTE, the Centre for INformation SYstems and TEchno-culture (INSYTE) which is an interdisciplinary research centre located in the south east of Ireland. She can be contacted at marydoylekent@gmail.com

Thank you in advance.

Proposed methodology:



1.What sector does your company belong to? (www.Enterprise Ireland, 2020)

- Bio Pharma Engineering
- Consumer Retail Products (Furniture, Textiles, Giftware, Jewellery, Apparel)
- Construction
- Consultancy
- DataCentres
- Education
- Electronics
- Energy
- Engineering
- Environmental and CleanTech Products and Services
- Food and Drink
- Health & Beauty Ireland
- Intelligent Transport System
- Medical Devices, Pharmaceuticals and Lifesciences
- Print and Packaging
- Public Sector Solutions (Software and Services)
- Software
- Telecoms, Internet, Media and Entertainment
- Trade Mission Directories
- Travel Sector Solutions (Software and Services)
- Other (please specify):

2.Which of the following is closest to your actual job title? (preliminary study Universal Robots SCB)

- Plant Manager
- Engineering Manager
- Production Manager
- R&D Manager
- Maintenance Manager
- Energy Manager
- Finance Manager
- Quality Engineer
- Continuous Improvement Engineer
- Manufacturing Engineer
- New Products Engineer
- Design Engineer
- Maintenance Technician
- Manufacturing Technician
- Quality Control Technician
- Junior Project Engineer
- Other (please specify):

3.What type of enterprise are you working in? (Official journal of the European Union 2003, 20.05.2003)

- microenterprise [enterprise which employs fewer than 10 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 2 million]

- small enterprise [enterprise which employs fewer than 50 persons and whose annual turnover and/or annual balance sheet total does not exceed EUR 10 million]

- medium enterprise [enterprise which employs fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million]

- large indigenous enterprise [Irish enterprise which employs greater than 250 persons and which have an annual turnover exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million]
- large multinational enterprise [non-Irish enterprise which employs greater than 250 persons and which have an annual turnover exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million]
- Other (please specify):

4.Describe your company's products/services?

- <u>Box for answer</u>

5.How would you describe your company's products/services in terms of unitary market value?

- <u>Sliding scale Low value Medium value High value</u>

6.In your view what are the top priorities in your area [rank in order]
[Management for Engineers, Scientists and Technologists Chelsom, Payne & Reavill.]

- Maximising the health and safety of the employee
- Ensuring workforce stability and continuity
- Maximising the career opportunities of the workforce
- Maximising workforce motivation with highly skilled teams
- Maximising workforce wellbeing
- Minimising the environmental footprint of the company
- Minimising the special footprint of the manufacturing space
- Ensuring product ingenuity and innovation of design
- Optimising product cost and competitive pricing
- Maintaining the high reputation of the brand
- Maintaining a position of the latest cutting-edge technology and automation
- Maintaining an excellent relationship with the company's suppliers
- Committing to customer's changing requirements
- Providing customer service excellence
- Satisfying regulation requirements
- Maintaining an excellent relationship with the customer

- Maximising the company's annual profits
- Responsiveness/agility to the changing marketplace by optimising volume and variety mix
- Ensuring optimum quality and reliability of the product and/or service
- Ensuring positive attitude to change management and continuous improvement
- Ensure accessible information to facilitate successful new product introduction
- Plus:
- Other x 2

7.In your opinion what level of experience does your company have with robotics and automation?

- Sliding scale Low Medium High

8.Have you heard of collaborative robotics [Cobot]?

- Yes
- No

Definition of a Collaborative Robot [Cobot]. A Cobot is a robot that works in collaboration with humans without guards due to high sensitivity of its sensors. It is light weight and easily programmed, has a low payload and is generally low cost. It is not seen as a replacement for human operators but their aid or third hand. Insert video if possible? *https://www.youtube.com/watch?v=pIcxOGo7ieU&t=56s*

9.Do you currently have Cobots in your manufacturing plant?

- Yes
- No

**** **Break the questionnaire into two streams**

10. If no, what are your three top concerns? (Choose multiple answers if appropriate) (preliminary study IMR)

- Prohibitive costs?
- Require more information on how they can be integrated into your factory?
- Need more highly trained technical staff?

- Worried about Health and Safety?
- Think they will not suit your type of product?
- Worried about redundancies?
- Worried about turnaround time and flexibility?
- Worried about the environmental footprint?
- No time to investigate.
- Not Applicable
- Other (please specify)

11.If yes, in what areas are they working in? (Choose multiple answers if appropriate) (preliminary study Universal Robots SCB)

- Packaging and Palletizing
- Machine Tending
- Industrial Assembly
- Pick and Place
- Quality Inspection
- Injection Moulding
- CNC Tending
- Assembly
- Polishing
- Screw driving
- Gluing
- Dispensing and Welding
- Not Applicable
- New product development
- Testing
- Prototyping
- Concept Generation
- Other (please specify)

12.What level of involvement does the Cobot Operator [Coboter] have with the Cobots? (Preliminary study IMR)

- Scale with then be sliding scale of % or hours….

13.What type of work does the Coboter do with the Cobots? (Preliminary study IMR)

- Programming
- Working side by side
- Working in collaboration
- Undertaking a risk assessment
- Other

14.What level of involvement does the Maintenance Technician have with the Cobots? (Preliminary study IMR)

- Scale will then be sliding scale of % or hours….

15.What type of work does the Maintenance Technician do with the Cobot? (Preliminary study IMR)

- Programming
- Working side by side
- Working in collaboration
- Undertaking a risk assessment
- Other

16.What level of involvement does the Automation Engineer have with the Cobots? (Preliminary study IMR)

- Scale will then be sliding scale of % or hours….

17. What type of work does the Automation Engineer do with the Cobot? (Preliminary study IMR)

- Programming
- Working side by side
- Working in collaboration
- uUndertaking a risk assessment

18.Has your experience with your Cobots met your goals and expectations so far?
Use a Likert scale: 1-5

- Has not met goals and expectations

- Has met some goals and expectations
- Yes, moderately met goals and expectations
- Yes, to a large extent met goals and expectations
- Yes, exceeded goals and expectations.

19.In your opinion how has your company changed due to the introduction of Cobots? [Rank in order] (preliminary study Universal Robots SCB)

- Increased autonomy and decision making
- Development of a social circle with fellow Coboters
- Improved communication with other employees [Technicians, Engineers, etc.]
- Improved social interaction with work colleagues and less isolation
- Improved job security because of working with Cobots
- Improved employment opportunities because of working with Cobots
- More interesting work because of working with Cobots
- Expanded educational opportunities because of working with Cobots
- Improved job satisfaction because of newly acquired technical skills
- Monotony of human work is reduced as the Cobot taking over these boring tasks
- Reduction to health and safety risks as the Cobot taking over these tasks with higher risks
- Improvement of ergonomics in the workplace due to the Cobot versatility
- Better wages due to higher work value as perceived by the employer
- Other, please specify

20.Have your business processes needed to be redesigned due to the introduction of Cobots? (Preliminary study IMR)

- Use a Likert scale: 1-5
- No, not at all
- Yes, some minor or minimal changes
- Yes, a rationalisation for improved efficiency
- Yes, moderate redesign
- Yes, a complete shift in thinking [paradigm]

21.To what extent have your engineering tasks needed to be redesigned to facilitate the introduction of Cobots? (Preliminary study IMR)

- No, not at all
- Yes, minor or minimal changes
- Yes, a rationalisation of tasks
- Yes, a moderate redesign
- Yes, a complete shift in thinking [paradigm]

22. Who redesigned the engineering tasks to facilitate the implementation of the Cobots? (Preliminary study UR & IMR)

- External Systems Integrator
- Internal Engineer
- Internal Technician
- Internal Cobot Operator [Coboter]
- Not Applicable
- Other (please specify)

23. To what extent did the Cobot need to be customised for your company? (Preliminary study UR & IMR)

- No, not at all
- Yes, minor or minimal
- Yes, some customisation
- Yes, moderate amounts of customisation
- Yes, a large amount of customisation

24. How long did the set-up of your Cobot take? (Preliminary study UR & IMR)

- 1-4 hours
- 5-9 hours
- Greater than one working day
- Other (please specify)

25. What tasks were undertaken during this set up-time? (Preliminary study IMR)

- Doing risk assessment
- Programming
- Interacting with Coboter

- Training
- Other (please specify)

26.Who installs, programs, calibrates, and maintains Cobots in your company? (Preliminary study UR & IMR)

- External Systems Integrator
- Internal Engineer
- Internal Technician
- Internal Cobot Operator [Coboter]
- Other (please specify)

27.To what extent, in your opinion, do Coboters require post Leaving Certificate education to successfully operate a Cobot?

- Not at all
- Slightly beneficial
- Moderately beneficial
- An advantage
- Instrumental

28.What other abilities should a Coboter have to successfully operate a Cobot?

- Sound technical aptitude
- Self-motivation
- Facility to pass on knowledge to others
- Tenacity
- Good attention to detail
- Other

29.In your opinion do third level Institutions currently prepare students to work in this collaborative environment? (Preliminary study IMR)

- Not at all
- They teach the basics
- The education is adequate
- The education is good

- The education is excellent

30.What additional education/information would benefit the Coboter to successfully operate a Cobot? (Preliminary study IMR)

- Mechatronics basics
- Quality control introduction
- Programming for automation
- Communications
- Teamwork
- Health & Safety
- Other (please specify)

31.How could this additional education/knowledge be accessed? (Preliminary study UR & IMR)

- Third party online from Robotics Company
- Traditional class-based module in a third level Institute
- Remote module in a third level Institute
- In-house hands-on training
- In-house digital training
- Hybrid of above options
- Other (please specify)

32.In your opinion would your company be interested in obtaining more value from Cobots by higher task optimisation?

- Yes
- No
- Please specify

****** Questions for both streams**

33.In your opinion, would your company be interested in accessing training in the automation of business processes?

- Yes
- No
- Please specify

34. What would be the best way, from your perspective, to access this training based on current company scheduling and workload commitments?

- Third party online from the Robotics Company
- Traditional class-based module in a third level Institute
- Remote module in a third level Institute
- In-house hands-on training
- In-house digital training
- Hybrid of above options
- Other (please specify)

35. In your opinion what would the most important outcomes of this training be?

- Open box for reply

36. The current Covid-19 global pandemic makes physical distancing a requirement in the workplace, does this influence your opinion on using Cobots in manufacturing?

- Yes
- No
- Please explain

37. Please enter your contact details:

- **Name**
- **Job title**
- **Company**
- **Email Address**
- **Contact number**
- ***Thank you very much for your time!***

List of WIT Graduates from 2000 to 2020 on BSc (Honours) in Manufacturing Engineering (formerly BSc (Hons) Computer Aided Manufacturing) & BEng (Hons) Mechanical & Manufacturing Engineering (formerly BSc Manufacturing Systems Engineering) totalling 570:

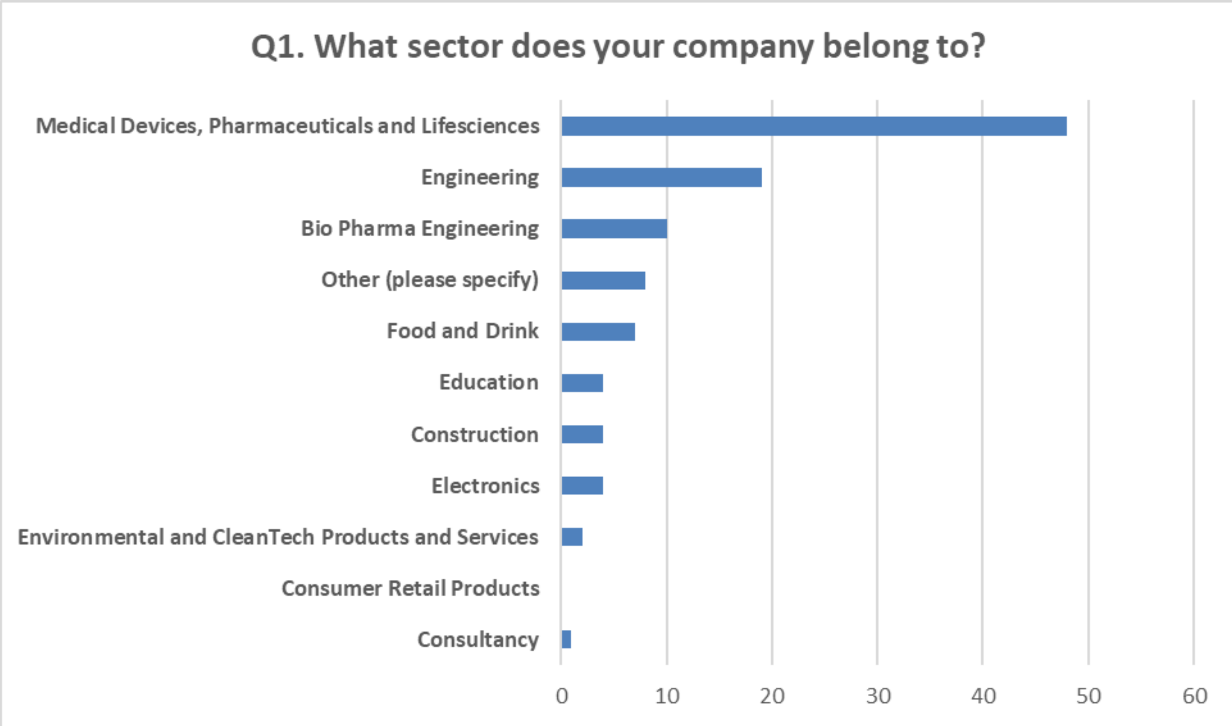
Year	BSc (Hons) Manufacturing Eng	BEng (Hons) Mech & Man Eng
2020	15*	13*
2019	6	11
2018	9	13
2017	16	27
2016	13	15
2015	7	20
2014	27	14
2013	19	12
2012	17	16
2011	12	20
2010	17	9
2009	12	9
2008	13	2
2007	19	2
2006	20	6
2005	24	8
2004	18	8
2003	17	7
2002	27	2
2001	20	--
2000	28	--

*Autumn results not yet processed

The statistics of Waterford Institute of Technology Engineering degree student numbers (Alumni)

Appendix C

Results of the Industrial Questionnaire

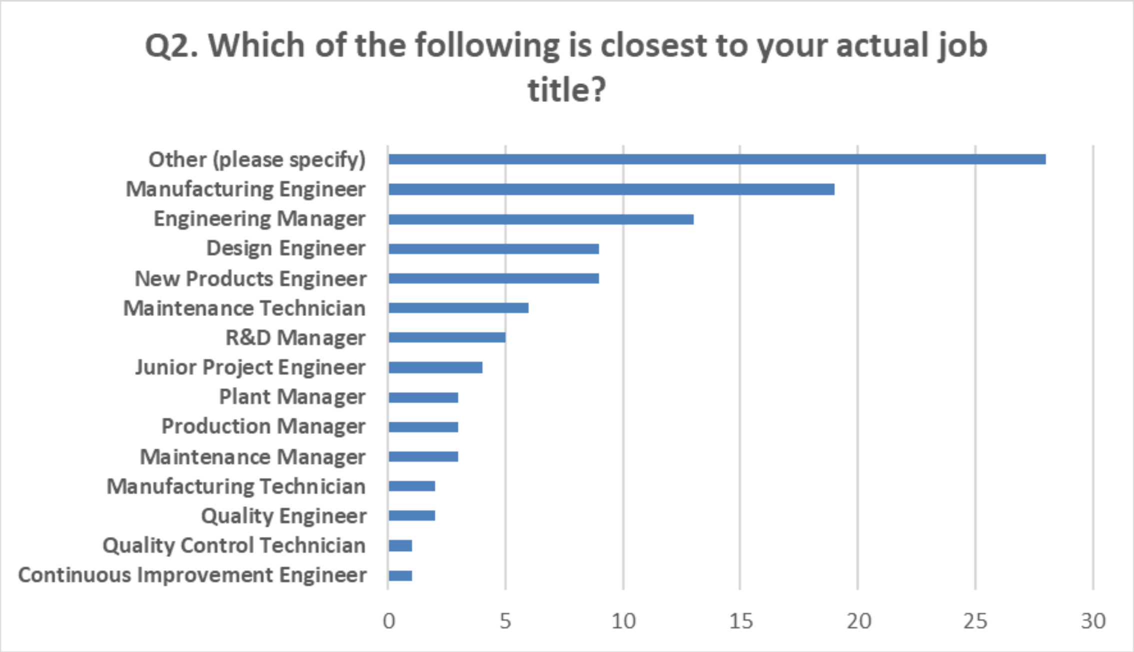


Q1. What sector does your company belong to?	
Consultancy	**1**
Consumer Retail Products	**0**
Environmental and Cleantech Products and Services	**2**
Electronics	**4**
Construction	**4**
Education	**4**
Food and Drink	**7**
Other (please specify)	**8**
Bio Pharma Engineering	**10**
Engineering	**19**
Medical Devices, Pharmaceuticals and Lifesciences	**48**
Total	**107**

Other categories

A lot of the above	**0**
Automotive	**2**
Lithography semiconductor	**1**

Design & Build of special purpose equipment (mostly Medical Device)	**1**
Aerospace	**1**
Semiconductor	**1**
Research and Technology Organisation (Advanced Manufacturing)	**1**
Total	**7**



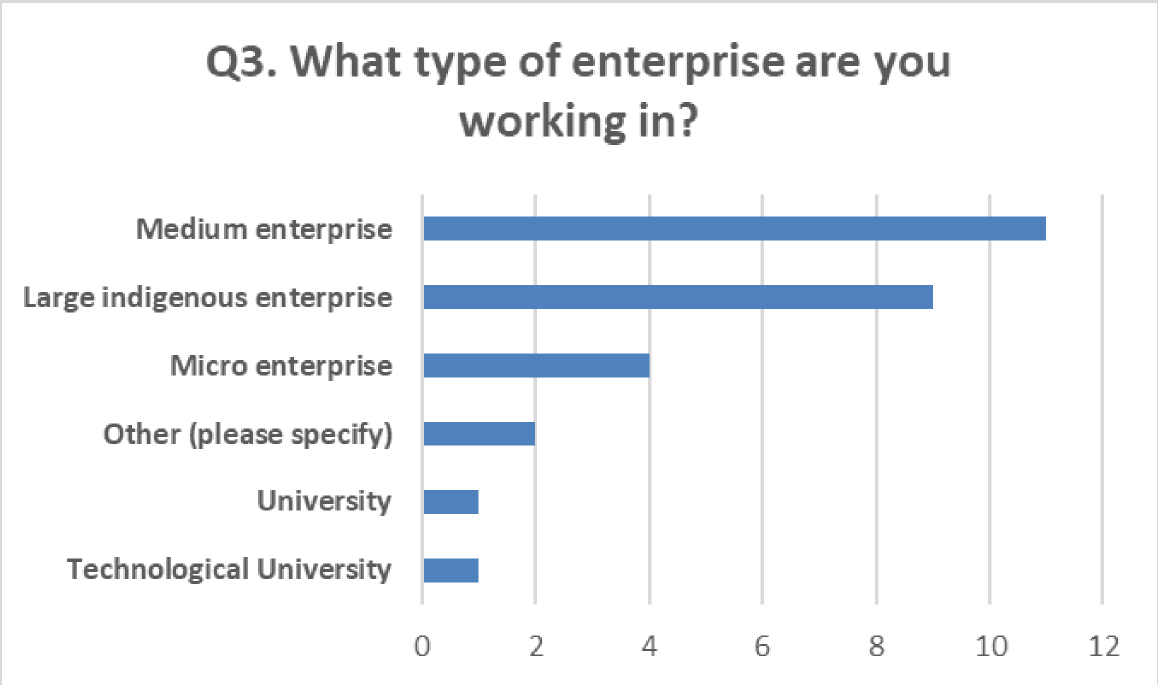
Q2. Which of the following is closest to your actual job title?

Continuous Improvement Engineer	**1**
Quality Control Technician	**1**
Quality Engineer	**2**
Manufacturing Technician	**2**
Maintenance Manager	**3**
Production Manager	**3**

Plant Manager	3
Junior Project Engineer	4
R&D Manager	5
Maintenance Technician	6
New Products Engineer	9
Design Engineer	9
Engineering Manager	13
Manufacturing Engineer	19
Other (please specify)	28
Total	108

Other categories	
National Sales Manager	1
Equipment engineer	1
Sales Engineer	2
Snr. Manufacturing Specialist	1
Technical Trainer	1
Quality Manager	1
Purchasing	1
most of the above	1
Chief Technical Officer	1
Quality Director	1
Automation Engineer	3
Design Quality Assurance Manager	1
Project Engineer	1
Electrical Engineer	1

Tester Technician	**1**
Research Engineer	**1**
Senior Lecturer	**1**
Supply Chain Management	**1**
Professor	**1**
Supplier Quality Engineer	**1**
Engineering Specialist	**1**
Service Engineer	**1**
Technical Lead	**1**
Performance Manager	**1**
Snr. Manufacturing Specialist	**1**



Q3. What type of enterprise are you working in?

Technological University	**1**

University	**1**
Other (please specify)	**2**
Micro enterprise	**4**
Large indigenous enterprise	**9**
Medium enterprise	**11**
Small enterprise	**15**
Large multinational enterprise	**68**
Total	**109**

Other categories	
Technological University	**1**
University	**1**

Q4. Describe your company's products/services.

Motor vehicle driver aids, reversing cameras

Automotive industry

Cameras and vision systems for autonomous driving and parking assist

Pneumatic and electric automation components

Industrial automation components

Meat production

Construction contracting and lightweight concrete products

Stainless steel fabrication

Technical education

Dairy ingredients manufacturer

Innovative total solutions in mechanical design and robot integration. (Cobots.ie)

Services provider to medical devices and pharma industries

Turnkey automation solutions provider

Cancer drug manufacture, testing and packaging

Meats primary, retail & food service

Medical guide wires

Medical devices

Pharmaceutical

Treatment of rare disease pharmaceutical

Contract manufactures of off-road vehicles and power generation industry

Reservoir tanks, acoustic enclosures, technology solutions and hygiene solutions

Biomedical coatings

Medical devices

Advanced driver-assistance systems

Lithography machines for chip manufacturing companies

Medical devices contact lenses manufacture

Post-surgical medical device AWT

Manufacture of treatments for ultra-rare diseases

Combination products

Scientific measurement - HPLC & Mass Spectrometry.

Technical education from Level 6 to Level 10

Catheters

Catheters & other medical devices

Pumps and agitators for wastewater market

R&D services

Teaching and research

Contact Lenses

Design and build special purpose equipment for mostly the medical device industry

Pacemakers/ defibrillators/ neuromodulation devices

Fuel, hydraulic systems for commercial and military aircraft

Medical and pharmaceutical respiratory devices

Medical devices - stents

Clean utilities fitout

Class 2 medical devices

Medical device

Bio-technology company inventing life transforming medicine for people with serious illnesses

Semiconductor equipment manufacturer

Bio-technology company that invents life changing medicines for people with serious illness

Robotics and automation solutions

Contract manufacturing partners specialising in metal fabrication

Design of plants, medical, pharma food etc.

Medical device stent manufacturing

Single use technology in the bio sector

Medical device and diagnostics device manufacturing

Vaccines and medicines for rare diseases

Milk and milk powder

Medical devices

Analytical laboratory equipment

Semiconductor chips for hardware devices like laptops, tables, mobile phones, and soon the automation industry for self-driving vehicles

R&D management services

Bio pharmaceutical manufacturing infrastructure

Pharmaceutical delivery systems

Medical guidewires

Diet feeders in agricultural sector

Drug product manufacture and supply of biologic medicines

Design, manufacture, and installation of bespoke feature metalwork

Medical devices and pharmaceutical

Contact lenses and retinal implants

Cancer treatment products -pharmaceutical

Robotic automation supplier integrator

Medical device - guidewires

Medical devices manufacturer

Medical devices

Contact lenses manufacturing

Panel wood manufacturing

Valves and pneumatic fittings

Histology & SPS

Medicine

Medical devices IVD

Vacuum technology

Urology medical devices

Custom machine designing and building

Valves

Run and maintenance chillers cooling systems

Additively manufactured medical implants

Construction and services

High TRL research for advanced manufacturing

Biopharmaceuticals

Medical device manufacture

Implantable medical device manufacture

Stents, catheters, vessel closure medical devices

Implantable and non-implantable medical devices and instruments

Wastewater equipment

Fruit juice - food products

Medical devices

Provide products to monitor environmental conditions in cleanroom manufacturing

Automotive

Medical device contractor

Surgical instruments

Pharmaceutical solid dose

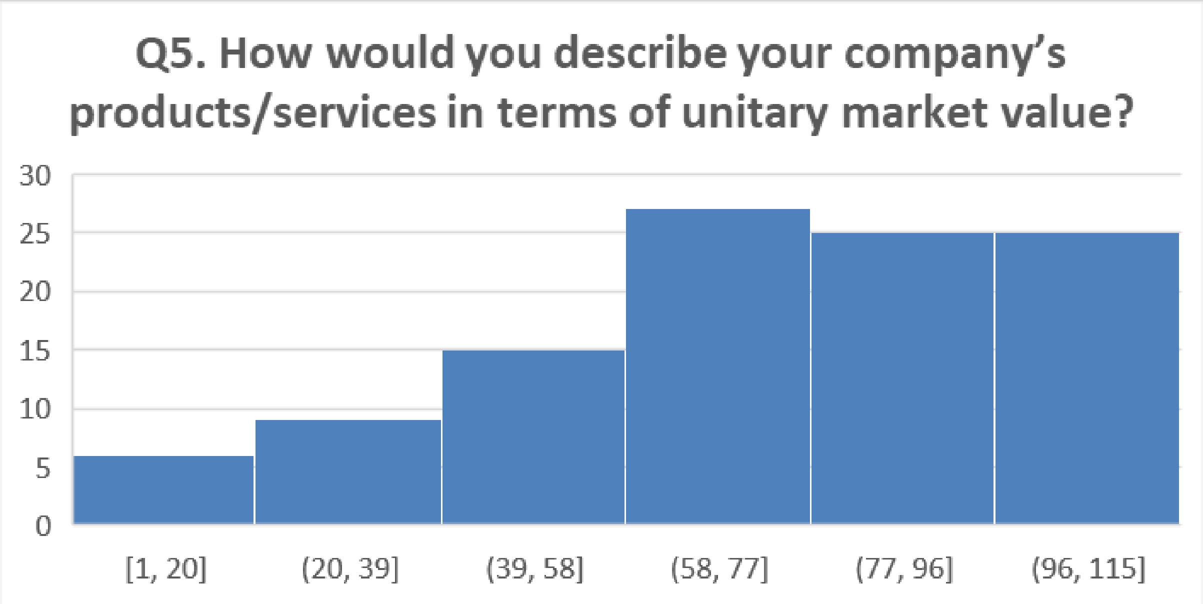
Manufacturing of microprocessors

Drug and pharma products

Surgical instruments and implants

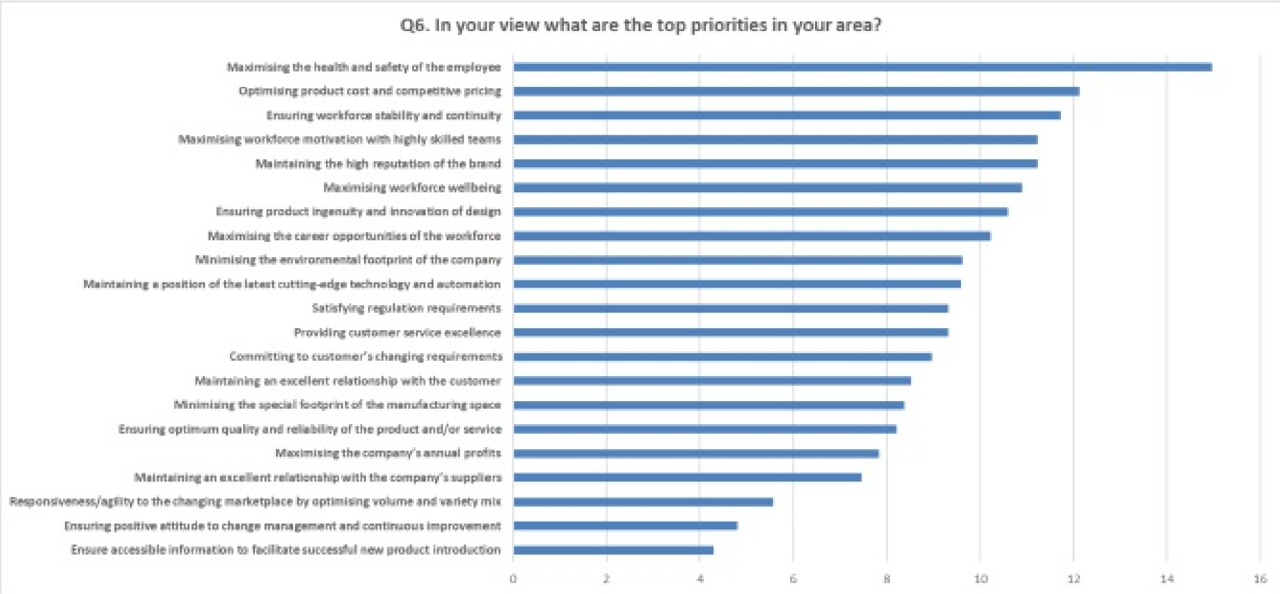
Contract medical/pharma device manufacturers

Food products, both branded and for industry



Q5. How would you describe your company's products/services in terms of unitary market value in %?

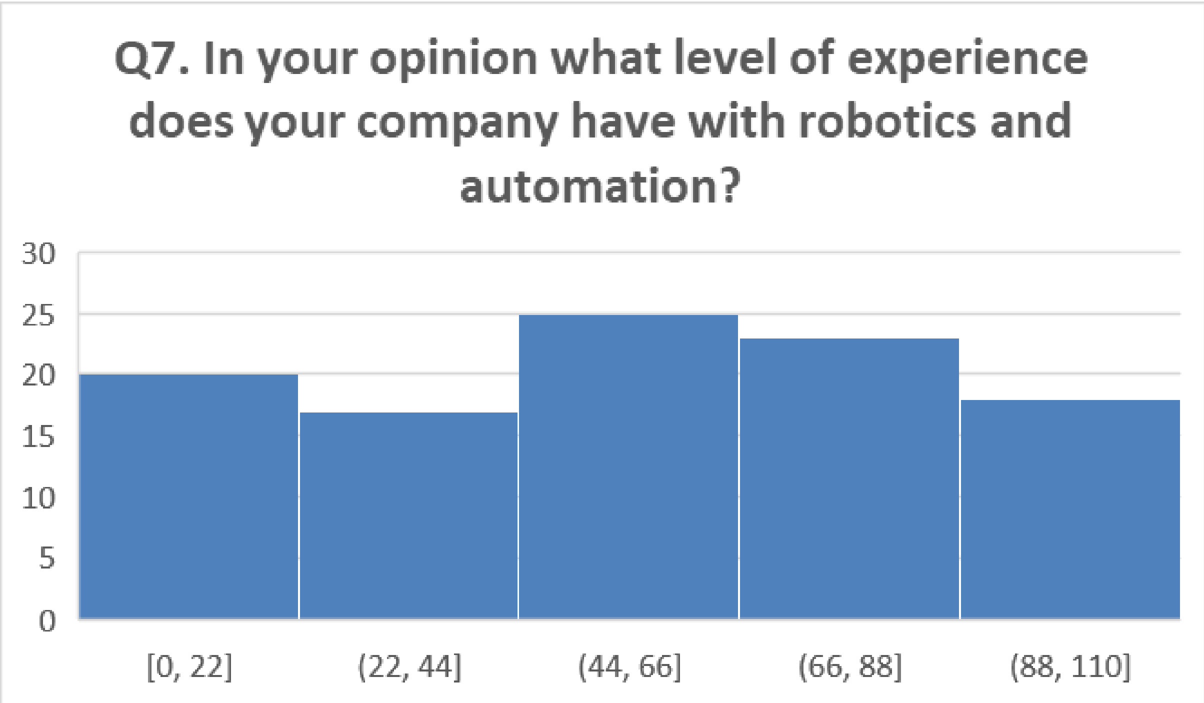
Total Number	**N**	**26.00**
Standard deviation	**δ**	**26.06**
Mean	**M**	**70.52**



Q6. In your view what are the top priorities in your area? (average score in %)

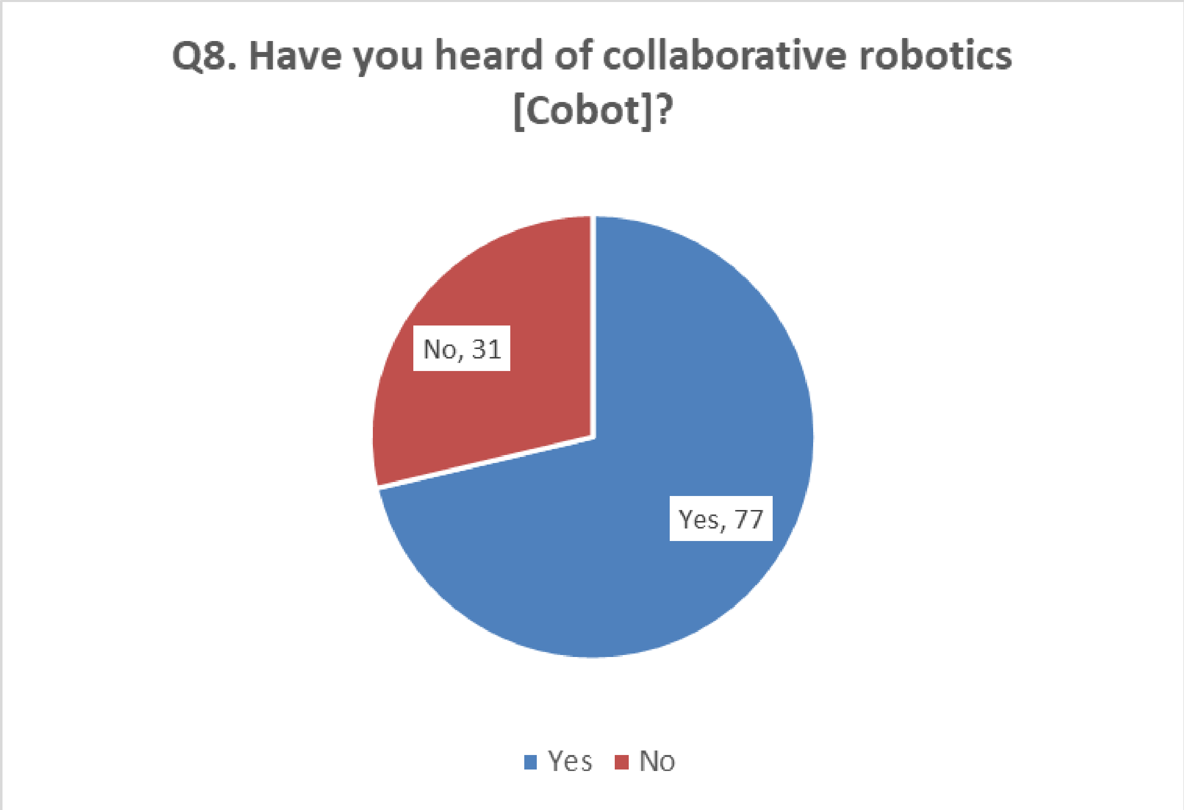
Maximising the health and safety of the employee	**14.97**
Optimising product cost and competitive pricing	**12.13**
Ensuring workforce stability and continuity	**11.72**
Maximising workforce motivation with highly skilled teams	**11.24**
Maintaining the high reputation of the brand	**11.23**
Maximising workforce wellbeing	**10.90**
Ensuring product ingenuity and innovation of design	**10.60**
Maximising the career opportunities of the workforce	**10.22**
Minimising the environmental footprint of the company	**9.62**
Maintaining a position of the latest cutting-edge technology and automation	**9.60**
Providing customer service excellence	**9.32**
Satisfying regulation requirements	**9.32**
Committing to customer's changing requirements	**8.96**

Maintaining an excellent relationship with the customer	**8.52**
Minimising the special footprint of the manufacturing space	**8.38**
Ensuring optimum quality and reliability of the product and/or service	**8.22**
Maximising the company's annual profits	**7.83**
Maintaining an excellent relationship with the company's suppliers	**7.47**
Responsiveness/agility to the changing marketplace by optimising volume and variety mix	**5.57**
Ensuring positive attitude to change management and continuous improvement	**4.81**
Ensure accessible information to facilitate successful new product introduction	**4.29**



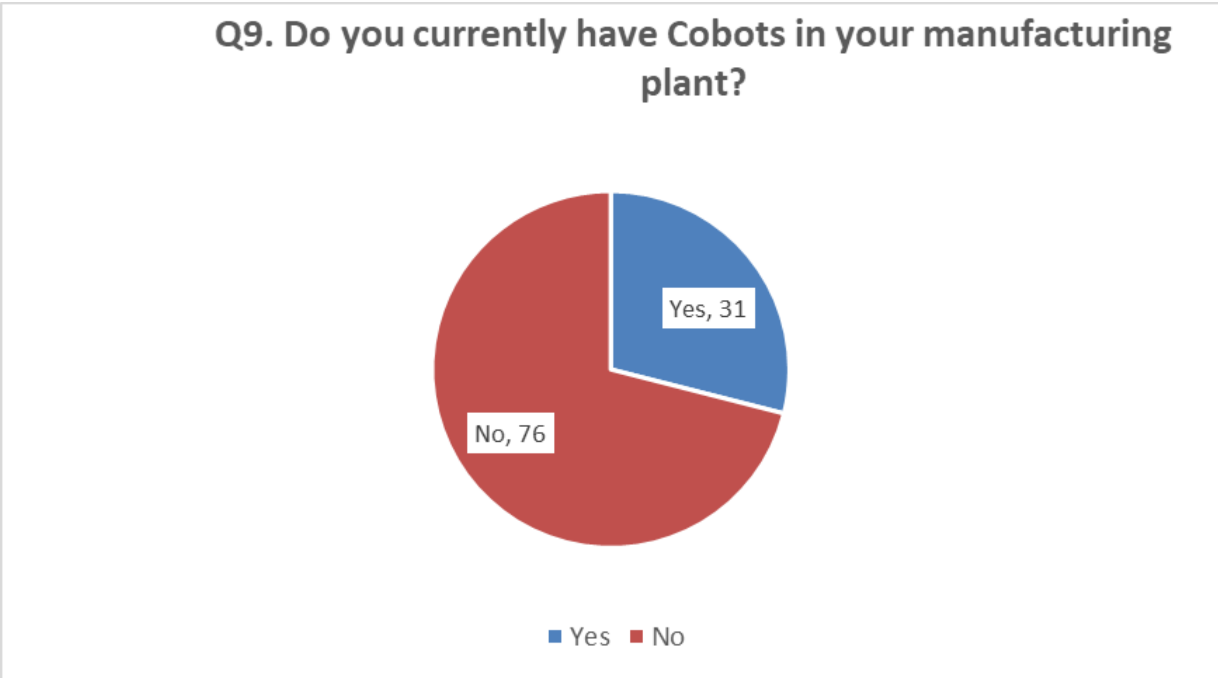
Q7. In your opinion what level of experience does your company have with robotics and automation in %?

Total Number	**N**	**103.00**
Standard deviation	**δ**	**16.26**
Mean	**M**	**55.17**



Q8 Have you heard of Collaborative robotics [Cobot]?

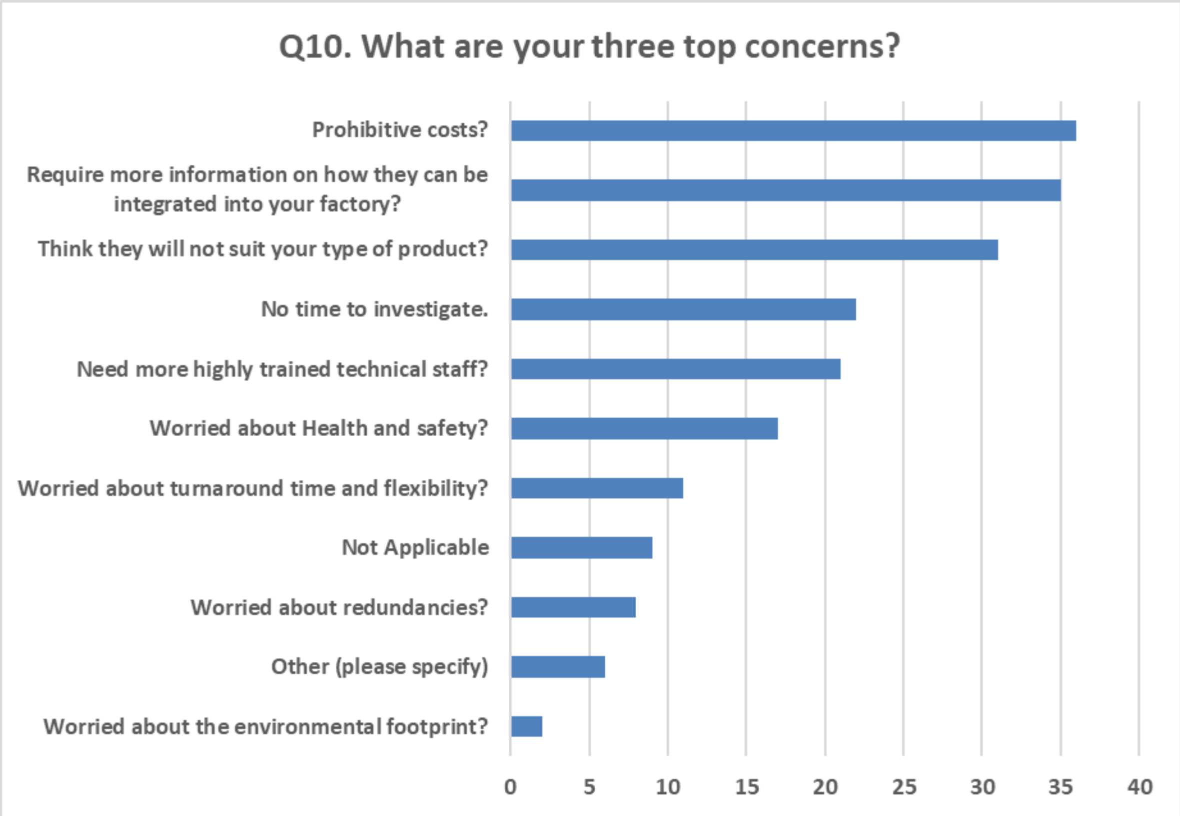
Yes	**77**
No	**31**



Q9. Do you currently have Cobots in your manufacturing plant?

Yes	**31**
No	**76**

Note:
Q10. is answered by companies that answered NO to Q9.



Q10. What are your three top concerns?

Prohibitive costs?	**36**
Require more information on how they can be integrated into your factory?	**35**
Think they will not suit your type of product?	**31**
No time to investigate.	**22**
Need more highly trained technical staff?	**21**
Worried about Health and safety?	**17**
Worried about turnaround time and flexibility?	**11**
Not Applicable	**9**
Worried about redundancies?	**8**
Other (please specify)	**6**
Worried about the environmental footprint?	**2**
Total	**198**

Other categories
Set up cost & space

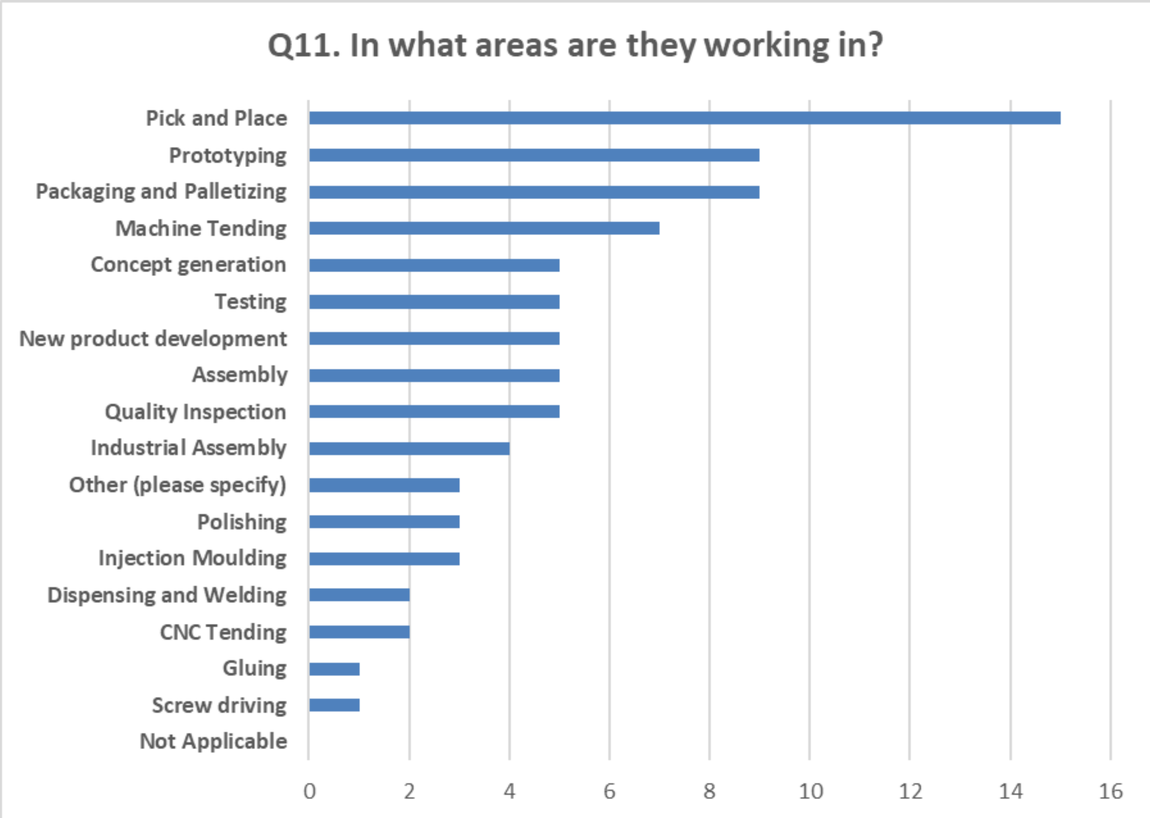
They are not currently safe enough to work alongside humans in the large majority of cases has been our experence. We have used several robots.

Floor space requirements

Regulatory requirements - CQV

How they are validated/qualified in a regulated environment

Note:
Q11. is answered by companies that answered YES to Q9.

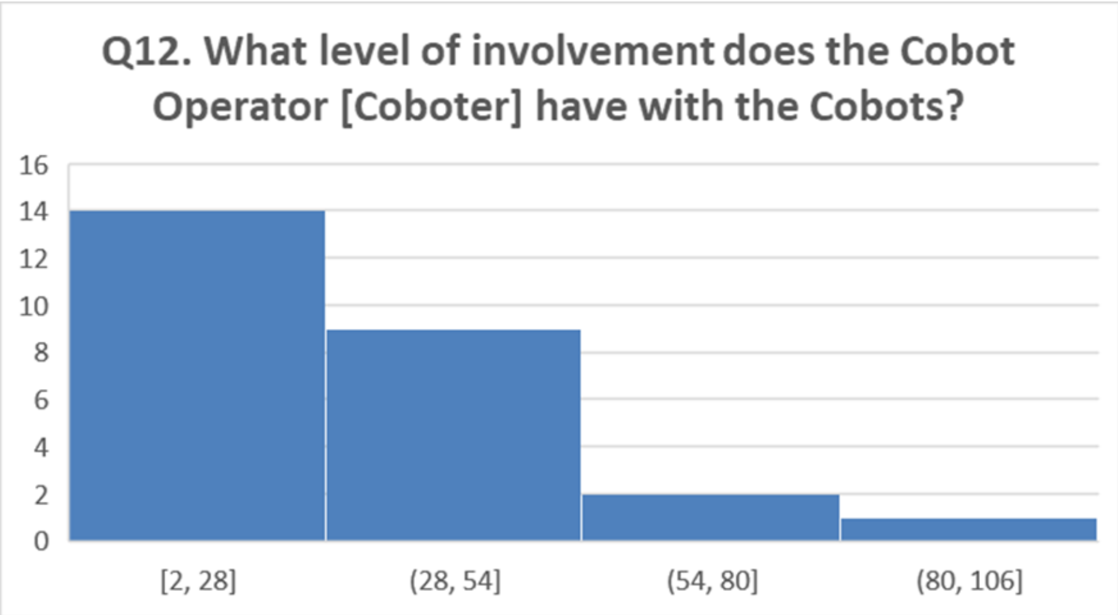


Q11. In what areas are they working in?

Pick and Place	**15**
Packaging and Palletizing	**9**
Prototyping	**9**
Machine Tending	**7**
Quality Inspection	**5**
Assembly	**5**
New Product Development	**5**

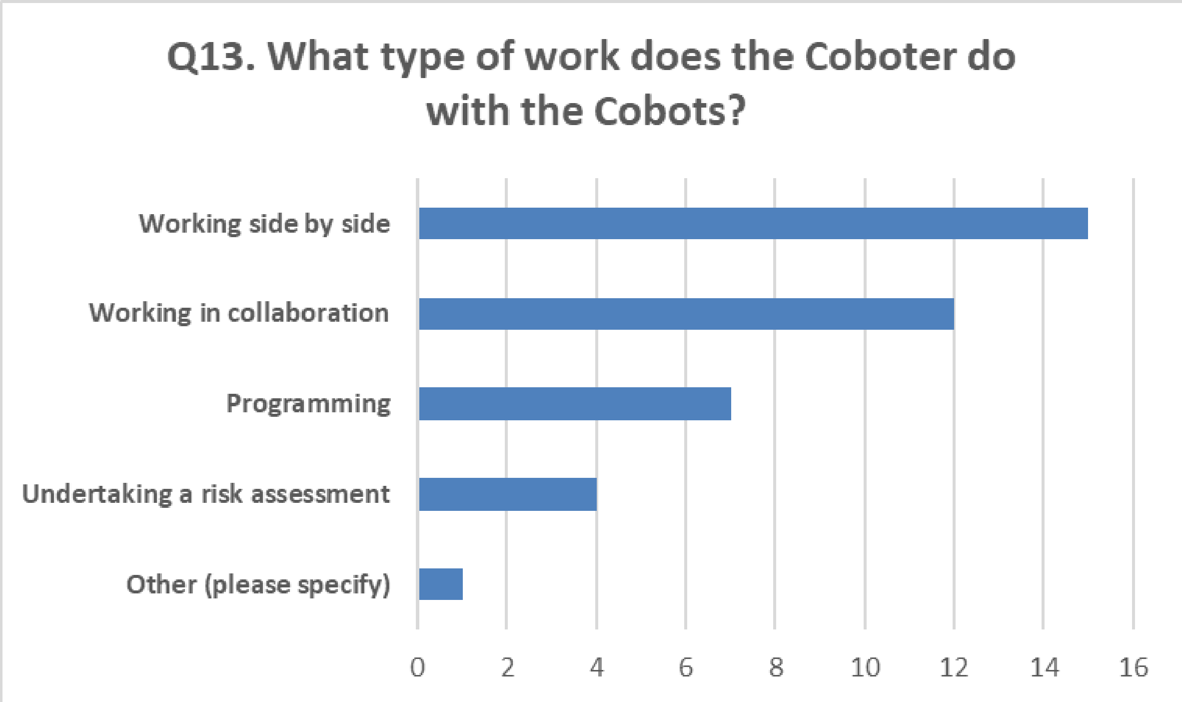
Testing	**5**
Concept generation	**5**
Industrial Assembly	**4**
Injection Moulding	**3**
Polishing	**3**
Other (please specify)	**3**
CNC Tending	**2**
Dispensing and Welding	**2**
Screw driving	**1**
Gluing	**1**
Not Applicable	**0**
Total	**84**

Other category
260 Cobots in production. Lots of different applications
Education
Blasting



Q12.What level of involvement does the Cobot Operator [Coboter] have with the Cobots?

Total Number	**N**	**26.00**
Standard deviation	**δ**	**21.91**
Mean	**M**	**29.92**

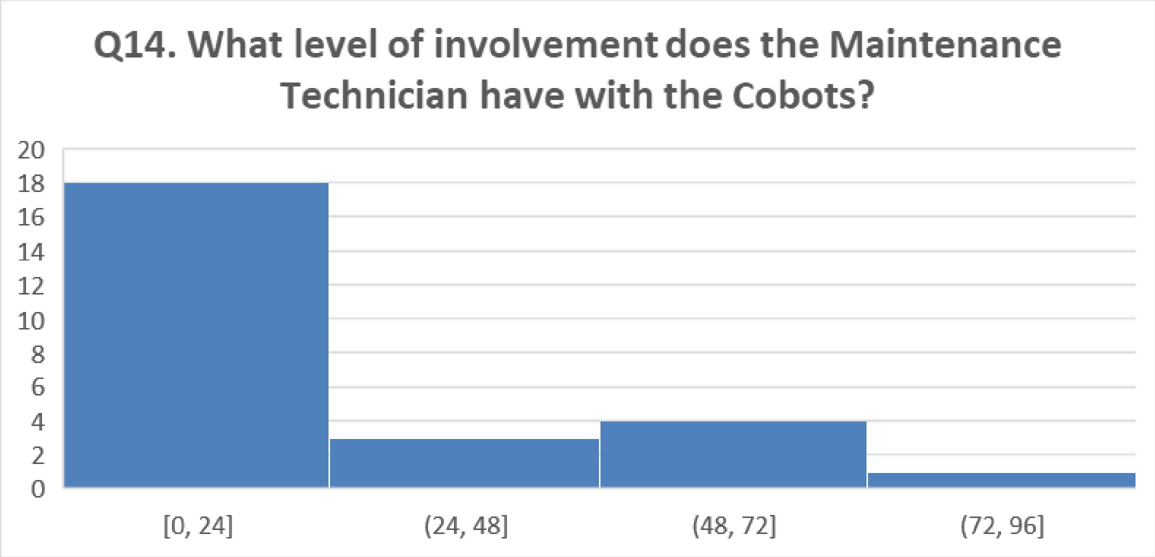


Q13. What type of work does the Coboter do with the Cobots?

Working side by side	**15**
Working in collaboration	**12**
Programming	**7**
Undertaking a risk assessment	**4**
Other (please specify)	**1**
Total	**39**

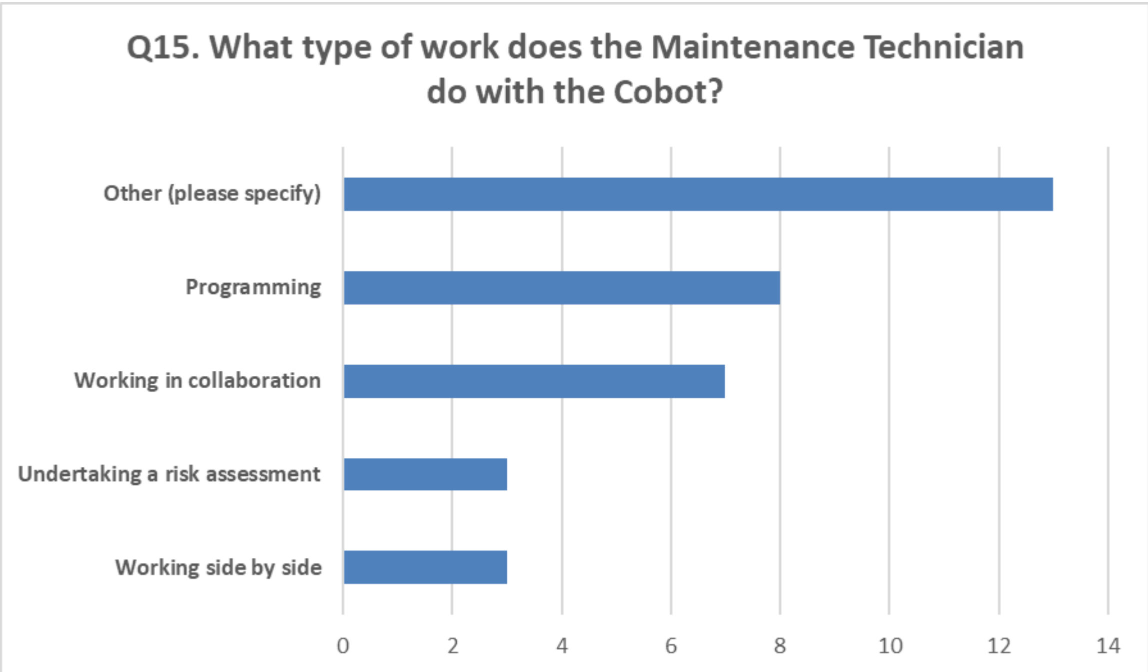
Other categories

Cobot is fully guarded. Cobot is stopped to load/unload machine. No collaboration



Q14. What level of involvement does the Maintenance Technician have with the Cobots?

Total Number	**N**	**26.00**
Standard deviation	**δ**	**20.55**
Mean	**M**	**22.23**

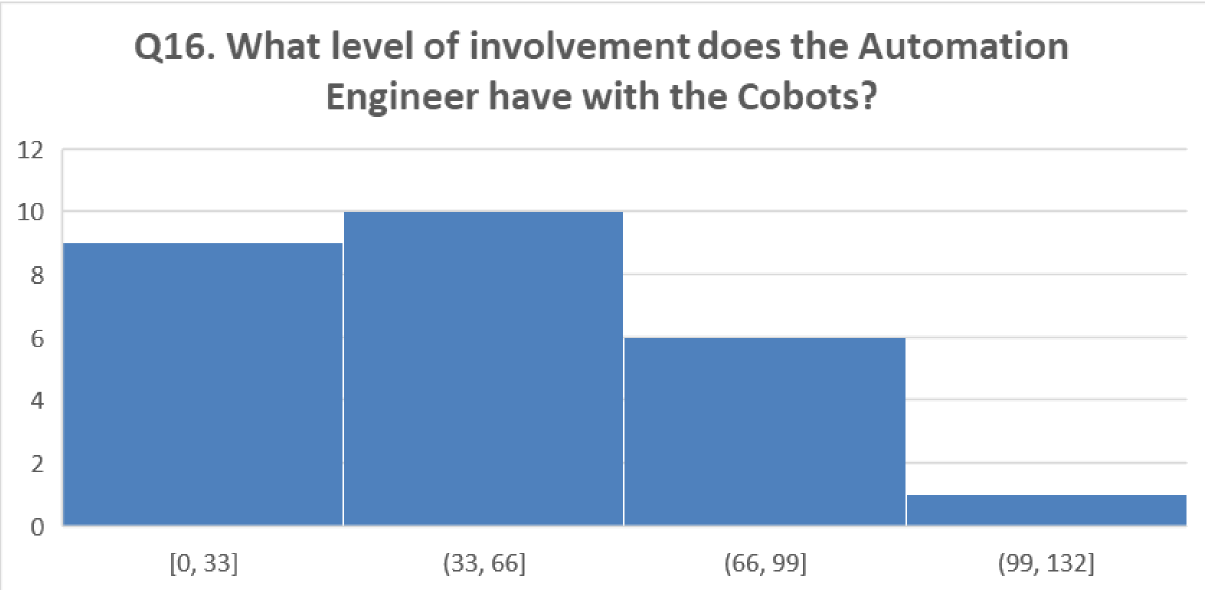


Q15. What type of work does the Maintenance Technician do with the Cobot?

Other (please specify)	13
Programming	8
Working in collaboration	7
Working side by side	3
Undertaking a risk assessment	3

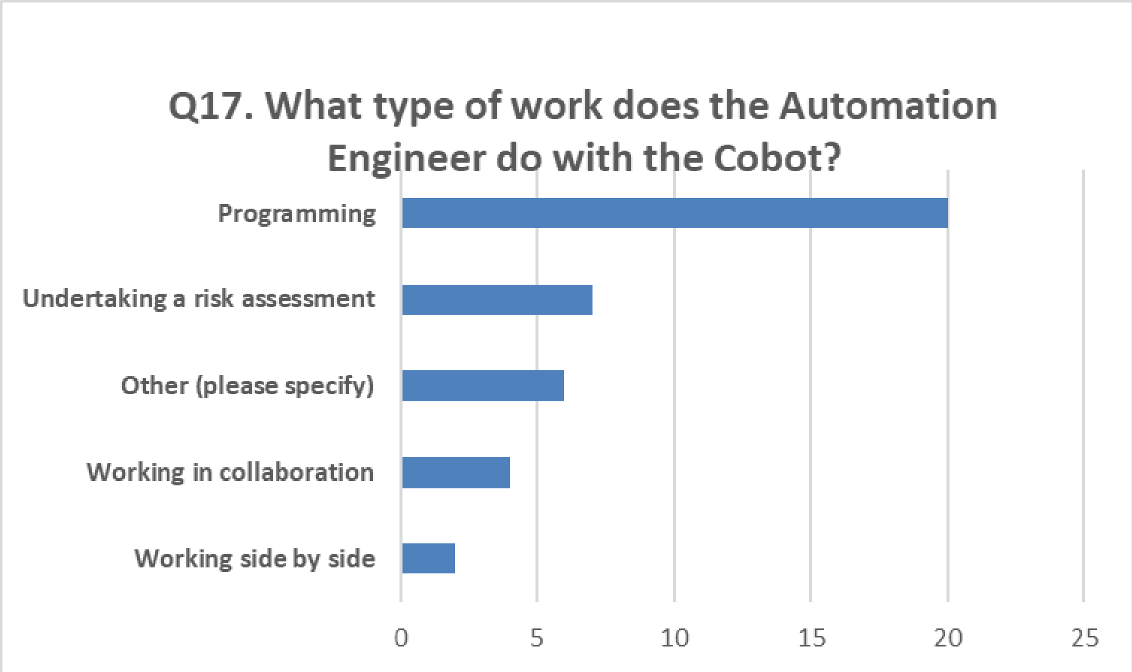
Total 34

Other categories
None unless a new product is introduced
Prevantative maintenance
Unblocks jams and recover from crashes
Very little work with Maintenance Tech to date
Planned preventive maintance
Maintenance
Maintenance/tending to breakdowns
Periodic maintenance
Preventative maintenance + repairs
Interventions with the tended equipment
Maintenance
Preventative maintenance
No maintenance technician per say as Cobot not used in production



Q16. What level of involvement does the Automaton Engineer have with the Cobots?

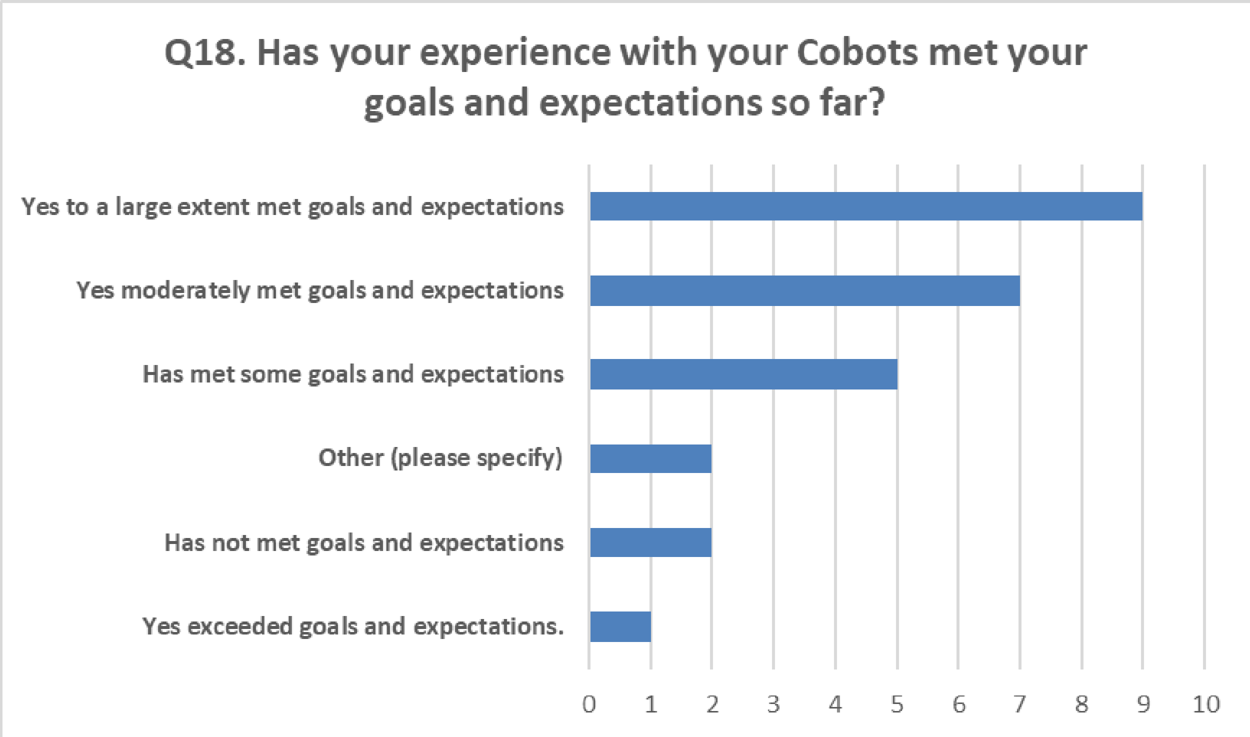
Total Number	N	26.00
Standard deviation	δ	27.62
Mean	M	48.31



Q17. What type of work does the Automation Engineer do with the Cobot?

Programming	**20**
Undertaking a risk assessment	**7**
Other (please specify)	**6**
Working in collaboration	**4**
Working side by side	**2**
Total	**39**

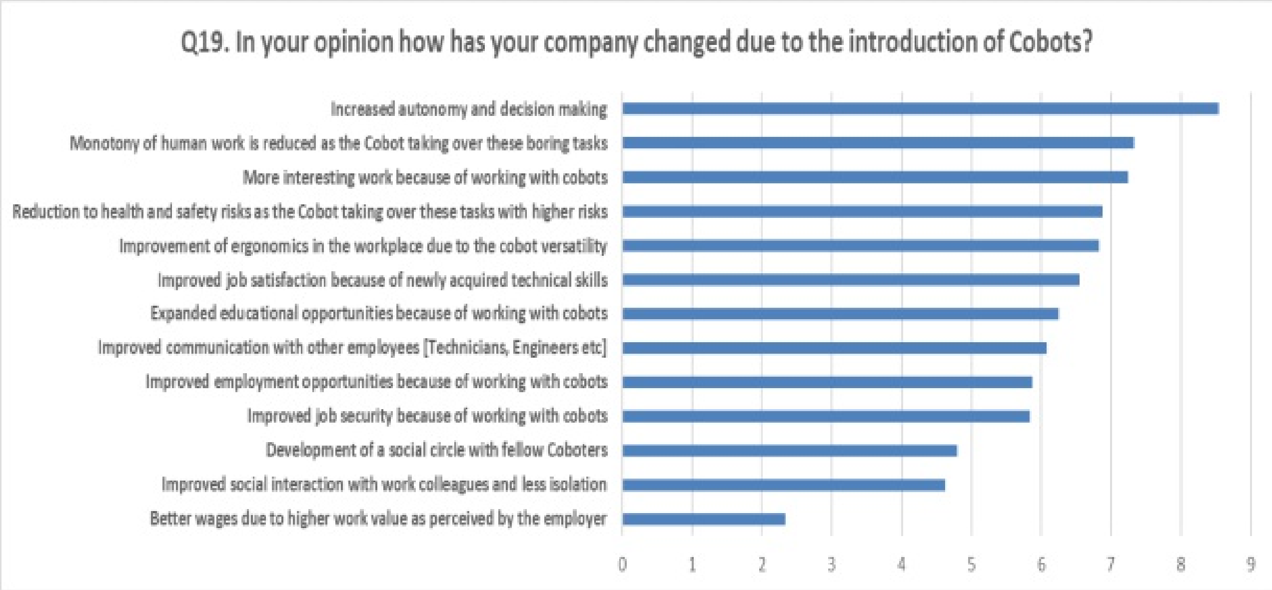
Other categories
Machine design
Optimising workflow
Looking for ways to improve interaction between Cobots and operators to make the process more efficient
Fault finding
Cell development
No dedicated automation engineer



Q18. Has your experience with your Cobots met your goals and expectations so far?

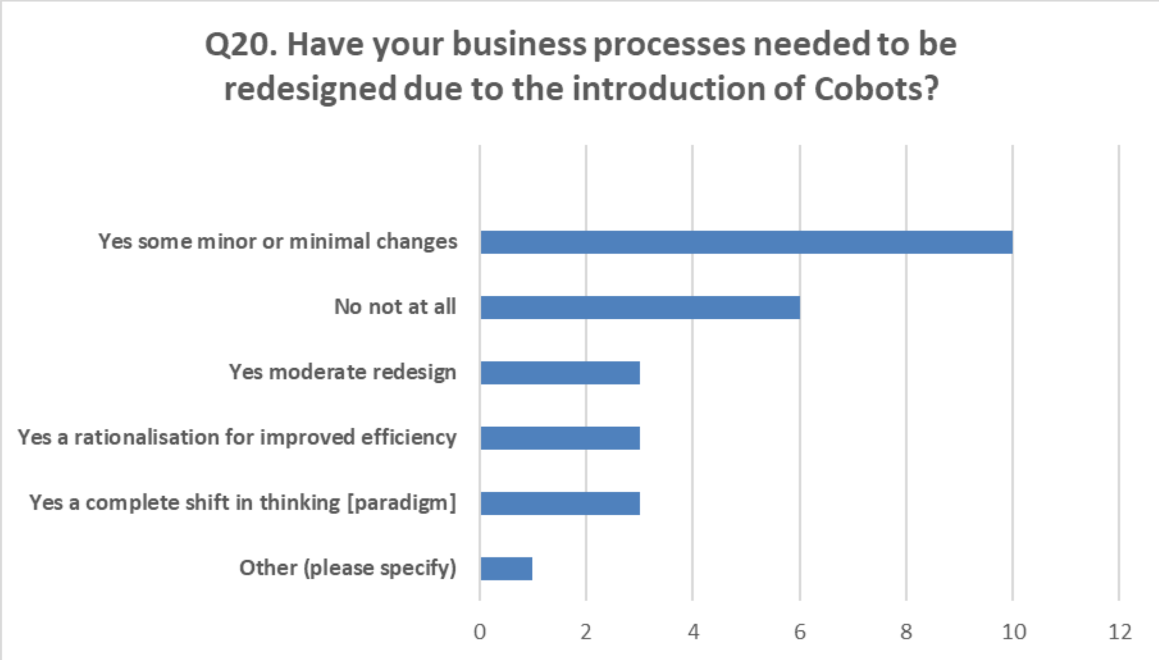
Yes to a large extent met goals and expectations	**9**
Yes moderately met goals and expectations	**7**
Has met some goals and expectations	**5**
Has not met goals and expectations	**2**
Other (please specify)	**2**
Yes exceeded goals and expectations	**1**
Total	**26**

Other categories
Too new to tell
We have unclear goals around Cobots



Q19. In your opinion how has your company changed due to the introduction of Cobots?

Increased autonomy and decision making	**8.54**
Monotony of human work is reduced as the Cobot taking over these boring tasks	**7.33**
More interesting work because of working with Cobots	**7.25**
Reduction to health and safety risks as the Cobot taking over these tasks with higher risks	**6.88**
Improvement of ergonomics in the workplace due to the cobot versatility	**6.83**
Improved job satisfaction because of newly acquired technical skills	**6.54**
Expanded educational opportunities because of working with cobots	**6.25**
Improved communication with other employees [Technicians, Engineers, etc.]	**6.08**
Improved employment opportunities because of working with Cobots	**5.88**
Improved job security because of working with Cobots	**5.83**
Development of a social circle with fellow Coboters	**4.79**
Improved social interaction with work colleagues and less isolation	**4.63**
Better wages due to higher work value as perceived by the employer	**2.33**



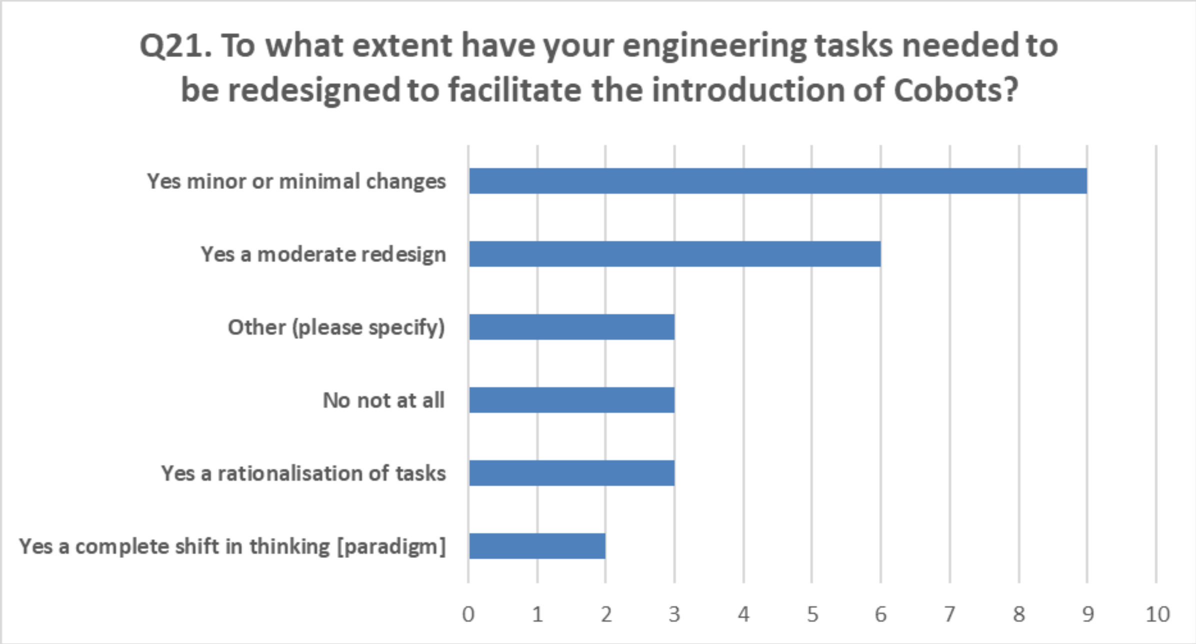
Q20. Have your business processes needed to be redesigned due to the introduction of Cobots?

Yes some minor or minimal changes	**10**
No not at all	**6**
Yes a complete shift in thinking [paradigm]	**3**
Yes a rationalisation for improved efficiency	**3**
Yes moderate redesign	**3**
Other (please specify)	**1**

Total 26

Other categories

Current application was new so new design was required. Will be incorporating into existing processes on the next process and expect some process redesign.

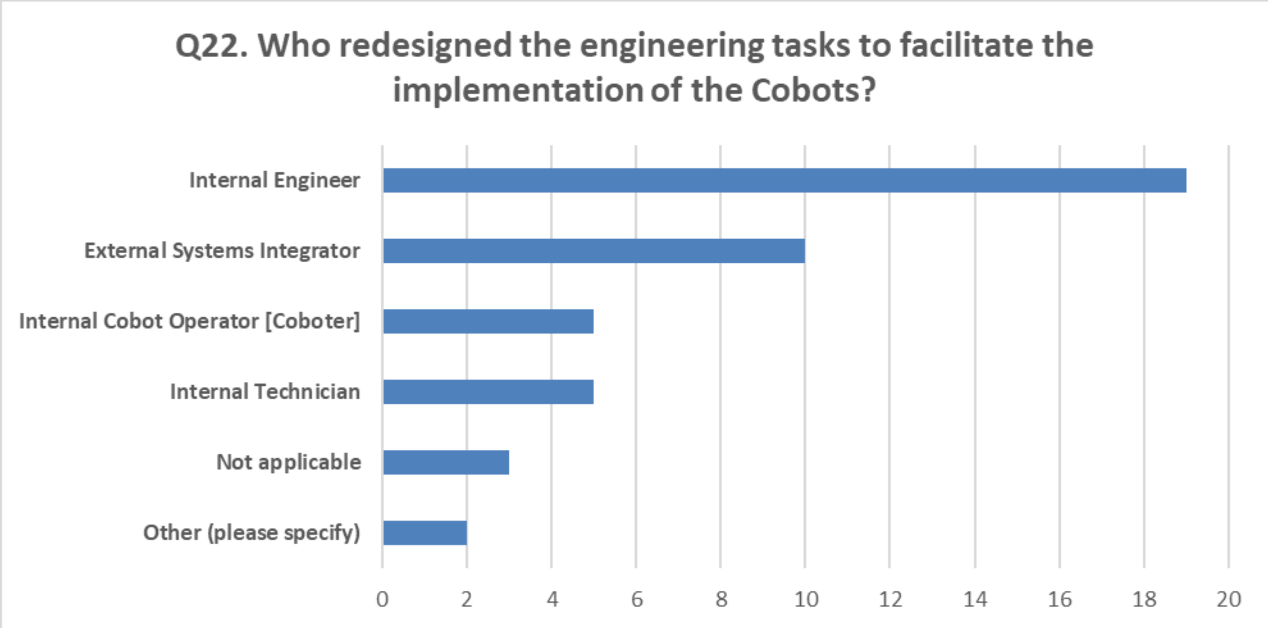


Q21. To what extent have your engineering tasks needed to be redesigned to facilitate the introduction of Cobots?

Yes, minor or minimal changes	**9**
Yes, a moderate redesign	**6**
Yes, a rationalisation of tasks	**3**
No, not at all	**3**
Other (please specify)	**3**
Yes a complete shift in thinking [paradigm]	**2**
Total	**26**

Other categories

Too new to tell
We are at an early stage. Long term I would expect that we would be looking at a significant change in engineering tasks.
Still at very early stage but major change is coming.

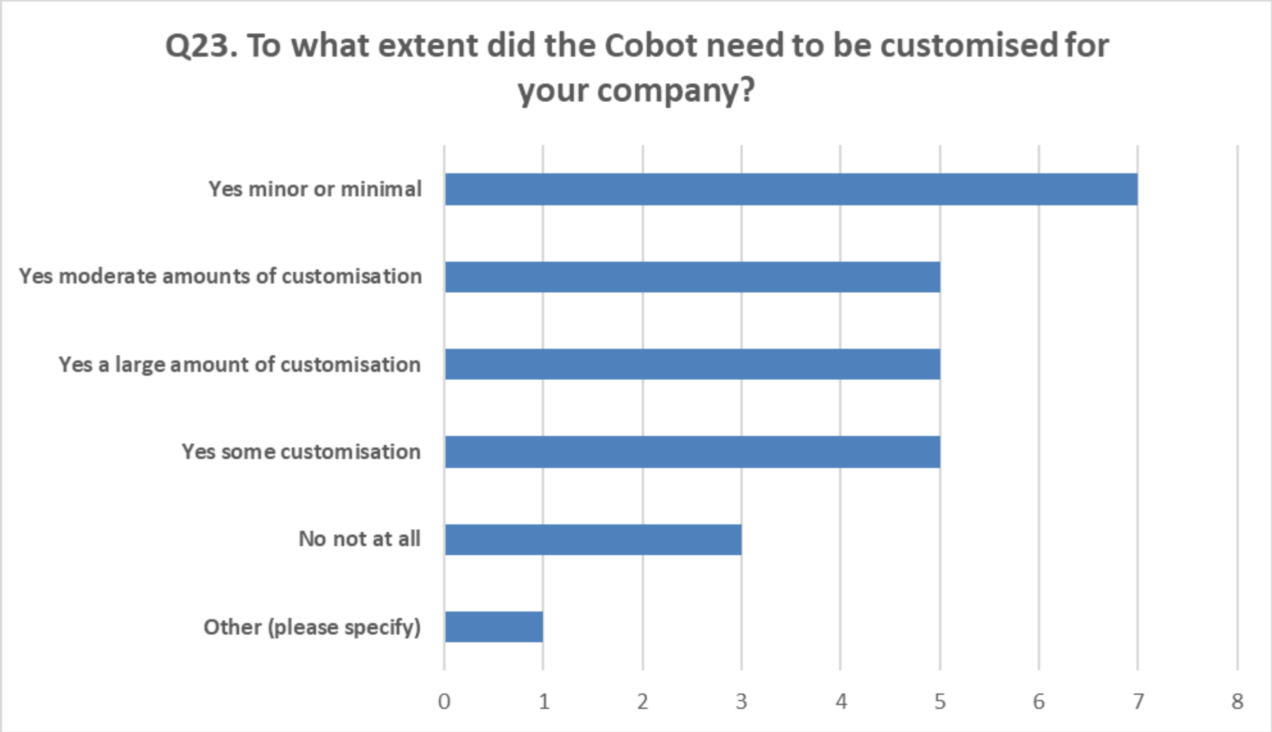


Q22. Who redesigned the engineering tasks to facilitate the implementation of the Cobots?

Internal Engineer	**19**
External Systems Integrator	**10**
Internal Technician	**5**
Internal Cobot Operator [Coboter]	**5**
Not applicable	**3**
Other (please specify)	**2**
Total	**44**

Other categories

Planning to develop internal skills
Research Engineers

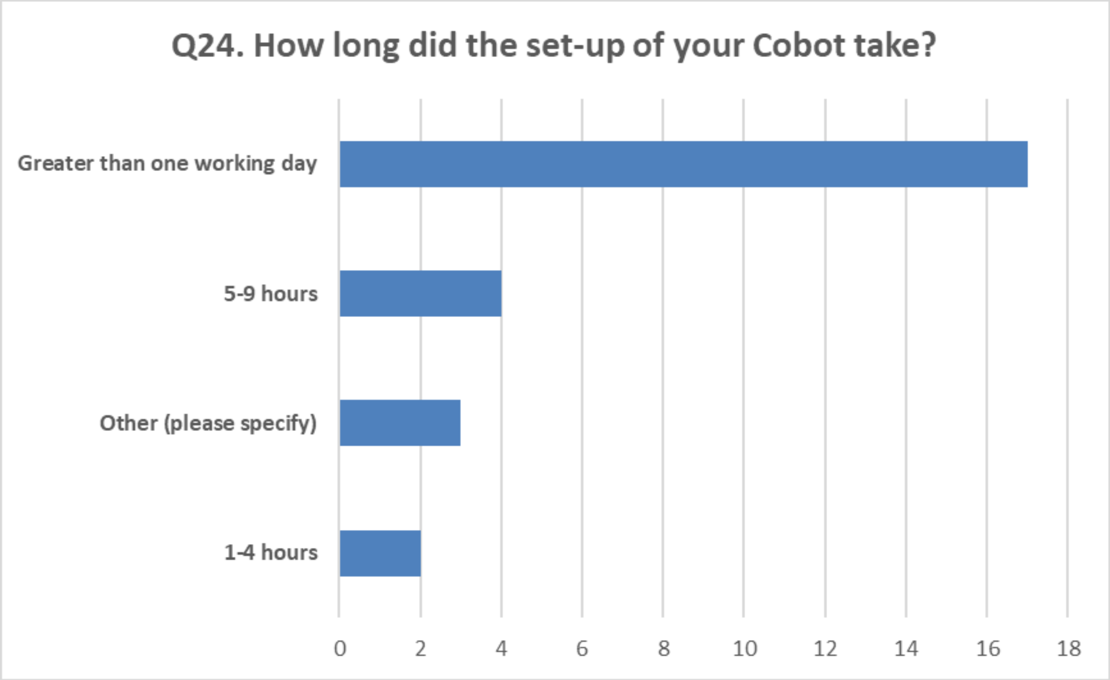


Q23. To what extent did the Cobot need to be customised for your company?

Yes minor or minimal	**7**
Yes some customisation	**5**
Yes a large amount of customisation	**5**
Yes moderate amounts of customisation	**5**
No not at all	**3**
Other (please specify)	**1**
Total	**26**

Other categories

No customisation on the Cobot, but specialised tooling needed on the arm

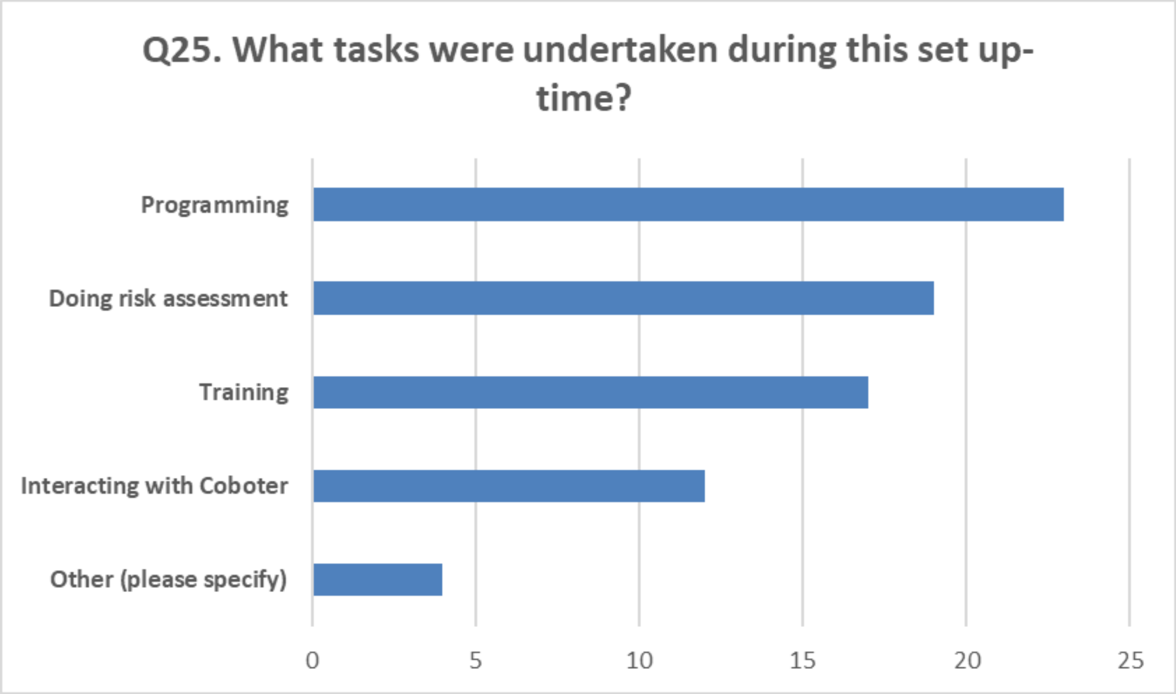


Q24. How long did the set-up of your Cobot take?

Greater than one working day	**17**
5-9 hours	**4**
Other (please specify)	**3**
1-4 hours	**2**
Total	**26**

Other categories

Greater than 2 months, new line had to be built.
Maybe I misunderstood but the turnkey system took 6 months to build and commission.
Over a year including operation qualification.

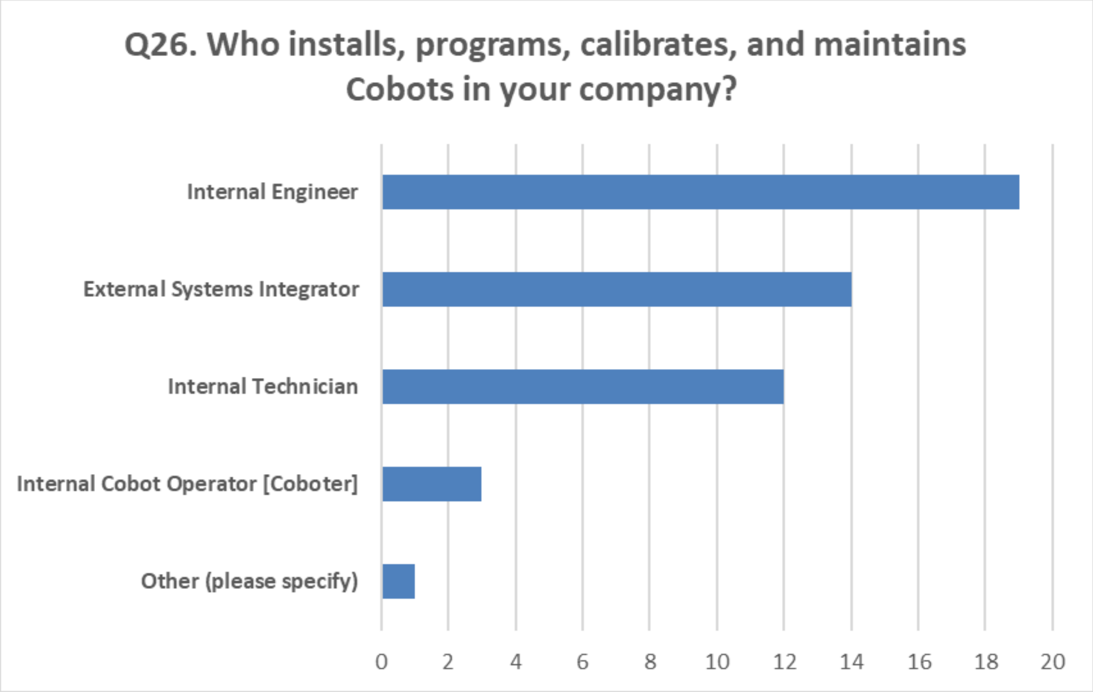


Q25. What tasks were undertaken during this set up-time?

Programming	**23**
Doing risk assessment	**19**
Training	**17**
Interacting with Coboter	**12**
Other (please specify)	**4**
Total	**75**

Other categories

Design of tool and machine frame, fabrication, wiring
Designing fixtures, safeties, end of arm tooling
Validation
Implementation of safety devices

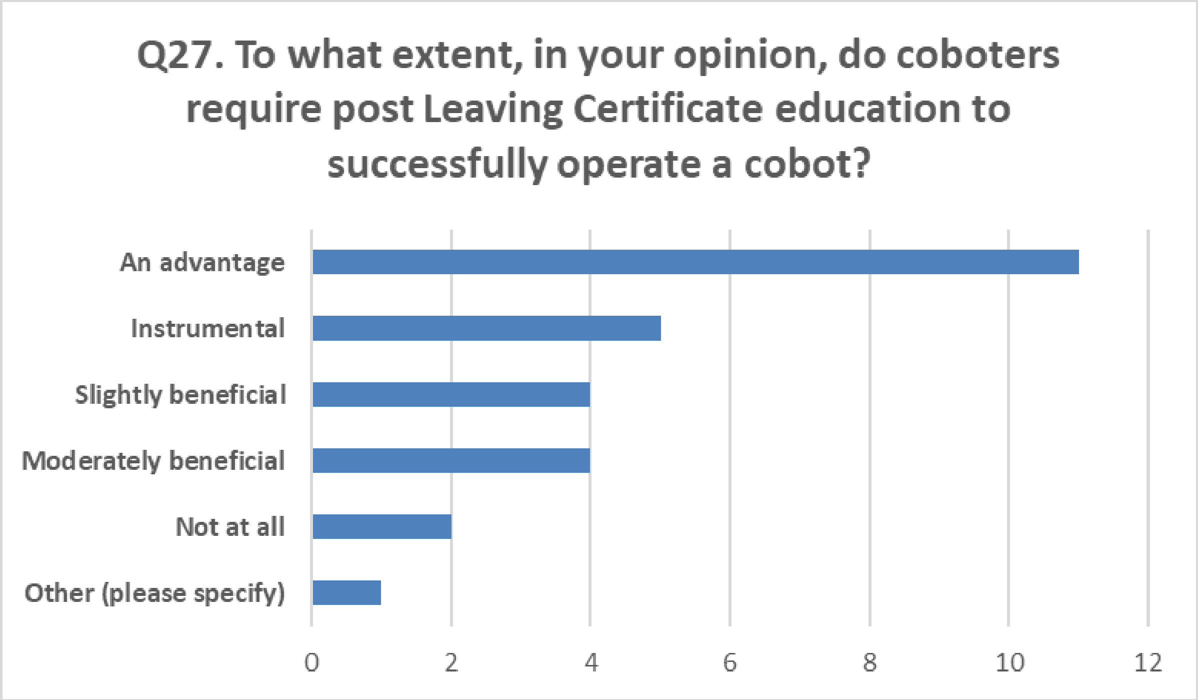


Q26. Who installs, programs, calibrates, and maintains Cobots in your company?

Internal Engineer	**19**
External Systems Integrator	**14**
Internal Technician	**12**
Internal Cobot Operator [Coboter]	**3**
Other (please specify)	**1**
Total	**49**

Other categories

Research Engineers

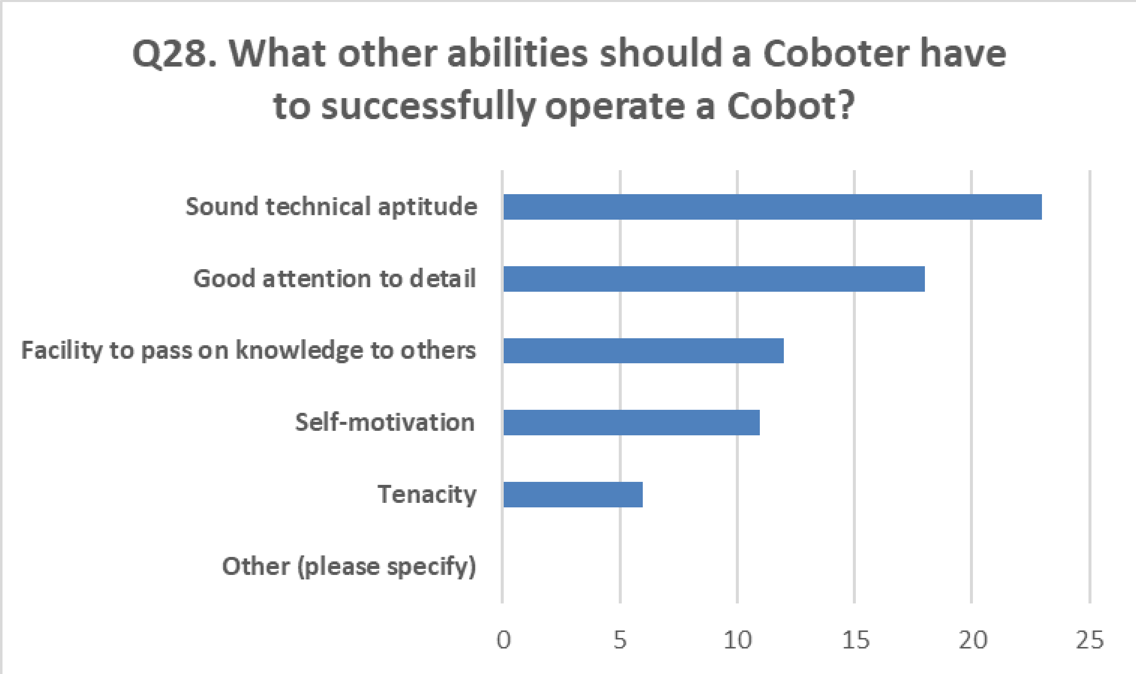


Q27. To what extent, in your opinion, do Coboters require post Leaving Certificate education to successfully operate a Cobot?

An advantage	**11**
Instrumental	**5**
Moderately beneficial	**4**
Slightly beneficial	**4**
Not at all	**2**
Other (please specify)	**1**
Total	**27**

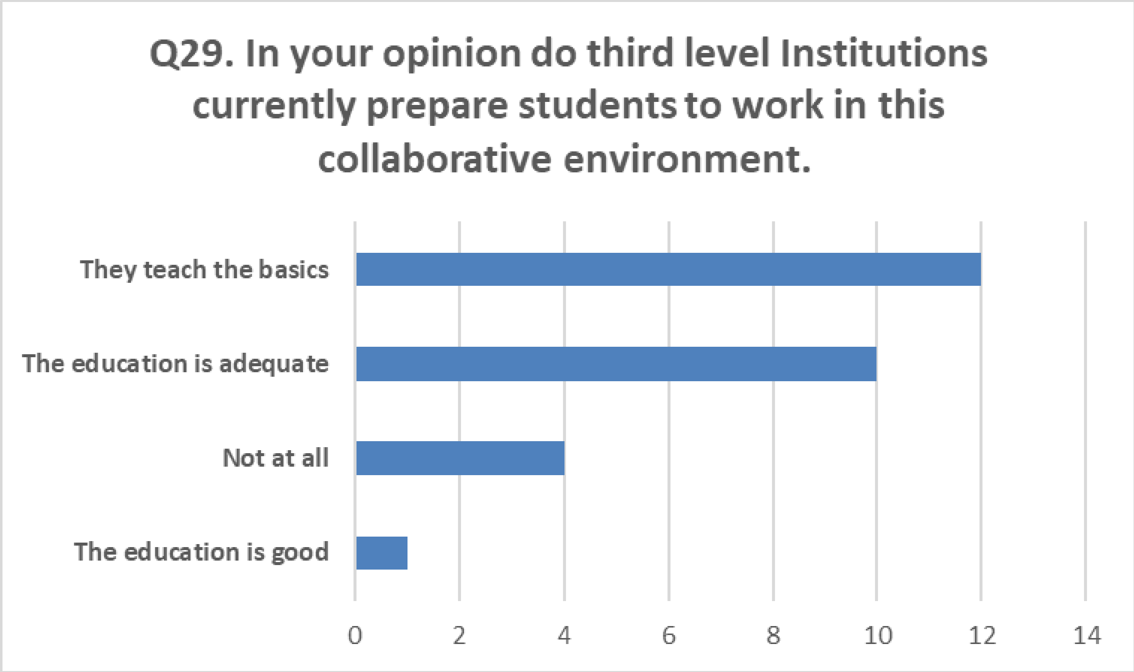
Other categories

Too early to make an assessment of this



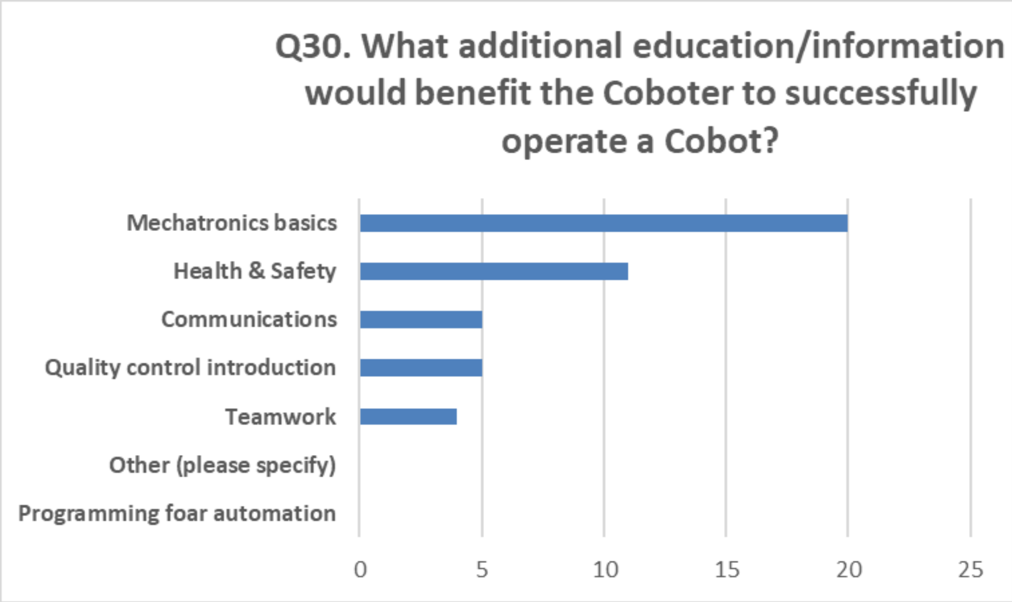
Q28. What other abilities should a Coboter have to successfully operate a Cobot?

Sound technical aptitude	**23**
Good attention to detail	**18**
Facility to pass on knowledge to others	**12**
Self-motivation	**11**
Tenacity	**6**
Other (please specify)	**0**
Total	**70**



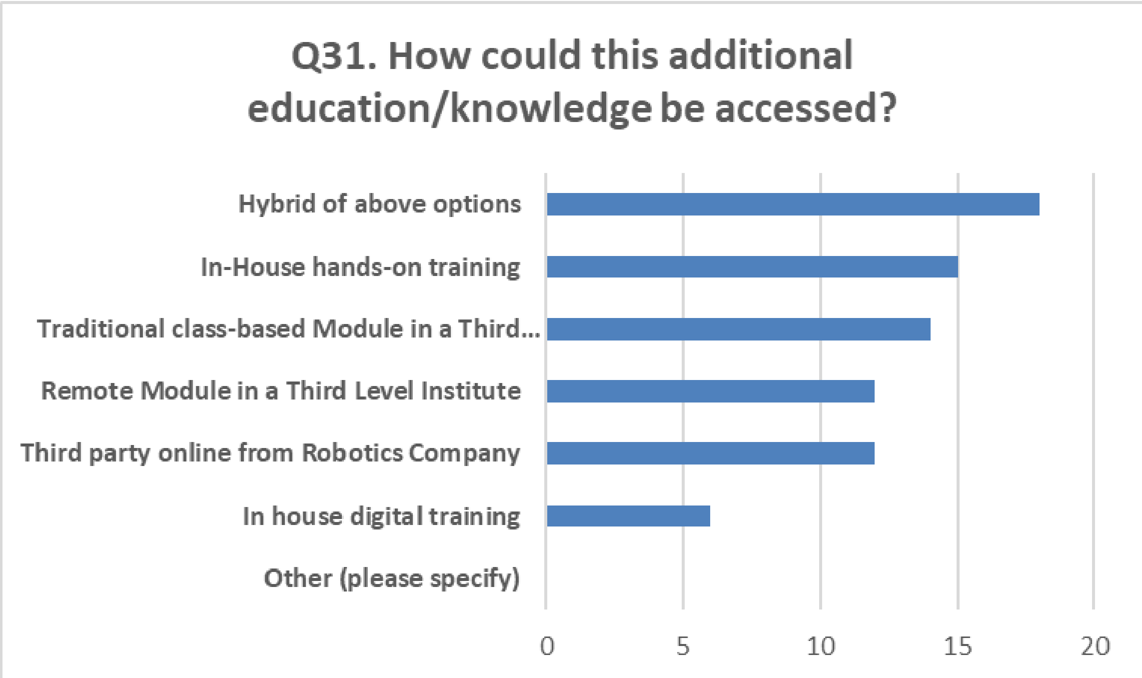
Q29. In your opinion do third level Institutions currently prepare students to work in this collaborative environment?

They teach the basics	**12**
The education is adequate	**10**
Not at all	**4**
The education is good	**1**
Total	**27**



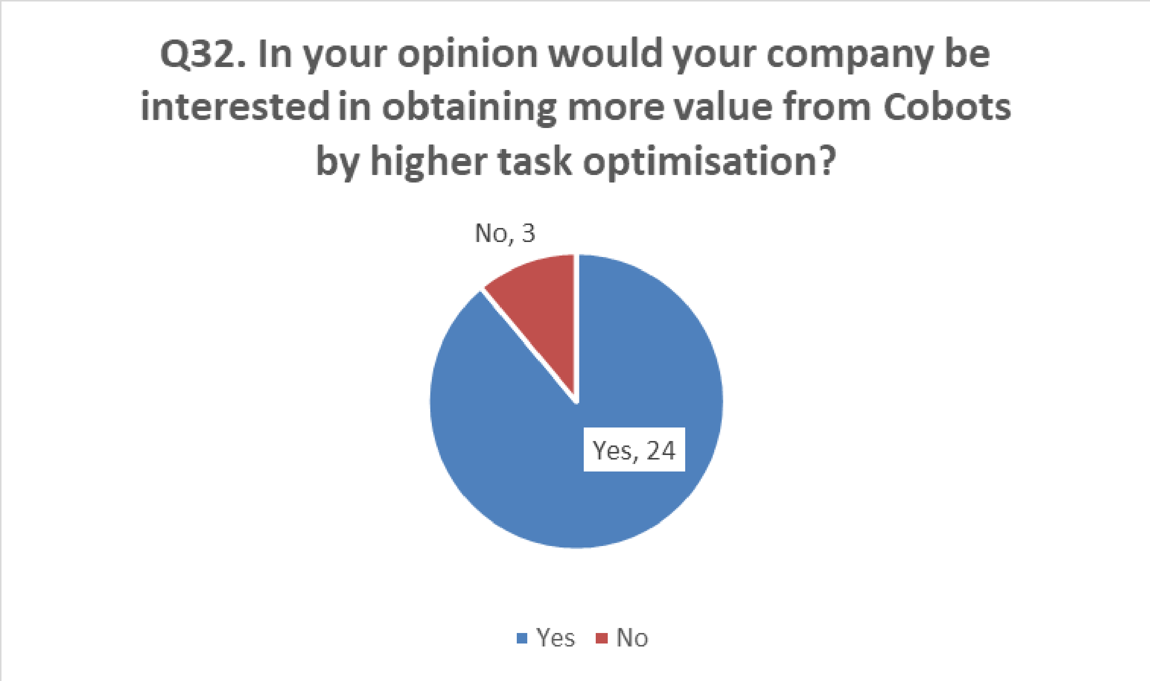
Q30. What additional education/information would benefit the Coboter to successfully operate a Cobot?

Mechatronics basics	**20**
Health & Safety	**11**
Quality control introduction	**5**
Communications	**5**
Teamwork	**4**
Programming foar automation	**0**
Other (please specify)	**0**
Total	**45**



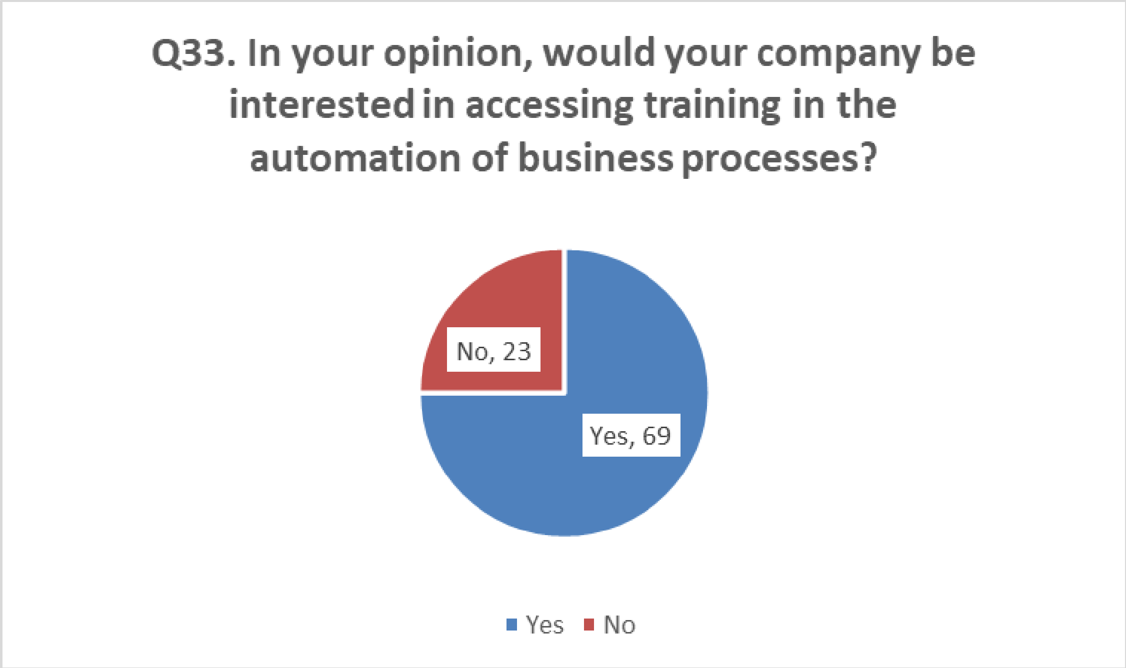
Q31. How could this additional education/knowledge be accessed?

Hybrid of above options	**18**
In-House hands-on training	**15**
Traditional class-based module in a third level Institute	**14**
Third party online from Robotics Company	**12**
Remote module in a third level Institute	**12**
In-house digital training	**6**
Other (please specify)	**0**
Total	**77**



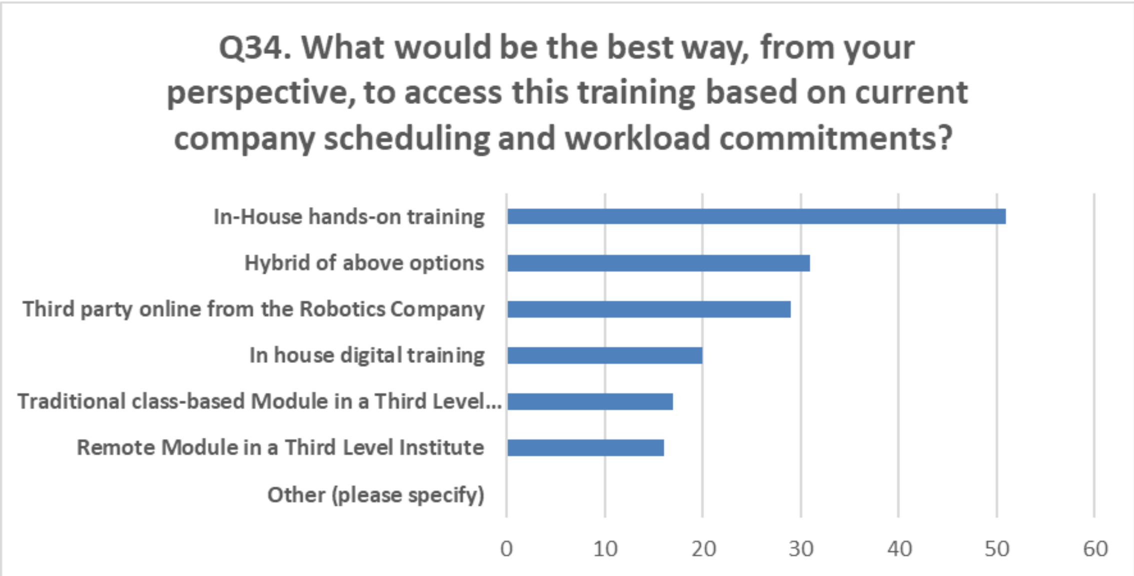
Q32. In your opinion would your company be interested in obtaining more value from Cobots by higher task optimisation?

Yes	**24**
No	**3**
Total	**27**



Q33. In your opinion, would your company be interested in accessing training in the automation of business processes?

Yes	**69**
No	**23**
Total	**92**



Q34. What would be the best way, from your perspective, to access this training based on current company scheduling and workload commitments?

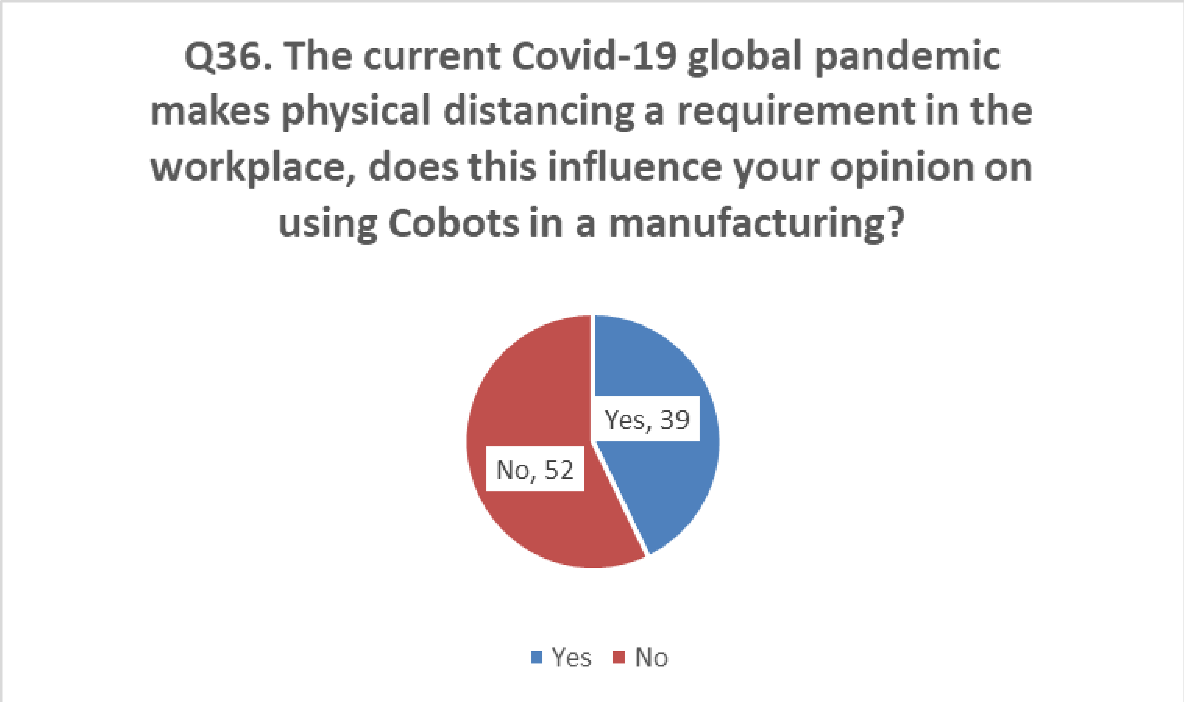
In-House hands-on training	51
Hybrid of above options	31
Third party online from the Robotics Company	29
In-house digital training	20
Traditional class-based module in a third level Institute	17
Remote module in a third level Institute	16
Other (please specify)	0

Q35. In your opinion what would the most important outcomes of this training be?

Skillset to install and program Cobot
To promote autonomy amongst engineering staff
Give us confidence in our abilities to harness Robotics and to develop core skill-set's with machine use
To be fully up to speed in programming and operation of the robot
Wish to use Robotics that are interchangeable for other various work duties
Skill level
Increased knowledge base
Return of investment and confidence that continual PM costs will not be required
Applications to suit company automation
Better understanding
Hands-on troubleshooting
Integrating with current systems, Health & Safety, audits
Accompolished in-house experts able to leverage the potential and stay at the cutting edge. Also, for senior mangers to have the understanding of the competitive advantage and the advantage be realised
Safety and overall knowledge of the system
Full appreciation for the differences between conventional robot and Cobot, including working envelope, safety considerations and thereafter, payloads, etc.
Educational on new possibilities with Cobots
Technical troubleshooting, functionality, integration in the work place and health and safety with respect to the product
Programming Cobots
Potential to improve our site automation
Knowledge gain
Practical skills to help identify opportunities, and skills to implement Cobots where identified
Enhanced technical knowledge and confidence/competence with developing technology with recognition of potential advantages and disadvantages of increasingly smart technology
Understanding the new technology
Increase output/increase yield

To build an in-house team of specialists with access to a high skilled local network
Knowledge of current systems and what is possible to implement in our own factory. Knowledge of operation
How to use robots safely and CE mark equipment with them
Eye opener to people on how Cobots could improve current processes and therefore increase competitiveness of the business
Understanding of when the right time to implement is
Ensuring attendees are SME's on the technology, who require limited support from integrators or OEMS for technical issue resolution.
Increased knowledge
Follow-up support for additional questions after initial training
Using the training to spot opportunities
To better understand Cobots with real situation examples provided to show the benefits
Better qualified staff
Ability to decide where Cobots might be useful and where not
Knowledge and adaptability
To use correctly and safely
Thorough knowledge of the product and competency in usage
Implementation
Knowledge of how technology can be used to provide tangible benefit/improvements to current practises
Increased understanding of Cobots
Expand knowledge of Cobot usage
People are trained up efficiently and with no issues to keep the company work at ease and no issues
Staff capability
Staff awareness
Knowledge and capability
Understanding of when and where to use robotics
Knowledge to invest
Generate a wider understanding of what it is
Understanding of proven robotic use cases, skills required to implement, cost of ownership and maintenance/ life cycle management of equipment and any special skills required
Clear, well thought out understanding of the bespoke applicability to our needs
Feasibility of implementing of the equipment
Understanding the operation/ programming of Cobot
Development of resources who can lead Cobot introduction and on-going support of these systems
Fast programming and operating of the robot after learning the module
Understanding of the setup/operation
Experienced robotic engineers
End uses
Any
Ability to program Cobot
Learn as it is to do.....

Overall competency in robot manipulation
Familiarization and applicability
Understanding of how robots can be used for different applications
Thorough understanding of their actions and decisions
Verifiable technical competency in the subject
Ability to operate the robot safely
Familiarization with capabilities and applications
Understanding of capabilities and limitations of Cobots and time required to teach simple tasks
Awareness
A focused understanding of how robotics can be integrated into manufacturing safely and effectively, rather than just the technical aspect of robotics
Robotic knowledge
Aid in the successful introduction of these machines to the manufacturing process
Understanding of the capability and understanding of the workings
Have gained experience in robot teaching and their perspective uses/ application. Payback analysis
Increased quality and efficiency
Confidence to improve and problem solve
Opening for role in this field
Enough high level knowledge to assess costs for prospective projects
Broad ranging knowledge shared among team. Integration, is it possible and if so do we have the confidence to implement?
Simpler, more streamlined process, using the tech available to the utmost to free people for creative thinking rather than reporting.



Q36. The current Covid-19 global pandemic makes physical distancing a requirement in the workplace, does this influence your opinion on using Cobots in a manufacturing?

Yes	**39**
No	**52**
Total	**91**

Q37. Please enter your contact details:These will be held in strict compliance with General Data Protection Regulation (GDPR)

Note: 83 respondents completed this section. This data will not appear in the research due to GDPR.