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Investigation into The Economic Viability of Industry 4.0 Practices in a Small Start-Up Setting: A Case Study

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INVESTIGATION INTO THE ECONOMIC VIABILITY OF INDUSTRY 4.0 PRACTICES IN A SMALL START-UP SETTING. A CASE STUDY

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Dedication

This work is dedicated especially to my wife and daughters.

I appreciate the support and care you have given me in these past two years and beyond.

It would also not have been possible without the support of other important people in my life such as my parents, sister, and in-laws.

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by

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THESIS

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Abstract

Industry 4.0 has been a hot button topic since the first rumouring’s of a fourth industrial revolution taking place in the early 2010s. Since that time many companies have attempted to transform their process, procedures, and systems to become streamlined, efficient, and overall, more profitable. An example of this can be seen in companies such as Microsoft and IBM, Mitsubishi and Siemens who have gained a stronger foothold in their respective markets by their efficient implementation of Industry 4.0.

Before we can address how small start-up companies can begin to compete with these behemoths, we must address the question; what is Industry 4.0? What is it made up of? Once these questions are answered one can investigate how it has been implemented into industry and manufacturing.

Herein is described the review of the relevant concepts that Industry 4.0 is comprised of their respective uses in industry and how they can benefit manufacturing and production shall also be discussed. An analytical case study of a start-up company will be performed thereby allowing practical examples to be addressed to determine whether implementation is affordable, feasible, and most importantly for stakeholders, profitable.

The outcomes of this study would benefit the company on which the data was collected, by providing them real solutions to issues addressed which are economically viable. It would also benefit other similar companies by providing a framework within which to work in order to either apply directly the methods discussed here or adapt the methodologies used by using a similar method of addressing issues and potential resolutions to them. This work will also benefit the

Industry 4.0 and Smart Manufacturing research world by addressing where implementation has occurred and areas for improvement in the manufacturing world. Furthermore, the current gaps problem areas regarding this implementation are addressed and solutions posited as part of the framework. Areas of further interest and future work is also discussed.

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Chapter 1 Introduction:

Industry 4.0 is a necessary implementation for all forms of industry, from the military to the manufacturing sector, even to healthcare. Part of the reason behind this necessity is the increased pressure and demand on each sector for commodities, resources, and cost-effective delivery of items to consumers[1]. This has put a strain on the global economy and the current supply chain, as well as consumers. The implementation of Industry 4.0 practices in each of these areas hopes to revolutionize the way in which the manufacturing of goods is carried out and delivered to the consumer in order to solve these issues while maintaining stakeholder desires at their heart. Industry 4.0 hopes to act in a similar fashion to the previous industrial revolutions in the way in which a distinct paradigm shift was created between the way in which things were done before and after.

1.1 Background:

Currently the depth at which implementation of Industry 4.0 into manufacturing sector has been adopted is limited with few companies able to really sink their teeth into its implementation and lead changes to the manufacturing landscape. The companies that have been able to more than scrape the surface of Industry 4.0 are heavy hitters in the world of manufacturing and technology and include Honeywell, Intel, and IBM in the USA, Siemens in Germany and Mitsubishi in Japan[2] all of whom have a large source of revenue which allows the ability to increasing efficiency and growth through new ventures. Part of the challenge regarding current global economics is the lack of dynamism some companies possess; this means they are unable to react fluidly to changing markets and resort to partial if not complete restructuring of the company in order to make the necessary changes[3]. Small or start-up enterprises, categorized by the United States Census Bureau and the US Small Business Administration, are companies that have a revenue ranging from $1 Million to $40 Million and up to 1500 employees[4]. These enterprises have a much more difficult time being able to adapt, this can be attributed to their lack of financial stability leading to a rigid approach and an inability to be able to firmly fund many of the necessities that are required in order to align with Industry 4.0 standards. This specifically will be investigated and discussed throughout this work, to show where implementation is possible and feasible. The framework laid out in this work will also serve to aid in small start-up companies which share common constraints with those addressed here, these can include lack of capital to fund relevant projects, lack of indepth knowledge of the given area – outside of market research, and difficulties regarding consistent workforce.

1.2 Motivation:

During my time working for a start-up company, I noticed opportunities to implement current engineering practices which I had learnt of in undertaking this degree. Some of these practices include those acknowledged as Industry 4.0 practices which are further discussed in this work. Although some of these could be fairly straightforward to implement, the Return on Investment (ROI) could be negligible or non-existent, other practices could render more reasonable approaches and they shall be discussed and analysed here. The opportunity for improvement within the company limited the company’s ability to grow with regards to safely securing a greater number of clients or wider variety of contracts from said clients, this was due to the necessity to not overextend the resources available to the company. Furthermore, the opportunities for improvement identified were seen in vital areas such as quality and production – specifically regarding production throughput. Throughput alone is not the only concern of many small or startup businesses, although it is arguably the largest, however others include the current global supply chain issues, which although compounded by issues such as Covid and the war in Ukraine, continue to snowball into a larger and larger issue that many companies will continue to face. Although this will not directly be addressed in the discussion, it shall be mentioned in the literature review as an area of use and expansion for Industry 4.0 practices to aid in solving.

1.3 Problem Statement:

The issue presented within focusses on the data and opportunities regarding my most recent employment at a start-up company and the style of production employed, however the issues addressed, and methods employed also take into account both issues and benefits I have encountered in working in production companies. In some of these cases the methods employed did not maximize the efficiency of employees or the production process, thus limiting the companies' financial security and growth potential. In other cases, the processes were relatively efficient but were looking for ways to grow and develop their efficiency model.

In each of the roles I have undertaken professionally I have seen areas for improvement and have retroactively assessed where improvements could and should be made. Unfortunately, in many of these positions I have not been in the position to affect the kinds of changes required, however in my position at the start-up company I was in a position to closely analyse areas for improvement and drive change.

The issue that is to be address in this work, is being able to suggest and implement more effective and efficient methods of production through the introduction of Industry 4.0 practices into the current production practices within the financial bounds available to the start-up company. This will be monitored through cost of implementation and the potential contribution that the company will see based on these implementations. A secondary challenge is to be able to lay a framework for other such companies to follow in order to implement Industry 4.0 and Smart Manufacturing practices.

1.4 Thesis Objectives:

The objective of this thesis is to outline the different subcategories/concepts of Industry 4.0 and tie together several different literature interpretations of things such as Cyber-Physical Systems, Smart Manufacturing, Artificial Intelligence, and Internet of Things, which are considered integral to Industry 4.0. Furthermore, a data analysis will be conducted consisting of real data collected during my time working as Operations Manager. This data shall be used to suggest potential changes to production methods or implementation of Industry 4.0 practices for the company to be more successful with regards to throughput and financial contribution of the project. The analysis will be used to determine whether the implementation is feasible and acceptable given parameters associated with a start-up company, as well as how successfully Industry 4.0 can be adopted. This work will also address a framework and assess its utility and viability for other similarly positioned enterprises, to be able to adopt some of the practices and strategies – either social, technical or both.

1.5 Organization of Thesis:

This thesis shall be organized as follows: Chapter 1 introduces the motivation, rational, and value of exploring Industry 4.0 methods, tools, and processes for small enterprises, and defines the scope and objectives for this study. Chapter 2 provides background information by; outlining definitions and current implementations of: Industry 4.0, and related concepts including CyberPhysical Systems (CPS), Internet of Things (IoT), Smart Manufacturing (SM), and Artificial

Intelligence (AI). Chapter 3 discusses the scenario of a small enterprise and the challenges identified with respect to the implementations of Industry 4.0 practices. Chapter 4 addresses the implication of these results for similar organisations and for the manufacturing domain. Lastly, Chapter 5 presents a summary of the limitations of the research presented and the future work which could expand the body of knowledge.

Chapter 2: Literature Review

2.1 Introduction to Industry 4.0

Industry 4.0 was a term coined by Germany in 2011[5] and was initially used to describe a process that the country's government wanted to move towards, through changing the way in which manufacturing was carried out in order to maintain their competitiveness in the global marketplace. It has been suggested that this approach was specifically undertaken by Germany in order to maintain their status as one of the powerhouses of the manufacturing sector. This was in part necessary due to the constant need for adaptability in the manufacturing sector in order to keep up with the consumer demand. Because of this and the groundwork laid out by the German government other countries quickly seized upon by this concept and since 2011 have worked towards implementing similar practices into manufacturing. Examples of this include USA, UK, China, and Japan, to name only a few[4].

With regards to the rippling effect of these changes we currently stand on the precipice of a Fourth Industrial Revolution which has been coined: Industry 4.0. This industrial revolution will be characterized by the increase in use, or first seen use of concepts such as, Artificial Intelligence (AI), Smart Manufacturing (SM), Cyber-physical Systems (CPS), and the Internet of Things (IoT) [6, 7, 8, 9], which will be described and discussed later.

Industry 4.0, like all previous industrial revolutions, aims to create a paradigm shift throughout several aspects of human life, most notably that of manufacturing and consumerism. This will be achieved by the increased reliance on machines to take further control of the methods in which goods are created and distributed. Giving the consumer greater freedom with regards to their personal life as well as the secondary effects that Industry 4.0 hopes to improve upon such as quality, speed of production, and aiding with the ever-growing problems associated with the global supply chain[3, 4].

Throughout human history, we have undergone 3 industrial revolutions that have each, in their own way, dramatically changed the paradigm in which goods are made, transported, and delivered to a consumer. Each of these revolutions has been built off the back of the preceding one. The first industrial revolution, beginning in (approx.) 1760 [10, 11] made use of coal and steam to power machines, allowing for a less 'hand-made' production approach to a machine-made production increasing the efficiency and speed at which goods could be manufactured

The Second Industrial Revolution – or the Technological Revolution - came about through the increased use of fossil fuels which allowed for an increase in efficiency of the previously used mass production methods, allowing for such things as the assembly line through the use of mechanical machinery powered by electricity allowing for an increase in production throughput and a decrease in intensive labour required to manufacture.

The Third Industrial Revolution – or the Digital Revolution [8] – began in the mid-late 1900's and involved the implementation of electronics and information technology into manufacturing. This allowed for an automation of many existing manufacturing methods which, as was the case with previous revolutions, increased efficiency, and overall throughput of production in the manufacturing sector thus increasing the speed and ease with which consumers receive their commodities. The digital revolution – as the name suggests – began a movement towards digitization of operations, processes and data collection, although this has developed immensely since the beginning of the digital revolution, Industry 4.0 hopes to capitalize on its advantages – which will be discussed throughout this work.

Table 1 Demonstrating important factors of the 4 Industrial Revolutions[8, 9, 10, 11].

	Industrial Revolution	Technological Revolution	Digital Revolution	Industry 4.0
Began / ended	1760	1850's	1950's	2010's
Enabling technologies	Steam power	Assembly lines Use of electricity	Computing capability – main frames, workstations, etc	Internet of Things, Smart Manufacturing, AI, Cyber Physical Systems
Enabling methodology / way of thinking	Move to machine made, not hand made	Mass production	Use of computers for data management and analysis	To be Determined
Examples of technology	Spinning Jenny	Ford – assembly line	Computer aided manufacturing & design;	Fully automated processes and Smart Factories.
Impact on people	Move to cities & manufacturing centres; deskilling of labour	De-skilling of labour	Reduction in unskilled activities; reduction in repetitive clerical activity	Reduction in labour intensive processes and clerical activity, move to automated data collection.
Economic impacts	Lower cost production; greater efficiency	Lower cost production; greater efficiency	Growth in businesses supplying computers and systems	Unknown

As with the previous industrial revolutions that have changed the very fabric of society, there will be many positives that can be taken from the global acceptance and implementation, including those mentioned above. However, it should also be noted that there are several challenges that Industry 4.0 must overcome prior to being implemented in any sector or any country, and that is the impact it will have on the current workforce, some of the challenges noted were directly identified in the enterprise on which this work is based, and others were developed throughout the literature review of the topic. One of the major challenges that will need to be addressed – especially in order for Industry 4.0 to be widely accepted – is that of the reduction of ‘unskilled labour’ positions, which will be taken over by machine processes, leading to a quicker, cheaper and higher quality production process; a recurring theme throughout each revolution. One of the challenges identified at this point regards the training or reskilling of the workforce, a point at which governments could – by necessity – incentivise. As mentioned, this has been and will continue to be, caused by increasing reliance on machines and progressively moving away from reliance on the necessity for ‘hand-made’ products. This has been compounded by the need to produce more efficiently and have increased volume and quality from the perspective of the consumer.

With these concepts in mind, Industry 4.0 is reliant on the inclusion of such concepts as Artificial Intelligence, Smart Manufacturing, Internet of Things, Cyber Security, Augmented Reality, Cloud Based Storage and Big Data Analytics, some of which contribute to being a CyberPhysical System. How well these concepts are adopted and implemented by manufacturers will dictate the extent at which Industry 4.0 is accepted and utilized. Many of these concepts have overlapping aspects of functionality which combine together to lay the foundation for Industry 4.0, however many of these concepts are in their infancy. This means that there is a significant amount of interchangeability in the usage of terminology throughout the literature[12]. There has more recently been attempts made to clarify these concepts and distinguish them individually, while ensuring that they can still make up part of a whole when applied to Industry 4.0[12].

Industry 4.0 was first mentioned as a concept to the engineering community in 2011 backed by the German government who began, proactively, implementing plans to move to a more sophisticated digitization of manufacturing. Part of the concept for Industry 4.0, according to Schutte [13], comes from the necessity for industry to have strong individualization of products under a highly flexible production process [14], that allows integration of customers and stakeholders into value-added processes. This in particular is a novel concept, as in prior industrial revolutions the aim was towards increased generalization and mass production [14], however a recent shift in consumerism has paved the way for the necessity of companies to address the individual needs of each of their consumers thus driving this concept of individualism of products and their requirements[14]. It has become increasingly clear that companies not only need to adapt to changing demands over a long period of time but be flexible in the short term in how the customer is satisfied and how this is achieved while maintaining or improving efficiency of production overall[15]. Furthermore, Industry 4.0 increasingly shows a pathway towards a distinct shift to intelligent manufacturing as opposed to current, solely automated manufacturing processes.

Industry 4.0 is a dynamic ideology, which depending on the perspective of the user, or the uses, the degree in which each category of Industry 4.0 is integrated can vary. Below one can see

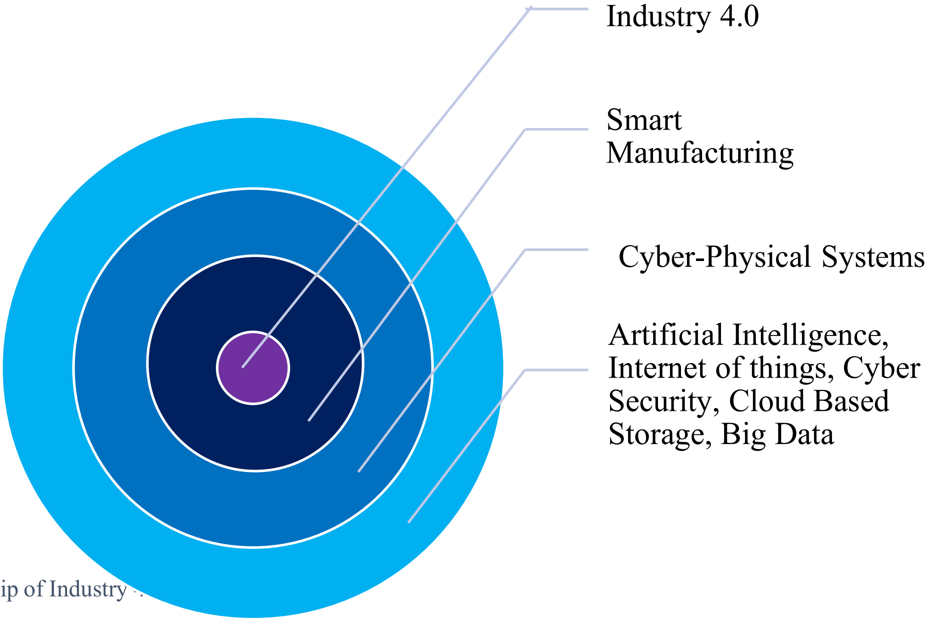


Figure 1 Relationship of Industry

what are considered to be the main contributors to the overall idea of Industry 4.0 and a representation of the relationship they have with one another. In the diagram I suggest that Industry 4.0 is the highest level of the 'system', with Smart Manufacturing at a level lower. This is to show that, for example companies can implement certain Smart Manufacturing methods, but may not necessarily show complete Industry 4.0 adoption unless this is completed uniformly. CyberPhysical Systems are a large part of the concepts that make up Smart Manufacturing and by extension the other facilitating concepts that make up Cyber-Physical Systems.

Each of these concepts of Industry 4.0 show a measure of commonality, therefore the degree to which each are implemented can affect the effectiveness. This shall be further explored, as well as how these concepts have started to be used in industry and the interaction between each concept to allow for complete functionality.

2.2 Smart Manufacturing

The concept of Smart Manufacturing can trace its roots to the same period of time as Industry 4.0, as the widely adopted terminology for the methodology used in the United States when referring to advancements in manufacturing capabilities[7]. An example of a current definition of Smart Manufacturing comes from the National Institute of Standards and Technology (NIST), which states that 'Smart Manufacturing is fully integrated, collaborative manufacturing system that responds in real time to meet the changing demands and conditions in the factory, the supply network and the customer needs.' [16].

Another definition of Smart Manufacturing comes from Wallace and Riddick who state it is 'a data intensive application of information technology at the shop floor level and above to enable intelligent, efficient, and responsive operations.'[7, 17]. Other entities have posited definitions for Smart Manufacturing which cover the same principles as the two mentioned above, others go into a greater length to describe the lifecycle of Smart Manufacturing[18].

Both of these definitions, and the ones not included, address a similar theme in that Smart Manufacturing encompasses many different facets of the manufacturing sector. In the NIST's definition, they focus on the ability to act flexibly on changing demands, whereas Wallace et. al. state that it is data intensive and takes place on the manufacturing floor upwards to allow for efficient operations - this seems more applicable to the general manufacturing operation. Both definitions combine to create a holistic view of Smart Manufacturing with regards to manufacturing planning and flexibility as well as addressing the necessity for changes to be made on the manufacturing floor – where it really counts - and ensuring that one of the most important aspects of manufacturing doesn't get forgotten.

Each of these definitions and much of the literature state the relationship between Smart Manufacturing and the other aspects of Industry 4.0 which are mentioned here such as

CyberPhysical Systems, Internet of Things, Artificial Intelligence etc. are intrinsically linked in order to

work and be implemented[19, 20, 21]. This will become apparent as a recurring theme throughout the concepts of Industry 4.0, that one cannot exist without the other, so not only are they linked through their connection to Industry 4.0 but also through their functionality. This adds more weight to the fact that each of these discussed topics add together to create a wholistic view of manufacturing in Industry 4.0 [22, 23].

With regards to Smart Manufacturing's implementation into the industrial domain, this has been adopted to a low level widely in well developed countries[24]. Asian countries also adopted the Smart Manufacturing approach to Industry 4.0 implementation early on, including Korea and Japan[7], however as noted by Ko et. al., in Korea, who has had great focus on Smart Manufacturing implementation, approximately 80% of the manufacturing companies implementing Smart Manufacturing are doing so at a low level of penetration in their manufacturing processes [25].

One example of why Smart Manufacturing is vitally important for global and nationwide economies can be directly related to the legislation from the US Senate and specifically Senator Shaheen who introduced the Smart Manufacturing Leadership Act. This was a piece of legislation aimed at assisting small to medium sized US manufacturers in adopting Smart Manufacturing practices. This was implemented to ensure that small or medium businesses do not get left behind the goliaths of the manufacturing world. Furthermore, the manufacturing sector has the potential to add $15 trillion to global Gross Domestic Product (GDP) over 20 years and $25 billion in energy savings to companies and individuals, by implementing improvements in automation and control through Smart Manufacturing implementation[26]. However, like any great political legislation, it has moved at a snail’s pace through government and a further press release in 2019 stated roughly the same information as above, however the $25 billion in energy saving prediction had been lowered to $5 billion by 2040[27], a significant reduction of the previous value. The same, or similar, piece of legislation has been reintroduced each year since 2015 by Senator Shaheen and other cosponsors from the senate, however according to Congress.Gov, each year of introduction of this legislation there is no further action, and it is halted in either the House or the Senate [28].

This has therefore stunted efforts to provide the benefits for small to medium-sized businesses in introducing Smart Manufacturing mentioned in the bill. However, in October 2022 a report submitted by the Subcommittee on Advanced Manufacturing Committee on Technology, included ‘Lead the Future of Smart Manufacturing’ and other objectives which will now be backed on a governmental level to ‘grow the economy, create quality jobs, enhance environmental sustainability, address climate change, strengthen supply chains, ensure national security, and improve healthcare. This vision will be achieved by developing and implementing advanced manufacturing technologies, growing the advanced manufacturing workforce, and building resilience into manufacturing supply chains.’[29]. This very recent move by the government to finally back Smart Manufacturing in small to medium enterprises further adds value to the work described herein by providing a comprehensive analysis of implementation strategies of Smart Manufacturing practices and potential framework for use in start-up or small enterprises.

2.3 Internet of Things

As has been iterated, one of the key concepts of Industry 4.0, and thus key to one’s ability to understand and be able to implement Industry 4.0, is the Internet of Things (IoT). The term IoT was originally coined by Kevin Ashton in 1999 [30], and several definitions and variations have been suggested since that time. Some examples of those are ‘The term ‘Internet-of-Things’ is used as an umbrella for covering various aspects related to the extension of the internet into the physical realm, by means of deployment of devices with identification, sensing and/or actuation capabilities.'[31] This definition allows one to begin to understand the way in which IoT is shaping consumerism and manufacturing, in that the mentioned devices have and will continue to be deployed throughout.

Another example of a definition is ‘The Internet of Things is a network of physical objects that are digitally connected to sense, monitor and interact within a company and between the company and its supply chain enabling agility, visibility, tracking and information sharing to facilitate timely planning, control and coordination of the supply chain processes.’[32]. This definition, although focussed on Supply Chaim Management specifically, can be adapted to many different uses thus employed among manufacturing as a whole. It goes a long way in describing where IoT fits into various industries, how it can be utilized and where the benefits lie when implemented. As with the previous definition, some emphasis on the tie in between the virtual and physical realms is noted.

The Internet of Things can be traced back to the use of Radio-Frequency Identification (RFID) as a primitive layer in Cyber-Physical Systems. These RFIDs were used to identify objects and transmit information through a network. Since the 1980’s and 90’s[33], in order to keep up with growing demand, the practice of product identification has undergone several improvements and renovations by way of the technology used and the way in which the monitoring and sending information is carried out[32]. Today the network which identifies, tracks and monitors objects is augmented by the increase in access to reliable internet and secure servers, as well as GPS availability in almost every device, smartphones, social networks, cloud-based computing, and data analytics[32]. These factors combined have increased the capacity at which we can think of IoT, thereby we can describe the Internet of Things as an ever-expanding universe of knowledge.

As will become apparent in a recurring theme of this literature review, the Internet of Things is no different to other Industry 4.0 concepts in that it is dependent on the other concepts to function correctly. This is due to the fact that many of these concepts are directly connected, in the case of IoT specifically with Cyber-Physical Systems (which will be addressed later) by the mutual use of shared data across the platform[30]. CPS would not be able to be considered Cyber if it did not have access to IoT to communicate and gather information outside of internal data collection or human input. This therefore doubles-down on the idea that Industry 4.0 is a dynamic and changing concept as each of the individual facets that make it up also change frequently depending on the technology available to them. This is also true for its implementation and the degree to which it is successful as it may be more applicable in some situations than others.

As described by Xu, He, and Li[33], a typical IoT network includes four main essential layers. The first of which is considered the sensing layer, which integrates physical things, such as the previously mentioned RFIDs – similar to the physical layer in CPS. Secondly there is a network layer which supports information transfer through a type of network connection – this will be similar to the network layer of CPS. The third layer is the service layer which integrates services and applications through a middleware technology. The fourth layer consists of an interface layer to display information to the user and that allows interaction with the system such as Human Machine Interface (HMI) which is also similar to the layers which will be discussed in Cyber Physical System portion of the literature review.

One current use of the Internet of Things - and a possible area of expansion - is Supply Chain Management. This is an area which is of critical importance considering the current political and economic tensions as well as other factors currently limiting the ‘normal’ supply of goods from country to country and even within countries themselves[32]. This can be vitally important in ensuring the correct and safe passage of information from within a company as well as from supplier to client, in order to maintain adequate supplies of whichever commodity is in question.

Another example of industrial applications and uses of the Internet of Things is the use of connective sensors in areas such areas as industrial research and development. An example of this research application is shown in a study conducted on the river Thames in the UK which was aimed at using the level sensing data collected to allow for anticipation of leaks or potential disastrous weather events. According to the results of the study vast savings have already been

seen, although the study is in its infancy[34, 35].

More recently efforts to link IoT with AI have been made in order to bridge the gap between sensors and monitoring and decision making in industrial settings[36]. This will again have significant importance in the manufacturing sector with regards to the machine decision making process, although this may be some way off yet, with AI still in the Machine Learning phase.

2.4 Artificial Intelligence

Much recent interest in industries such as manufacturing, healthcare, and other industrial settings, concern Artificial Intelligence, this is due to the rapid advancement in the area[37]. Currently the scope of Artificial Intelligence and its implementation into these sectors is limited, definitions that have been posited help on ensuring the scope is defined. A very preliminary example comes from Alan Turing, who would question “Can machines think?’ which would then be followed by the determination whether one would be able to distinguish between a human and machine in the responses[38]. A more recent definition states ‘It is the science and engineering of making intelligent machines, especially intelligent computer programs. It is related to the similar task of using computers to understand human intelligence, but AI does not have to confine itself to methods that are biologically observable.’[39]

Although Artificial Intelligence has been a concept since as early as the 1950s and 60s little traction was achieved until much more recently[40, 49]. This can partly be determined by the early thinkers in this area who initially decided to encode rules for everyday simple tasks that humans carry out. However, this became impractical when the scope of conscious and unconscious decision making was realized, they came to learn that throughout any of these simple tasks’ innumerable choices, observations and inferences were made, all which are difficult to express algorithmically [41].

Currently difficulties are present with regards to how AI can properly and consistently perform human operations and learn in order to outperform humans at the same tasks. Due to these difficulties many industries have implemented Machine Learning, which can be considered as Artificial Intelligence Lite. Machine learning is based around the concept of finding patterns in data and using the determined patterns to make predictions[49], this can of course be carried out by humans although the concept relies upon machines to be able to outperform humans’ overtime with these calculations or data analytics. This aims to be able to reduce the dependence on human intensive tasks and free time to be able to work on other ventures for growth and opportunity. Given the current situation of AI and Machine Learning however, this will not be able to avoid human interaction with the data and specifically with the data analysis, interpretation and decisionmaking which will take place after the data gathering and pattern identification that Machine Learning can perform. This is where the gap between the current situation and the ideal situation lies, an opportunity for growth. Machine Learning, although improved upon the current status quo of manufacturing still relies heavily on human interaction, making it a Cyber-Physical System of sorts, Artificial Intelligence would remove human interaction by being able to not only gather data and see patterns, but analyse data, interpret it and make decisions based on it, thus removing even more of the human interaction with that portion of manufacturing[49].

As mentioned, currently Artificial Intelligence is being used in industry to a limited degree, one example of this and the struggles that are encountered is with facial recognition software. This is an area of great interest from government entities and thus has garnered much of the research and funding into AI, however it is far from perfect. Primarily there are issues with how the recognition software works, as the machine is being programmed to 'learn' how to identify different facial features etc. it is reliant on the information it is fed by the programmer. With regards to the facial recognition, this mainly consists of white males, thus it is very good at identifying that demographic but has a blind spot with regards to other demographics[42]. This example exemplifies the current limitations of AI, it must be constantly fed information in order to learn and develop, which does not feasibly work when a vast number of variables is present, however when a small number of variables are present or the data is well organized and large enough, AI/Machine Learning can outperform humans in utilizing the data[43].

Although the above may paint the picture that AI is not useful in the manufacturing domain yet, this is not strictly true as there are many potential uses for it, these include its use in quality inspection utilizing repetitive behaviour to allow for anomalies to be detected, optimizing supply chains by monitoring and managing inventory on a very micro-level compared to humans, an example of this is the use of drone inspections within warehouses[44]. Other examples include advanced robotics in which a custom-built machine performs human actions through learning to imitate human functions – which can dramatically reduce costs over an extended period of time – this concept would require the machine to practice a task to succeed and continually improve to achieve maximum efficiency[45, 46].

2.5 Cyber-Physical Systems

The term Cyber-Physical Systems traces its origins from a National Science Foundation (NSF) workshop held in 2006, with an initiative calling for a 'new generation of engineered systems that are highly dependable, efficiently produced and capable of advanced performance in information, computation communication and control.'[47].

Although the NSF did not posit a definition at that time, one they have produced since states that CPS is 'engineered systems that are built from, and depend upon, the seamless integration of computation and physical components.' This definition helps us to understand the relationship between the Cyber and Physical aspects of a CPS, however it does not state to what extent the Cyber or Physical needs to be integrated, is there a 50/50 split between the two or does one predominate? Nor does this definition give us a hint as to what a Cyber-Physical System should do. Although both of these factors are dependent on the context in which CPS is applied.

Another example of a definition comes from the Institute of Electrical and Electronics Engineers (IEEE) who state 'A CPS is composed of a collection of devices interacting with each other and communicating with the physical world. It integrates computation and communication aspects together with control and monitoring techniques.'[48].

In comparing both of these definitions we can see that they address the very basics of Cyber and Physical components interacting with one another, however the IEEE definition goes slightly further by stating the integration occurs in control and monitoring techniques. This gives us some idea of what the role of a CPS could be once implemented in industry.

In order to expressly and concisely piece together the various definitions of CPS, we must first see how it can be integrated into industry and the functions that it performs. As CPS has been made a top priority issue to maintain US industrial competitiveness[48], the understanding of CPS and its use in industry has begun to become explore. One succinct example of this is the 5-layer approach which was addressed by Ali, Gupta and Nabulsi[49], this approach has been adapted and is demonstrated in the figure below.

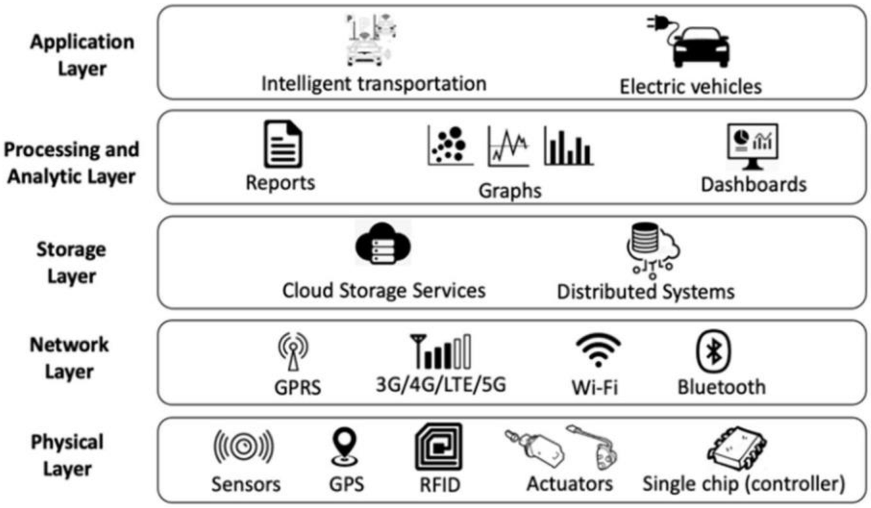


Figure 2 Demonstrating the 5 layers to Cyber Physical Systems[48]

Each of these complexity levels have a degree of usefulness for any business or endeavour looking to implement CPS into its repertoire. The diagram can be read going from the Physical

Layer up to the Application layer with regards to complexity. Almost all levels of industry contain at least a physical and network layer which are essential and can be associated with late technological advances in Industry 3.0.

In order to understand the figure completely, each layer will be broken down and described. The Physical layer relates to the components in the physical space domain. As seen some examples of these are sensors, RFIDs, and chips. These all interact with humans in order to bridge the gap between Cyber and Physical. This layer represents largely the most widely adopted form of CPS in all levels of industry.

The Network layer represents the communication and data transfer channels which facilitate the transmission of data from one source to another, as one can see examples of this are Wi-Fi and Bluetooth. Again, these are tools that are widely available and have been used in industry for a significant length of time.

The Storage layer is the first of the more recently accepted layers to become prominent with the increase necessity for Cloud-Based storage in both a commercial and industrial setting. Commercially these systems are used for convenience by allowing one to back up documents, files, and pictures to be accessed from any connected device to the storage network [50, 51]. Industrially, these systems are useful in sharing documentation through a secure server[50, 52], allowing documents to be worked on by multiple entities at one time, removing the necessity to constantly update or resend updated documents, as well as providing much needed Cyber Security to the domain. This is really the first example in this layer format, that is starting to become commonplace in businesses, but is not universally implemented through my industrial experience.

The Process and Analytics Layer is another example of a layer that is beginning to come to prominence in industry. This layer relies on the gathering of large data sets and the analysis thereof[53]. This process allows for greater information and information processing through Machine Learning (ML)[54] – a precursor to AI - in the decision-making process and allows companies to take risks or make decisions with greater confidence given the data used as well as being able to make decision quicker. This can be a great example of CPS as the Cyber portion will be associated with obtaining and gathering the data, the Physical portion is the analysis and decision-making portion. This area represents an area for improvement and will be expanded upon in this work.

Finally, the Applications layer is the highest and most complex layer presented here. One such example which has the most direct application of CPS is enhanced process control[55]. Another example is with regards to automated warehousing techniques allowing flexible controls using a CPS perspective[56]. These examples represent an aspect of the Human-System interaction of a CPS. This layer is of particular interest in its implementation and adaption into industry as Gurdur et al. (2016)[57] found out, there had been little proof of industrial adaptation of CPS models due to lack of validation and development.

Throughout a literature review conducted by Chen[58] very little of the articles noted concerned the manufacturing sector and in fact only 2 of the papers which were reviewed were related to Smart Manufacturing. This seeming lack of depth of integration of CPS in the manufacturing sector – in a move towards Smart Manufacturing – gives more validation to this work in accessing how CPS – and other Industry 4.0 and Smart Manufacturing practices – can be implemented into the manufacturing domain.

The Process and Analytics, and Applications layers can be seen as the two most important layers of the five due to their relative newness in the domain and the perceived ability of them to add value to the process[58], a point which will be discussed herein. However, this is not to say the other layers are not important and will not be mentioned here.

In this work several of these layers and applications will be reviewed for their ability to be used and adapted to the manufacturing environment with specific focus on start-up enterprises or small businesses.

Another avenue of exploration in the industrial environment would be in report creation which can be generated from information inputted by a user, such as production information like downtime, run time, total production, total scrappage for the day or other information which could be considered Key Performance Indicators. Ideally, for this to be considered a CPS the data collection would be performed by machines and inputted into a report system where the analysis would be conducted in the physical domain, this avenue can also be explored. The application of this to quality control by use of a similar interface to allow for modelling and reporting on quality issues, would help with root cause analysis if the same types of issues were present each time.

2.6 Problems with the Current State.

At present there are many issues with the current state of the above-mentioned concepts and how they play a role in Industry 4.0 in general and how these things can improve productivity, throughput, and profitability of companies. Part of this is down to the little penetration of the social aspects of this kind of revolution. Much of the application interest of Industry 4.0 and the concepts mentioned has been centred on the technical ability and function of the machinery or system to be put in place. However, there has been little acknowledgement into the way in which the paradigm shift can both be brought about through social aspects and with therefore have an impact on the social aspect on professional and personal lives. In the following section this shall be addressed as ways in which to use the social aspect of industry to facilitate a move towards Industry 4.0, as well as the social impacts Industry 4.0 has on working people in order to be included in the framework for other companies to follow.

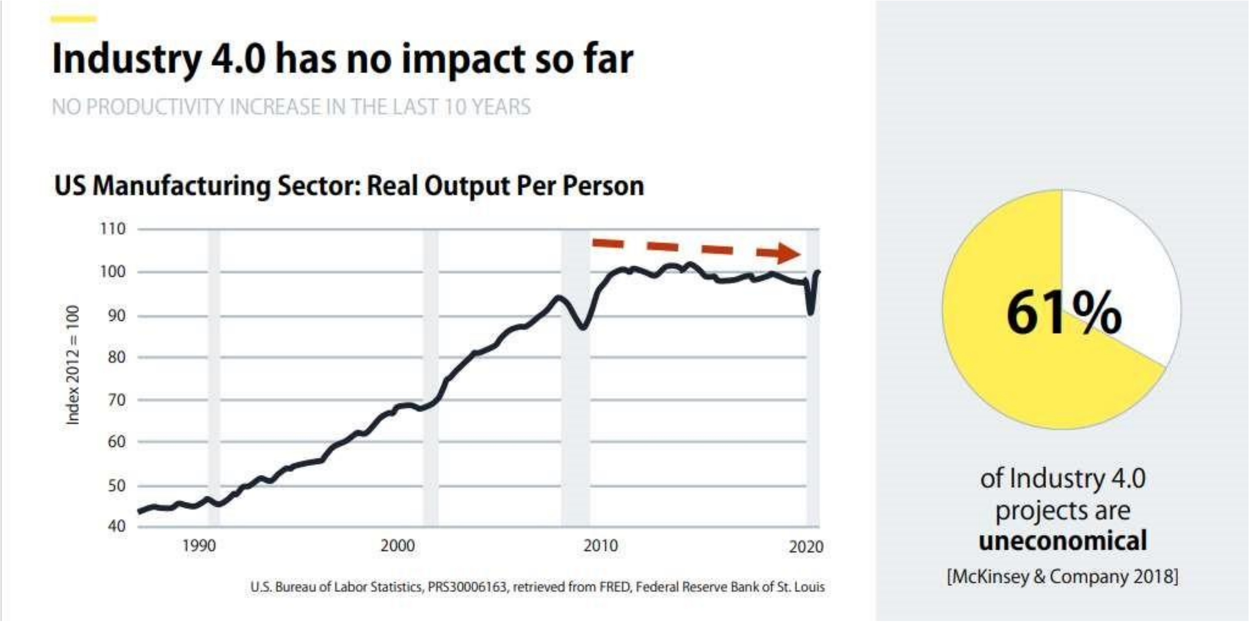
Another major issue which can be seen through the previous discussion is the reduction in the workforce which will inevitably impact the socio-economic lives of individuals whose positions may have become obsolete through the move towards Industry 4.0 and Smart Manufacturing. This issue can be addressed, but cannot be completely resolved, by training and upgrading skillsets of the existing workforce, a move which has been backed by the government in their most recent publication regarding Smart Manufacturing diversification and expansion of the Talent Pool [59].

A further challenge, whose importance is exemplified by the figure shown below (Figure 3), is the ability for companies to be financially able to afford the move towards Industry 4.0 and Smart Manufacturing. The extent of this is demonstrated in the data collected by the US bureau of labour statistics showing an initial plateau then reduction in the 'Real Output Per Person' index since 2012 with a large drop – likely related to Covid-19 – in 2020[60]. This is further compounded by the statistic obtained by McKinsey and Company showing 61% of Industry 4.0 projects are uneconomical[60]. This statistic shows the stark reality companies and individuals are facing in attempting to navigate through Industry 4.0 and Smart Manufacturing with the hopes of allowing for growth and increasing company size, revenue and profitability.

Furthermore, McKinsey surveyed over 800 businesses and determine 3 of the major challenges were regarding finances, organization problems, or technological roadblocks[61]. These with other factors mentioned are shown in table 2.

Table 2 Various problems identified with the implementation of Industry 4.0 practices in the literature review and practice.

Problem Space	Problem	Possible Solution
Social	Being new and inexperienced in the industrial space.	Using company-to-company relationships in order to learn about the industry and be mutually beneficial.
Social	Reduction of workforce due to use of machines to replace human positions.	Potential government wide incentivization of re-skilling and retraining in beneficial areas.
Technical	Requirement for financial stability in order to fund necessary projects to move to Industry 4.0.	Use of company-to-company relationships to allow for potential investment opportunities – a key point discussed.
Technical	Requirement to obtain or consult with a Subject Matter Experts in order to approach the shift towards Industry 4.0 appropriately.	Directly hire someone with a background in this area (like me) or look towards institutions for assistance. This may cause secondary problems including salary or consultation costs that should also be addressed.



Industry 4.0 has no impact so far

NO PRODUCTIVITY INCREASE IN THE LAST 10 YEARS

US Manufacturing Sector: Real Output Per Person

U.S. Bureau of Labor Statistics, PRS30006163, retrieved from FRED, Federal Reserve Bank of St. Louis

of Industry 4.0 projects are **uneconomical**

[McKinsey & Company 2018]

Figure 3 Graphic showing the impact of Industry 4.0 on total output per person in the USA from 1990s to 2020s and a graphic showing the percentage of Industry 4.0 projects that are uneconomical.

This figure further demonstrates a real requirement for a ‘framework’ or blueprint to help guide similarly situated enterprises be able to identify problems, analyse the potential solutions, and be able to implement them in an efficient and economical way. These things will be addressed in this case study to show manufacturers and enterprises a method of introducing Industry 4.0 practices, while considering the social, technical, and financial challenges that are present.

The mentioned framework is shown below in Figure 4. This shows a general thinking which has been adopted and used during this work. This includes aspects of Systems thinking to be applied to the industrial setting.

Figure 4 Framework to be adopted and examined during this work.

The framework shown above demonstrates several of the steps which will be examined here. The first would be to understand the goal or problem with the company or project in question. Defining the requirements in order to address the problem or goal would be the next step in this framework which would demonstrate full understanding and begin to determine what the requirements are for the problem. From there understanding and determining how improvements can be made or problems solved in the industrial space. This would be accomplished by assessing the necessary technology required for this, this is also linked to the previous step.

From there, and a crucial part of this work, is the route into the technologies and assessing how these can be feasibly and viably obtained by the enterprise. The next step would be to identify standards associated with this process. Developing the workforce with regards to new methodologies and technologies would also be a crucial step and finally the implementation of the process addressed in the previous steps into practice. Due to the scope of this work, only the first 4 stages will be addressed and analysed.

Chapter 3: Data Collection and Analysis

3.1 Introduction and Background to Case Study Company

The company on which this work has been based on was a small start-up company consisting of few members of management – below 5 – and a small number of line workers – below 50. The line workers consisted of machine operators, quality control technicians and general line workers. The company had a few different projects during my tenure all of which I contributed during my time there. However, the contract manufacturing portion of the venture is what this work shall be based on and the results that follow. The contract manufacturing entailed filling and packaging of perfumes both Work in Progress (WIP) which was semi-processed and would be sent to be finished at another contractor and Finished Goods (FG) which was a complete filling and packaging project ready to be shipped to distribution centres for sale.

During my time with the company, I was able to identify several areas in which the company could perform more optimally, through the courses I had taken during this degree I knew that changes to the quality, inventory management, and production could have a great impact on the company as a whole. Also, during my time with the company, I began to understand the concepts of Industry 4.0 and Smart Manufacturing and how these concepts may be implemented into the business.

Herein I address some of the challenges that are noted above, as being challenges towards the implementation of Industry 4.0 and Smart Manufacturing practices in businesses, through the use of data analysis which was collected during my time with the company. This analysis will be evaluated to determine whether small start-up companies would effectively and efficiently be able to incorporate these practices into their current model by adopting parts of the framework which is to be laid out.

3.2 Production Process

Below the table (Table 3) shows each position of the production line, the function performed in that position, and the number of people required for that position. Also included are three figures which show a visual representation of the production line that was implemented, and which will be referenced in this work. For ease and understanding each important location or function has been allocated a letter that denotes the function carried out at that location. This has been included to allow visualization and understanding of the types of issues currently faced in production as well as the location at which any implementations take place which will aid with regard to understanding the effectiveness of these implementations.

Table 3 Positions of the production line.

Production Label	Function	Number of employees required
A	Legal Label – Here the legal label is added to the bottom of the bottle. This contains legal information such as minimum quantity.	4
B	Staging area for bottles to be ink-jetted.	1 Floater from A
C	Ink Jet – The bottom of the bottles is ink-jetted with the lot code required for the bottle.	1
D	Carousel – Labelled and ink-jetted bottles pending filling.	1 Floater from C
E	Totes – This denotes the place in which the totes were staged which provided the perfume	0
F	Vessel – This denotes the pre-fill vessel, the intermediate between the tote and filling	0
G	Filler – This denotes the filling machine where the perfume bottles are filled. This can be adjusted depending on the necessary fill volume, however required frequent calibration to ensure correct fill volume. Could only fill 4 bottles at any one time.	1

	Time limiting location	
H	Conveyor belt – This was the conveyor belt; at point H the bottles would have the perfume crimp and actuator placed in position ready for crimping.	2
I	Crimping – This was where the pump and actuator was crimped onto the bottle to activate the actuator and allow for proper use. This was deemed a critical control point.	3
J	Folding Cartons – This is where the Finished Goods folding cartons were assembled prior to the finished bottle being placed in them. This was a very labour-intensive section due to the time required to make the carton vs. using.	4
K	Boxing – At this point the finished boxes were assembled with the finished bottles placed inside them.	4: 2 Workers 2 QC Technicians
L	Second Lot Code – At this point a second lot code was applied to the box in the same manner and design as the first.	0

M	Cellophane – This would wrap the finished box with cellophane ready for sale. Many issues were encountered here due to the necessity for a tight seal around the product.	1
N	Conveyor – Taking the finished, cellophane wrapped items to the packaging area	1
O	3-Pack Boxing – At this point the boxes were placed in 3 pack shippers.	1
P	Shipper – This was the final stage where the 3packs would be placed inside a master shipper which was placed on a pallet and ready for distribution.	1

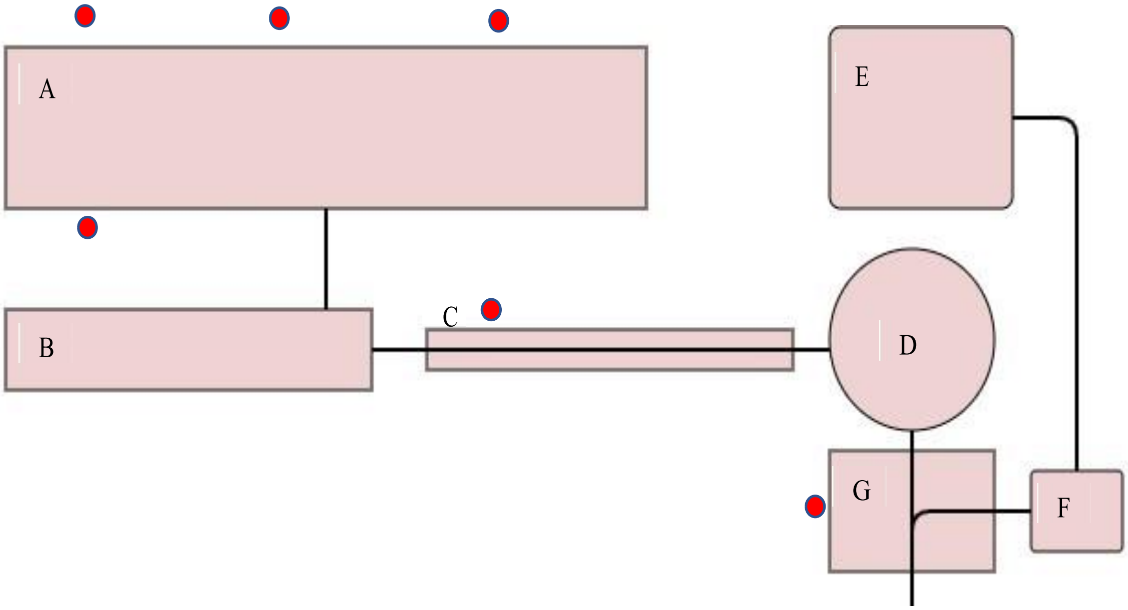


Figure 5 Representation of the perfume filling process, up to bottle filling.

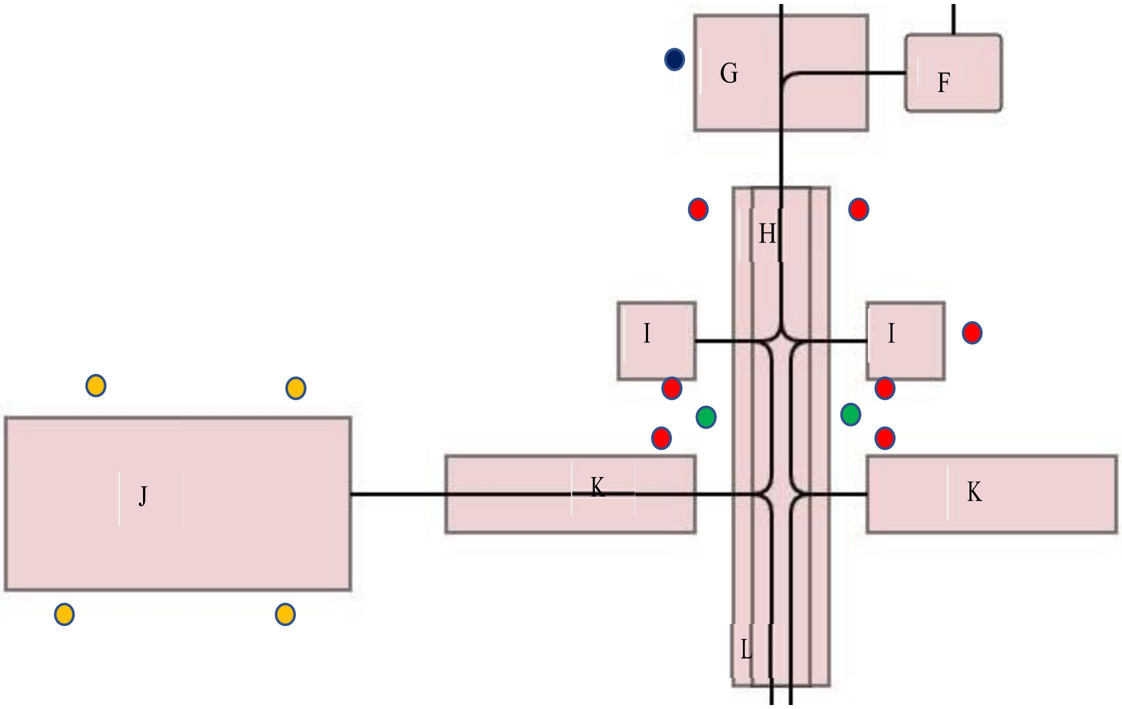


Figure 6 Representation of the perfume filling process from bottle filling through to second lot code.

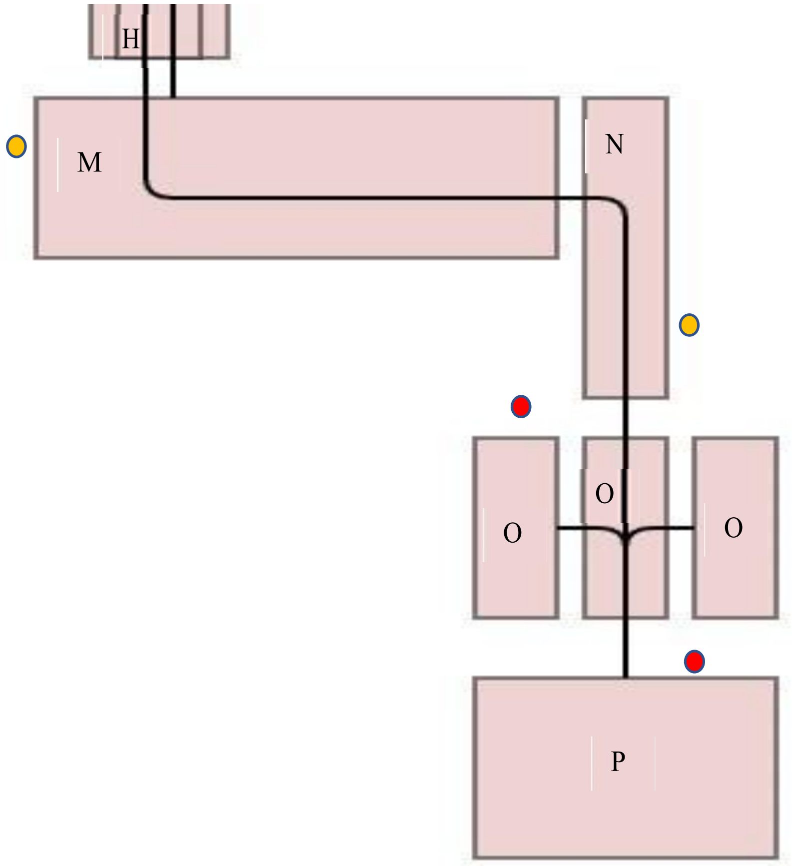


Figure 7 Representation of the perfume filling process from second lot coding to palletizing.

The red dots represent the number of workers assigned to each specific area that are required whether the product being produced is Work in Progress (WIP) or Finished Goods. Those in Blue represent repeat workers between the Figures for ease and to ensure they are not double counted in the head count. Those in green represent the Quality Assurance Technicians that operate on the line to ensure quality as well as perform the quality tests. The orange dots represent those that are required for only the Finished Good product.

🔴& 🟢	Work In Progress: 17 Workers required
🟢	Quality Personnel: 2 Workers
🟠& 🔴& 🟢	Finished Goods: 23 Workers required

As the table above shows, the two types of products that were produced using the above setup were Work in Progress, which was a partial filling and would be shipped to another location to complete the packaging process. From experience, this is a common strategy for large distributors allowing them to maximize efficiency and reduce costs through logistical manoeuvring. The Work in Progress item that we produced for example, was to be completed by a separate contract manufacturer, which although the reason was not shared with the company, was likely due to labour costs, or distribution capabilities, the closer to a central distribution point one is, the lower the freight costs.

The Finished Good was the complete filling and packaging of the product which would be sent directly to distribution to send to stores for sale. As can be seen the Finished Good product required a larger workforce and was subsequently more expensive to produce.

The above number of workers shall be referenced throughout this analysis and be used in both costs for the workers and savings by utilizing Industry 4.0 practices and thus removing them from the production line and savings associated with that. This shall account for part of the analysis that will be conducted and demonstrated in the following sections.

3.3 Cost Analysis of Amortization

In this section I will address one method of optimization of the production line through the use of a more advanced Cyber-Physical System. I will explore how companies can position themselves in the social space in order to explore these kinds of options, where the limitation and benefits lie in employing the discussed technique in the framework that is being laid out.

Below is a table of real data taken from a 20-working day production run during April. The data presented was gathered throughout the production run in order to inform the client on the process of production so they could monitor our progress, make suggestions, or pressure production to more comfortably meet their demands. This data also became valuable with regards to internal monitoring of production, however there was again opportunities for improvement in this area.

Table 4 Production information from the 20-day production run.

Total Units Produced	Total Workers	Cost of units	Gross of units	Cost per unit
2146	14	$ 2,278.00	$ 1,841.27	$ 1.06
2945	15	$ 2,398.00	$ 2,526.81	$ 0.81
2567	14	$ 2,278.00	$ 2,202.49	$ 0.89
2485	15	$ 2,398.00	$ 2,132.13	$ 0.96
2478	17	$ 2,638.00	$ 2,126.12	$ 1.06
3287	16	$ 2,518.00	$ 2,820.25	$ 0.77
3879	18	$ 2,758.00	$ 3,328.18	$ 0.71
4210	18	$ 2,758.00	$ 3,612.18	$ 0.66
4187	18	$ 2,758.00	$ 3,592.45	$ 0.66
5176	22	$ 3,238.00	$ 4,441.01	$ 0.63
3964	21	$ 3,118.00	$ 3,401.11	$ 0.79
5684	22	$ 3,238.00	$ 4,876.87	$ 0.57
5521	19	$ 2,878.00	$ 4,737.02	$ 0.52
5974	22	$ 3,238.00	$ 5,125.69	$ 0.54
5638	20	$ 2,998.00	$ 4,837.40	$ 0.53
5948	21	$ 3,118.00	$ 5,103.38	$ 0.52
6108	21	$ 3,118.00	$ 5,240.66	$ 0.51

6220	21	$ 3,118.00	$ 5,336.76	$ 0.50
5478	22	$ 3,238.00	$ 4,700.12	$ 0.59
4791	19	$ 2,878.00	$ 4,110.68	$ 0.60

In analysing the data one of the first points of note is the average daily completion of 4434 finished units for the time period that was measured. In viewing trends in the data, part of this can be attributed to the low numbers of workers at the beginning of the project and fluctuating numbers throughout the production run, with an average employee turnout of 19 for the 20 working days used. The low production numbers directly impact the net contribution for the number of units completed. The labour cost is a constant, unless there is a fluctuation in the number of workers. Some of the other costs are variable dependent on the number of total units produced, however this is noted to be negligible, therefore it will be accepted that an increase in production would increase the overall contribution for the company in a linear fashion.

Another factor that can be used to explain the production numbers at the beginning of a production cycle is the necessary training of employees in the Good Manufacturing Practices (GMPs) of the company and those required by the FDA. Ensuring the workers became proficient at their job was also a factor in speed of production.

For transparency, the value for cost per unit includes, the workers hourly salary, management salary, and the incidentals that were included in the project and key to production. As mentioned, these factors follow a linear pattern meaning once the cost has been met anything above will contribute to the overall contribution for the company.

The data demonstrated that the total throughput volume was not optimum for the production process being carried out, this meeting and surpassing the minimal threshold for contribution was limited. This would have a compounded effect on the business as a whole by drawing reliance from other aspects of the business and removing confidence in either the project or the project strategy. This would also cause restrict any expansion possibilities in this area which would first need to be stabilised prior to any growth.

At this juncture, a multifaceted problem has been identified, and as stated throughout a discussion and potential framework into how best to approach this issue from an Industry viewpoint will be suggested. Specific focus on how one can increase production potential without further overhead, sacrificing quality, or overextending the reach of the company.

One potential answer to the above problem is the implementation of more advanced production equipment, paving the way for a movement to Smart Manufacturing through use of equipment containing such things as CPS. The equipment which was identified to assist in the process would include reduction human involvement in the process, the ability to record and gather data, send reports based on the data to selected users, and in doing so, monitor the critical quality aspects of the production process. Furthermore, the equipment would have a higher potential throughput for the process than was currently in use. Although this type of equipment has many benefits within the context of the production process, and within this work, it is not without its drawbacks. Firstly, the machinery is an expensive asset to outright purchase, and due to the situation with interest on bank loans this option was deemed inappropriate for the company at its current situation. Secondly, how would this affect the number of workers in the social space – implementation of this type of process would reduce staff in a difficult economic period or require specialized training to remain relevant in the process. Another factor that was presented was how would this type of machinery be relevant to this work in introducing Industry 4.0 practices into manufacturing and production?

Regarding the latter question, the machinery proposed would allow a move towards Smart Manufacturing and be an example of a Cyber-Physical System by virtue of collecting and processing data as well as relying on input from external entities with regards to the type of data required, modes and adjustments to the machinery, and the analysis and utilization of the data. Another of Industry 4.0’s categories that is met through this proposed implementation is that of the Internet of Things, specifically with regards to the previously discussed Network Layer by way of transfer of data and information, as discussed in section 2.3 there are many similarities and points of overlap between CPS and IoT.

The second challenge would act as a double-edged sword as reducing the total workforce would be good for reducing the overall costs of production and maintaining consistency. However, it does throw another issue into the equation as removing people from the workforce during an economically difficult period cannot be taken lightly, this is especially prudent in start-ups or small companies where individual workers bare relatively more weight. This is however a sacrifice associated with moving towards a more advanced process as has been seen previously, the workforce is reduced and is required to advance their skillset.

The first issue can be addressed through a cost analysis regarding production prior to and after obtaining the machine. Amortization of the equipment will be used as a viable example. There are several reasons regarding this approach which can be made applicable to other industries and contract manufacturers. Firstly, as mentioned above, loans for any entity are currently less viable with interest rates, this would put added pressure on the company to succeed through necessity and could put undue risk on the senior leadership and the company itself. In addressing amortization with the client, we were working with for large ongoing projects, many forms of positive feedback were provided between members of senior leadership. This was favourable on the side I operated as it would not require great capital expense from the company. From the other side we gained positive feedback due to the willingness to take on large projects with the potential for large quantity throughput, a positive relationship between the senior leadership team and the favourable area in which the contract manufacturing would take place (El Paso) allowed for this to be a viable option for both parties. In particular the location of the contract manufacturer was of interest, this was likely due to several factors including cost of labour, availability into surrounding markets, and transportation routes.

The proposed machinery had been quoted at $150,000, including installation and a certified technician during the beginning phases of use, this was dependent on the length of time someone was required to be assist until a line worker could be assigned as a machine operator. Below is the data gathered from both the current mode of production, and the production potential once the machinery was implemented. In order to correctly quote the machinery, ensure it could carry out the necessary function, and determine potential throughput an in-person visit from the manufacturer took place. It was then determined that the required machinery had a production throughput potential of 10,000 units and would be able to perform filling, crimping, and capping of the perfume bottle, which were identified as the ‘bottleneck’ areas in the production line. This would reduce overhead by 6 people thus significantly reducing production costs. This data was tabulated and demonstrated in Table 3.

The data represented shows the comparative cost for the updated production model introducing the Cyber-Physical system discussed. Although the manufacturer stated a throughput potential of 10,000 units per shift, a conservative estimate of 6000-8000 was used in the analysis in order to account for any difficulties operating the machine initially, other sources of downtime and to ensure optimum productivity was achieved.

Table 5 Total production values for a 20-working day period.

Units Produced	Total Workers	Cost of units Produced	Gross of units produced	Contribution	25%	Cumulative Contribution
2146	14	$2,278.00	$1,841.27	-$436.73	-$109.18	-$109.18
2945	15	$2,398.00	$2,526.81	$128.81	$32.20	-$76.98
2567	14	$2,278.00	$2,202.49	-$75.52	-$18.88	-$95.86
2485	15	$2,398.00	$2,132.13	-$265.87	-$66.47	-$162.33
2478	17	$2,638.00	$2,126.12	-$511.88	-$127.97	-$290.30
3287	16	$2,518.00	$2,820.25	$302.24	$75.56	-$214.74
3879	18	$2,758.00	$3,328.18	$570.18	$142.54	-$72.19
4210	18	$2,758.00	$3,612.18	$854.18	$213.54	$141.35
4187	18	$2,758.00	$3,592.45	$834.44	$208.61	$349.96
5176	22	$3,238.00	$4,441.01	$1,203.01	$300.75	$650.71
3964	21	$3,118.00	$3,401.11	$283.11	$70.78	$721.49
5684	22	$3,238.00	$4,876.87	$1,638.87	$409.72	$1,131.21
5521	19	$2,878.00	$4,737.02	$1,859.02	$464.75	$1,595.96
5974	22	$3,238.00	$5,125.69	$1,887.69	$471.92	$2,067.88
5638	20	$2,998.00	$4,837.40	$1,839.40	$459.85	$2,527.74
5948	21	$3,118.00	$5,103.38	$1,985.38	$496.35	$3,024.08
6108	21	$3,118.00	$5,240.66	$2,122.66	$530.67	$3,554.75
6220	21	$3,118.00	$5,336.76	$2,218.76	$554.69	$4,109.44
5478	22	$3,238.00	$4,700.12	$1,462.12	$365.53	$4,474.97
4791	19	$2,878.00	$4,110.68	$1,232.68	$308.17	$4,783.13

As shown in Table 5, the fluctuation of the workers throughout the period of time that was assessed, was a leading factor with regards to the total number of units that could be produced per shift. Although the relationship between these two values does not always correlate to ‘more people, more production’ that was the general theme when total number of workers dropped below 19. Using the information in the table it can be deduced that, in order to generate sufficient contribution from the production line to be able to purchase the equipment outright, it would take 628 days (using an average contribution of $239.16/day). The use of 25% of the contribution from this project was determined appropriate due to the volatile nature of the company and its various ventures, therefore a significant buffer was required, this mindset can and should be applied to other businesses in a similar financial situation in order to not incur uncalculated risks.

Table 6 Predicted production potential after implementation of the proposed CPS process.

Potential Production	Cost of Production	Gross from units	Total Contribution	25%	Cumulative Contribution	Amortization reduction
6000	$ 2,644.50	$ 5,148.00	$2,503.50	$625.88	$625.88	$149,374.13
6000	$ 2,644.50	$ 5,148.00	$2,503.50	$625.88	$1,251.75	$148,748.25
6000	$ 2,644.50	$ 5,148.00	$2,503.50	$625.88	$1,877.63	$148,122.38
6000	$ 2,644.50	$ 5,148.00	$2,503.50	$625.88	$2,503.50	$147,496.50
6000	$ 2,644.50	$ 5,148.00	$2,503.50	$625.88	$3,129.38	$146,870.63
7000	$ 2,644.50	$ 6,006.00	$3,361.50	$840.38	$3,969.75	$146,030.25
7000	$ 2,644.50	$ 6,006.00	$3,361.50	$840.38	$4,810.13	$145,189.88
7000	$ 2,644.50	$ 6,006.00	$3,361.50	$840.38	$5,650.50	$144,349.50
7000	$ 2,644.50	$ 6,006.00	$3,361.50	$840.38	$6,490.88	$143,509.13
7000	$ 2,644.50	$ 6,006.00	$3,361.50	$840.38	$7,331.25	$142,668.75
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$8,386.13	$141,613.88
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$9,441.00	$140,559.00
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$10,495.88	$139,504.13
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$11,550.75	$138,449.25

8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$12,605.63	$137,394.38
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$13,660.50	$136,339.50
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$14,715.38	$135,284.63
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$15,770.25	$134,229.75
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$16,825.13	$133,174.88
8000	$ 2,644.50	$ 6,864.00	$4,219.50	$1,054.88	$17,880.00	$132,120.00

Table 6 demonstrates the same parameters as Table 5 using the production volumes previously mentioned which were estimated by the manufacturer. This example clearly shows an increase and consistency in the total production potential, with a ramp up over the 20 days to the lower limit of the manufacturer's predictions which would allow for a 'warming up' period. As the proposed machine would remove the necessity for having 6 people (filler x1, pump x2, crimper x3) the cost of production would stay consistent as all changing variables have been removed.

As, in this scenario, the $150,000 machine has been purchased under an amortization agreement, the total contribution towards the amortization is included, again based on 25% of the total contribution from this project. This shows that using the flow of production that was predicted by the manufacturer, the amortization goal of $150,000 would be met in 168 working days giving an ROI of 0.64 years for a 155.6% return on investment over the first year.

Although this information could not be captured and addressed during my tenure with the company, it does convincingly show that if an amortization agreement were to be reached, it would be mutually beneficial to both companies by allowing the increase in production volume. Furthermore, this would be beneficial on the side of the client as they would have a faster and more reliable route to obtaining their product in a more structured timeline, this was addressed as a significant factor in order for them to forecast and plan ahead. The increased volume and consistent throughput would lead to a greater contribution on the side of the contract manufacturer, thus benefitting the stakeholder, this would also be positively impacted by the reduction of total workforce from 23 to 17 due to the implementation of the CPS system. Other by-products of this implementation include the ability to record and report the production numbers provided by the inter-server communication of the machine with cloud-based storage, although this does not definitively provide tangible value to the company, it does add to the ease at which key performance indicators are measured and monitored.

The described process thoroughly shows a positive option of the company to address issues with production and serves as a platform for the framework model, potentially for other companies to follow with regards to understanding the 'social' aspect – creating dynamic inter-company relationships – as well as the technical process through implementation of a Cyber-Physical System. Furthermore, this example shows a close relationship to the framework presented by addressing the goal, defining the requirements to meet the goal, assessing the necessary technologies in order to achieve the goal and determining a viable route into the technology.

3.4 Cost Analysis of Rework

Quality of process and product is paramount for manufacturers and consumers. Therefore, it is an area which requires significant attention and monitoring in order to ensure things that can be controlled are, and to the best possible standards. This therefore is an opportunity for improvement at all levels of manufacturing.

Presented here is an example that would apply to increasing quality control parameters over the production process by implementation of upgraded production equipment, mentioned in section 3.3.

It has become an industry standard practice to have machinery that is able to adapt to many different shapes and sizes for contract manufacturing and filling as the industry as a whole tried to adapt to changing norms and keep up with the Industry 4.0 practices of smaller quantity greater variety. Included in their adaptability, these proposed Cyber-Physical System machines also boast improved quality over the typical operation lines and quality procedures. These typical processes have been present prior to implementation of Industry 4.0 practices; however, this is not always the case.

The quality benefits that stem from the introduction of this type of machinery can also be demonstrated in the following example:

In pursuing contracts for contract manufacturing of perfume filling and packaging the company invested in a ‘filling machine’, which would be used to fill the receptacle with the desired product, as well as separate pneumatic crimpers. This was chosen due to low initial cost and the perceived adaptability these machines would provide the company to quickly adapt to the different needs of the client, allowing for flexibility with regards to small order sizes, without incurring excessive downtime.

During the early stages of production, it was noted that a ‘people heavy’ approach to production, although cheaper in the short term, could and would, cause problems longer term. Part of this was due to the integration of quality procedures into production, primarily driven by the FDA required regulations and the client standards that needed to be met. With regards to the filling of perfume, the quality procedures primarily consisted of leak testing, which ensured that a sufficient seal has been formed during crimping, verifying no leakage at low pressures would occur. This test had to be undertaken by the quality personnel on the line, a factor which could not change. This was regarded as a critical quality control point. However, the steps that were critical to the process such as filling the perfume to the appropriate level, placing the pump, and crimping the pump in place, were all done by line personnel and had the potential to affect the result of the quality checks. This was addressed as an area for change and improvement.

The process became particularly important during the beginning phases of the production process. This initial phase would allow identification of challenges that would pose issues to quality throughout the project. A representative from the contract company would inspect the finished product prior to its release and shipping to ensure their quality standards were met. During this inspection it was noted that a specific batch of units produced contained an unusually high number of defective actuators these units contained the same lot code and so could be identified. The normal specification for the type of inspection performed is 0% in line checks and 0.5% contractor inspection checks if defective product is found an Acceptance Quality Limit (AQL) is performed. Due to the nature and severity of the issue a 100% quality recheck was performed to ensure that the compliance target for the 3rd party client was met.

Table 7 Initial phase production run.

		Units Produced	Total Workers	Cost of units Produced	Gross of units produced	Total Contribution
Lot #	452022-1	2675	14	$ 2,225.50	$ 1,738.75	$ (486.75)
	462022-1	2943	14	$ 2,225.50	$ 1,912.95	$ (312.55)
	472022-1	3876	14	$ 2,225.50	$ 2,519.40	$ 293.90
	482022-1	4218	14	$ 2,225.50	$ 2,741.70	$ 516.20
	492022-1	3921	14	$ 2,225.50	$ 2,548.65	$ 323.15
Cumulative		17633				$ 333.95

Table 7 shows a 5-day stretch of production in which the mentioned incident occurred. Similar metrics were used as in the previous example to monitor total cost for the units produced and the contribution of this project. Emboldened is the defective lot code which was to be subject to a 100% inspection.

In order to carry out the inspection on 4218 units, 3-line personnel were required to recheck each of them using the standard procedure for vacuum checking. This consisted of placing the units on their side and subjecting them to a vacuum of 20mmHg or 0.065mPa of pressure (low pressure) to ensure the perfume did not evaporate and seep from the bottle. This process took the 3 workers 2 days to complete a full inspection. It was found that there was a total of 5% defective units across the sample size giving a total scrappage of 211 units. Using these cost factors, the total cost for the rework totalled $497.15, which included the cost for the workers for the duration and for the loss in revenue from the defective bottles that could not be reworked. This slightly outweighs the total contribution gained for the initial 5 days of $333.95, leading to a loss of
$163.20 over the five-day production stretch.

It was found that one of the causes for the significant defect rate could have been to do with the fill volume of the bottles. During the shift associated with the lot code, on average, the bottles were filled to a greater volume with slightly more outliers than on previous shifts. This was deemed to play a significant role in the defectiveness of the crimping process. Furthermore, this was compounded by the introduction of a new ‘crimper’ during the previous shift and thus an adjustment in the pressure which could be imparted on the crimping process, this was noted and immediately rectified.

Due to this event, implementation of a separate device or machine was proposed, which would be able to better secure the quality of the product prior to the testing and remove the human aspect from the specific portion of production. This would remove some of the variability or inconsistency people bring to the production line, which although is required to some degree, hindered the process at this junction by the inconsistency of production quality. The machine proposed in the previous section which has been highlighted as cost effective through the metrics discussed. This example adds further weight to that argument by not only ensuring the critical control points of the production line are controlled and consistent, but also through the monitoring of separate control parameters measured by the machine. According to the manufacturer this could include the angle of crimp, the pressure applied during the crimping process, the exact fill volume, and the weight of the unit, the proposed unit would also allow for a certain effectiveness with regards to machine learning in being able to identify when products were out of specifications – within their measured bounds – and automatically reject the item.

Unfortunately, this avenue of quality improvement was not pursued, and instead manual adjustments to the critical control points were made which allowed for improved – but not perfect - consistency on the part of the operator. This was done by allowing uniformity across the pressure applied, greater control over fill volume and weight by more strict monitoring, and increased vacuum testing to be able to determine out of specification products quicker, allowing production to react earlier, although this was not using ‘hard’ aspects of Industry 4.0 by implementation of advanced equipment, it was continued advancement in the area of quality through improved documenting and monitoring through manual methods, which falls under the auspices of Smart Manufacturing. Although these changes could and would prove effective it would add more work on to the operators with regards to manual labour processes.

After the point at which the changes were made, no major issues were reported in a quality control sense, which was augmented by the fact that multiple operators had been cross trained on the equipment at the critical control points. Furthermore, these incidents were more closely monitored for quality checks, recorded, and uploaded to a shared storage device for management to be able to view the quality control metrics. This was the beginning of implementing IoT practices in the production and quality process.

In this section, I have addressed another issue which is of universal importance throughout manufacturing in quality and ways in which the costs of quality faults can be determined and addressed, as well as building on the previous sections use of CPS to not only improve on a scale relating to production but also the impact these types of Industry 4.0 practices have on quality as well. Furthermore, I have again used the suggested framework, and extended it to include the quality space and the important role it plays in manufacturing as well as suggesting possible ways of improving and implementing these things in manufacturing. Although I was not able to follow the framework as closely as the previous example, I was able to show another route into addressing the problem without the implementation of improved technology through improved process.

3.4 Improving Efficiency Analysis

Improving efficiency throughout the production process is of paramount importance throughout industry. In the prior situation discussed there has been large focus on human interaction with production. However, improvement and movement towards Industry 4.0 practices cannot only be considered in this domain as there are also a myriad of other factors that can increase efficiency, therefore throughput, within the production domain. Outside of the human aspect in the production domain, improvements can be made to machine processes, by either increasing speed of the throughput of the machine (discussed previously) or by decreasing downtime accrued. Many areas of opportunity for improvement with these factors in mind were identified. One such example is discussed in the following.

As the production process was one of filling, there would always come a point where the fill material – in this case perfume – would run out. This required the line to stop working, several employees remove the empty tote, fit the new one and reconnect it to the production filling apparatus. Although this process seems straightforward, it did become a source for significant downtime. This was exacerbated when the production throughput was increased causing a more rapid use of the fill material, which resulted in changeouts to occur more frequently. This example was highlighted as one which – when addressed - would lead to a significant reduction in downtime.

A potential solution to this issue was the installation of level monitoring sensors which could be placed inside totes that were in operation and the one which would be implemented next, this would enable level monitoring of the tote. The information/data would be relayed to through Wi-Fi to an application enabling monitoring of the level in real time. The sensor could be calibrated to the dimensions of the tote as well as the material inside in order to give and accurate reading on the quantity that was present. This was specifically important due to the nature of perfume, specifically the density and temperature.

Furthermore, the sensor would enable augmentation of the information provided and distribute it to the production and management team through monitoring level through time to allow for usage rate determination, minute-by-minute, hour-by-hour, day-by-day and weekbyweek. This information would be crucial in allowing for production forecasting, and wastage determination.

During the times totes were changed, the average time taken was monitored and on average would take 1 hour. This included the retrieval of the tote from storage and attaching the new one. The proposed sensor would reduce the amount of downtime in production by allowing prior action to be taken rather than acting in a reactionary fashion, ensuring the replacement tote was in place and ready for installation. This would mean the only source of downtime would be associated with the installation of the new tote. Below is the table associated with the cost to production in replacing the tote as was conducted in regular production.

Table 8 Cost associated with changing tote normally

Cost of 1 hour replacement		Number of replacements in 20-day cycle
Cost of workers involved	$45.00	7
Total lost contribution	$543.48	
Stationary workers	$285.00	
Total	$873.48	$ 6,114.37

The above table demonstrates the total cost per change out and the cost associated with the changeouts of the 20 days previously reported, also shown in Supporting Information. The costs associated with the people involved in the retrieval and installation are based on 3-line workers. The contribution lost is associated with 1 hour of no production at a rate equal to that of the average production throughout 20-day cycle presented. Stationary workers are included in this calculation as, although they are not involved in the replacement process, the downtime still contributes towards their paid time.

Below is the updated table in the same format using the same measured data, however the time required to replace the tote is reduced from 1 hour to 45 minutes. This time was associated with locating the necessary tote from inventory and bringing it to the production floor. The time required to change the tote would not be affected by implementing the sensor. The time reduction was determined through the use of trials by having someone constantly check the level of the tote visually from above to allow for close monitoring, once the tote was close to being finished another one would be staged to allow for a quicker transition, although this was not a practical use of the line worker's time, it did allow for determination of the time savings.

Table 9 Cost associated with changing tote using the sensors, a savings comparison is also included

Cost of 45 minutes replacement		Number of replacements in 20day cycle
Amount of people involved	$33.75	7
Total lost revenue	$409.07	
Stationary workers cost	$213.75	
Total Cost over 20 days	$656.57	$ 4,596.01
Saving	$216.91	$ 1,518.37

As the table demonstrates, the overall cost is reduced by $216.91 per changeover by implementing the aforementioned monitoring. Over the of 20-day production period would save $1,518.37. This represents significant monetary savings while only saving approximately 15 minutes of downtime per changeover. This was compounded by the inability to continue production during the lost time leading to the cost of lost contribution. This represents another example of a Cyber-Physical System and utilization of the Internet of Things and how it can be effectively implemented into the production arena.

An important note is the cost associated with implementation. This was investigated and the cost associated with the appropriate sensor for this use ranges between $1,000 - $3,000, to include the previously mentioned monitoring process. The most appropriate sensor system that was found was $2,500 due to the necessity for easy transfer and storage of information. This would include the sensor, display and software to be able to transmit the data to a selected device for monitoring. Due to the nature of the process implementing 2 sensors would allow for greater efficiency as one can be utilized by the current tote in use, and the second would be installed in the tote that would replace, removing the necessity to remove and install the sensor which could become time consuming. This would then recur on rotation. A cost of $5000 is therefore associated with the implementation.

Using the cost of the implementation against the savings per switch and per 20-day cycle, a ROI of 4.34% per switch or 30.37% over the 20-day cycle noted. This would therefore give a payback period associated with 23 total tote switches or a 66-work cycle – 3 months 1 week and 1 day – assuming the same average production numbers. If production were to increase the number of changes would also increase and the payback period would be reduced due to increased savings.

Again, this example represents a simple, effective, and highly feasible method of implementation of Industry 4.0 and Smart Manufacturing practices. The examples used in this scenario are Cyber-Physical System and Internet of Things, which would provide an effective way of improving contribution by controlling downtime associated with production.

Furthermore, as has been a secondary objective throughout this thesis, an additional aspect to the framework has been addressed, that being looking for other alternatives to improving efficiency. Although the primary answer to this is making changes to increase throughput, which has been addressed separately, in this example reduction of downtime – a significant source of time waste – is also addressed and done so in an effective manner. The importance of this strategy was confirmed to me when I moved to another company in which downtime monitoring is part of the regular process, which allows for identification of the sources and plans in reduction, once adopted in an effective manner this has allowed for more efficient production to take place. As with the previous example, the framework addressed demonstrates the ability to evaluate the problem space as well as solutions and technologies available, this example has highlighted the necessity for constant re-evaluation and re-determination of possible routes into the solving of the assessed problem.

Chapter 4: Conclusion

As has been shown herein, there are many feasible ways in which a small start-up company can implement Industry 4.0 practices in order to become more economically efficient, viable and increase the overall contribution of the company, thus adding value to the stakeholder's contribution in the company. The various examples that have been demonstrated in this work include implementation of modes of Cyber-Physical Systems, Internet of Things, Artificial Intelligence and Smart Manufacturing, all which come together to create an Industry 4.0 system. Furthermore, the work shown in each individual section helps create the blueprint or framework any similar small or start-up company can follow in order to make a successful transition into the realm of Industry 4.0 and Smart Manufacturing.

The first example demonstrated here showed how a relatively large investment – worth $150,000 – can be accessible, feasible and implemented through the chosen route of amortization, again, as this option was available to the company due to the company-company relationship which had been built during my time there, this aided in laying the foundation. The method of implementation of this route can vary depending on the communication and relationship between the parties involved. However, in the case addressed here a discussion between the contract manufacturer (us) and the client had taken place – opening the way for the amortization deal. The solution to the problem of production performance – to include throughput, overall contribution, and consistency – was demonstrated to be solved by updating and implementing a machine with CPS, AI, and IoT capabilities, this would be a big step towards creating a smart manufacturing company and aiding in addressing the issues highlighted in the introduction, such as the technical and social aspects involved. As demonstrated, the ROI of 153% for the machine at the capabilities guaranteed by the manufacturer, mean that the implementation is feasible and a large step towards implementation of Industry 4.0 practices is therefore achievable.

The second example presented here doubled down on the above process by demonstrating another area for improvement that the proposed machine would be able to assist in achieving. As per the manufacturer, quality metrics such as weight, fill volume, and crimping pressure would be controlled and consistent, thus removing the inconsistency of human hands in the process. The demonstrated cost analysis shows the cost that had been incurred due to an error in production affecting quality. Again, the cost analysis shows a very feasible method of implementing Industry

4.0 practices adding to the previous mentioned contribution, through another route outside of purely increasing throughput. Although this was proposed during my time with the company, not all of the data was analysed and presented, therefore the approach which was taken was adapting the current production and training operators more specifically on each piece of critical equipment. Further quality checks and a closer monitoring of quality metrics was applied, this was an effective way of implementing quality driven control integrated within Smart Manufacturing into businesses.

The third example again addresses a feasible move towards Industry 4.0 practices by adopting a Cyber-Physical System, to include access to Wi-Fi and internet systems which is associated with IoT. As mentioned, this would bring into play a positive cost saving to provide a favourable ROI. Although separate from the other methodologies in their implementation of machines, this example offers another separate route into increasing contribution through cost savings related to downtime. As mentioned previously, since I have left the role in which this data was collected, I have gained a greater perspective on how important this aspect of increasing a company’s efficiency can be. With this is mind an additional layer to the framework posited here can address the need to look outside of the increase in efficiency can be achieved at other companies looking to implement Industry 4.0 and Smart Manufacturing practices.

The work herein has addressed the need for a reasonable and feasible framework in adopting Smart Manufacturing and Industry 4.0 practices, the need for which was exemplified by the statistic showing that 61% of all Industry 4.0 related projects are uneconomical. The framework addresses the necessity to ensure adjustments using technical, social, and other aspects of manufacturing that would allow for movement to Industry 4.0. I provided several practical options for increasing throughput, improving quality, and reducing downtime. Although these different practical options may not be directly applicable to every small company, the way of thinking and approaching these problems – that make up part of the framework – can allow other similar companies to adopt these practices in how they think about the issues that they face in production and how to address them.

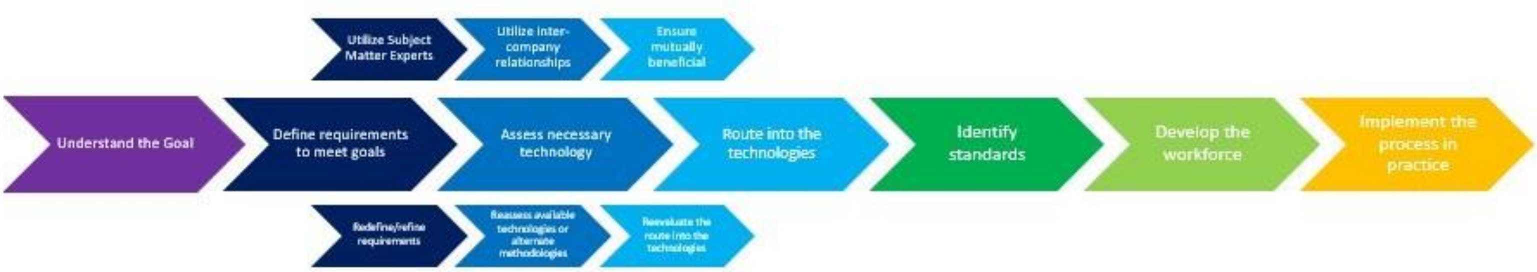


Figure 8 Updated framework addressing the route into Industry 4.0 practices.

The above figure (Figure 9) shows the updated framework to include the various points addressed in this work, to include the necessity to re-evaluate the problem and solution spaces as well as understanding some aspects required in adopting changes while following the framework.

Chapter 5: Limitations and Future Work

During the process of conducting this work there were certain limitations which influenced the information that was presented here. Part of this limitation was due to the availability of data; this was in part due to the time in which I worked with the company and therefore time I had availability to collect relevant data. The second part of the limitations was the access to data which would be able to be used in such a work as this thesis from the company, obviously not all of the data could be presented here and had to be approved prior to compiling and analysing, this meant that certain aspects of the company that would also benefit from a similar analytical review, were inaccessible to be used here.

Other limitations include the scope of which could be included in this work, as many other Industry 4.0 practices could be implemented such as utilization of a cloud-based storage system in order to be able to share and distribute files and information. Although this would aid in the availability of data and understanding throughout the company, this would not have been relevant with regards to one of the core purposes of this work, being to add stakeholder value through implementation of Industry 4.0 practices. This would have been a definite move towards Industry 4.0 but would not add direct stakeholder value and could be included in the statistic of uneconomical project by not increasing efficiency of a contribution producing process.

With regards to future work, I would like to continue to explore areas of continuous improvement where Industry 4.0 is concerned and its implementation to improve processes and increase throughput and contribution. However, since I am no longer affiliated with the company, I would pass these suggestions on to my former employer. I would however like to explore a comparison between my previous employer and current employer with respect to implementation of Industry 4.0 practices. Unless my current employer allowed any form of data to be disclosed this would be a private project.

Although I do not plan on pursuing a PhD where Industrial Engineering is concerned, I will continue to utilize the skills and knowledge I have gained in my time in the IMSE department and hope to continue to grow my career.

Supporting Information:

	Units Produced	Volume Consumed	ml	L	kg	Cumulative (kg)
4-Apr	2146	187.78	214600.00	214.60	187.78	187.78
5-Apr	2945	257.69	294500.00	294.50	257.69	445.46
6-Apr	2567	224.61	256700.00	256.70	224.61	670.08
7-Apr	2485	217.44	248500.00	248.50	217.44	887.51
8-Apr	2478	216.83	247800.00	247.80	216.83	1104.34
11-Apr	3287	287.61	328700.00	328.70	287.61	1391.95
12-Apr	3879	339.41	387900.00	387.90	339.41	1731.36

13-Apr	4210	368.38	421000.00	421.00	368.38	2099.74
14-Apr	4187	366.36	418700.00	418.70	366.36	2466.10
15-Apr	5176	452.90	517600.00	517.60	452.90	2919.00
4/18/2022	3964	346.85	396400.00	396.40	346.85	3265.85
4/19/2022	5684	497.35	568400.00	568.40	497.35	3763.20
4/20/2022	5521	483.09	552100.00	552.10	483.09	4246.29
4/21/2022	5974	522.73	597400.00	597.40	522.73	4769.01
4/22/2022	5638	493.33	563800.00	563.80	493.33	5262.34
4/25/2022	5948	520.45	594800.00	594.80	520.45	5782.79
4/26/2022	6108	534.45	610800.00	610.80	534.45	6317.24
4/27/2022	6220	544.25	622000.00	622.00	544.25	6861.49
4/28/2022	5478	479.33	547800.00	547.80	479.33	7340.81
4/29/2022	4791	419.21	479100.00	479.10	419.21	7760.03

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Vita

Joseph Lindley studied abroad at The University of Texas at El Paso (UTEP) during and exchange program with Newcastle University in 2015, where he completed his Master of Chemistry in May 2017. He since re-joined UTEP in January of 2021 to complete the Master of Science in Industrial Engineering in December 2022. His research interests are regarding uses and advancements in the manufacturing and industrial sector with regards to Industry 4.0.

From embarking on the master's degree in 2020, Joseph has maintained full time employment as well as full time parenting to two little girls. During his time in the degree program, he has benefitted tremendously from the knowledge he has gained and the skills developed which has been shown through pursing better and better opportunities professionally on more than one occasions during this program, which has led him to becoming Assistant Plant Manager at the time

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of this publishing. Joseph will continue to work in the manufacturing sector and use the knowledge and skills in his current position.