

Assignment 2 - Introduction to Industry 4.0 Essay

MSc International Innovation Management MSc Industry 4.0 Advanced Manufacturing

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Introduction

During the late 1700's to the early 1800's, the first industrial revolution began, mechanising production methods with the use of steam power. During this period, the invention of the rotary steam engine by James Watt and Matthew Boulton, resulted in steam power rapidly spreading through industries such as flour, paper and cotton mills, distilleries and iron works (History, 2018). The innovation reduced the dependency on physical labour and sped up production. Later developments in technology created the steam locomotive and steam ship, which were used transport valuable coal to power machines.

From 1870 into the early 20th century, the second revolution saw considerable technological advancements as the use of carbon fuels and electricity as energy sources were developed. Breakthrough production methods were also developed when Henry Ford created the first assembly production line, reducing cost in manufacturing his automobiles, a process that was traditionally carried out from a single workstation (redshift.autodesk.com, n.d.). Ford's process not only increased productivity but reduced costs, with both his business and production line concepts still around over a century later. As productivity soared and new markets were developed, the need for better communication saw the invention of the telegram and the wireless telegram, which made it possible for people to communicate over long distances (Kiger, 2021).

From around 1969, the third industrial revolution formed the beginning of digitalisation. In industry, innovative technologies such as Programmable Logic Controllers (PLC's) and computers paved the way for automated production lines, bringing further benefits to productivity and efficiency. Advancements in personal computers and mobile telephone devices resulted in the transformation of the global communication network. Arguably, the most infamous technology created in this age was the protocol known as Transfer Control Protocol/Internetwork Protocol (TCP/IP). Developed in 1983, TCP/IP revolutionised the way in which information was shared, forming the modern-day internet.

Today changing demographics, globalisation, scarcity of resources, the challenges of climate change and mass customization are the megatrends that challenge the future of manufacturing (Reinharta and Zukunft., 2001, as cited in Prause, 2019). These changes imply volatile, uncertain, complex and ambiguous environments for firms and affect them across their strategic environment (Bauer *et al.*, 2022, as cited in Prause, 2019). Industry 4.0 is the 4th industrial wave of technological advancement (Rüßmann, M et al., 2015) in which new firms adopt new concepts such as digitalization, Internet of Things (IoT) and Cyber Physical Systems (CPS), which play a significant role in transforming traditional companies into Smart Factories of the future (Erboz, 2017). Industry 4.0 concepts allow businesses to gather, analyse and share information, helping increase efficiencies and productivity, reduce costs and improve data driven decision making.

Nine pillars of Industry 4.0 and how adoption impacts SMEs

Many larger firms, particularly in developed countries, are advancing with industry 4.0 technologies. However SMEs, who are described by many as the backbone of economies, face much greater challenges. In 2021 UK SMEs represented 99.9% of the business population, accounting for three fifths of the employment and around half of turnover in the private sector (Department for business, 2022). The sizable contribution to UK GDP alone, highlights the considerable need for SMEs to transition and adopt digital technologies. This paper reviews the 9-pillar model by Rüßmann, M et al. (2015) and explores how Industry 4.0 technologies impact SMEs in smaller countries Fig 1. details the European definition of SMEs.

Company category	Staff headcount	Turnover	or	Balance sheet total
Medium-sized	< 250	≤ € 50 m		≤ € 43 m
Small	< 50	≤ € 10 m		≤ € 10 m
Micro	< 10	≤ € 2 m		≤ € 2 m

Fig1. European Commission definition of SMSs (single-market-economy.ec.europa.eu, 2021)

Big Data and Analytics

Acquiring and using information effectively is critical to how organisations function. Big data is a tool that allows businesses to analyse vast, complex data sets to improve decision making. Compared to traditional measuring and managing methods, which require greater time and resource, big data concepts use algorithms and cloud computing to process and analyse information across supply chains, production and distribution networks. For SMEs, this could reduce time spent on manual test time, data entry and archiving, help optimise processes, reducing costs and increase productivity. Data sets can also be used predictively to identify patterns and correlations. Using customer, supplier and product information, as well as analysing market trends, SMEs have the ability to identify potential problems and opportunities, improving resilience and competitiveness.

The advantages of big data for SMEs are considerable, however there are also challenges that could inhibit firms from transitioning. New technology or upgrades to existing IT infrastructure would require significant investment. Training required to upskill employees could also result in increased costs and the availability of new talent for hire maybe limited for SMEs operating in smaller countries, with smaller industry clusters. Cyber security is also a risk to firms operating large complex IT systems, SMEs will need to protect digital infrastructure against the potential threat of malicious attacks.

Autonomous Robots

Automated robot technology is used to carry out repetitive tasks with a high degree of precision. Unlike early industrial robots, which operated behind machine guarding, advanced collaborative bots are able to operate safely alongside workers. Erboz (2017) quotes “Robots are used in manufacturing industries in order to solve complex tasks which cannot be solved easily by a human”. SMEs looking to increase productivity and reduce costs, automated robots offer an attractive

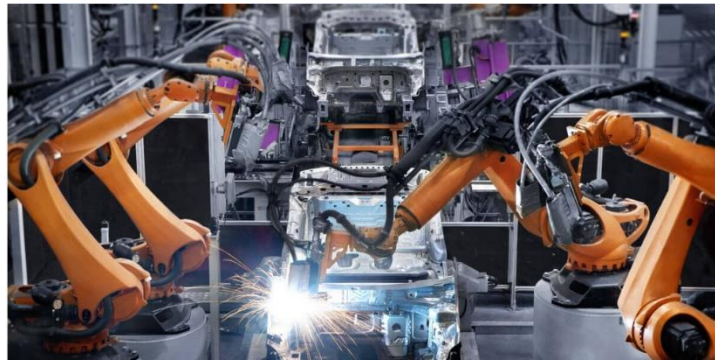


Fig 2. Industrial robot arms in the Automotive industry (www.netscribes.com, 2018)

solution compared to traditional human workers and can help accelerate industry 4.0 concepts. Robots can operate at high speeds, for prolonged periods without fatigue or risk of injury. Operations are not disrupted by sickness or holiday absence and a robot will not deviate from its specific commands, reducing the likelihood of error. Automated robots can be used in a variety of applications from production to logistics and distribution facilities. Robots offer SMEs flexibility within manufacturing environments, reducing the requirement for larger multi-disciplined workforces. Advanced robots can be reprogrammed to carry out specific tasks, are highly manoeuvrable with interchangeable tools such as arch welding heads, suction and claw grabbers.

For warehouse applications, automated guided vehicle (AGVs) provide SMEs solutions in which goods can be transported and tracked via predetermined routes to specific locations, minimizing errors, thus improving inventory efficiency. As with automated robots, AGVs are fitted with safety devices that allow machine to machine and machine to human collaboration, improving workplace safety. Matt, Modrák and Zsifkovits (2021) suggest that autonomous mobile robots are an important part of the smart factory concept, where the transport of materials across the factory floor is required, while avoiding obstacles and identifying pickups or material drop-off in real-time.

Improved machine reliability and reduced maintenance cost could also be expected, as sensors installed in the robots send data to monitoring systems, contributing to big data analytics. This data can be used to create predictive maintenance environments, which identify potential faults and maintenance requirements.

Despite the potential for SMEs to reduce operating cost, automated robotics require considerable investment to purchase equipment and integrate into existing processes. There is also the challenge of finding adequately trained engineers to maintain the machines, a problem that may be exacerbated in countries with smaller resource labour pools. With the acceleration in demand for robotics in manufacturing and the ability to reduce the dependency of larger workforces, trust in the technology may stifle progression within SMEs. A reminder of how successful robots are becoming integrated into industry is within Amazon, who now operate more than 200,000 robots throughout its distribution centres worldwide, while Ocado employs more than 1,000 at a single facility in the UK (Ford, 2021). Although this could be perceived as a good news story for innovation, it may also create negative perceptions toward the technology by workers, as low skilled employment opportunities reduce and as the technology

advances, the encroachment of automation will not be limited to the often low-paying, less desirable occupations, where worker shortages are currently concentrated (Ford, 2021).

Simulation

Simulation in industry 4.0, gives SMEs the ability to use computer modelling to analyse digital representations of physical processes, products or systems. Simulation reduces the risk of testing physical assets. In product development, waste is reduced, as the need for creating physical prototypes is replaced by virtual models. Software allows designers to analyse options such as material type, weight, speed and test using different conditions such as vibration, thermal transfer and loading to identify potential points of failure (Baker Baynes (Pty) Ltd, 2021). For SMEs in smaller countries this could reduce the need for larger R&D testing facilities, as designers replace physical testing with virtual models. Using simulation to optimise and test, against real world scenarios before manufacturing, decreases the likelihood of field errors and recalls. For SMEs this could reduce product time to market and enhance product quality, resulting in increased competitive advantage.

The use of digital twin technology also enables firms to better manage shop floor productivity. A digital twin presents SMEs with the ability to make a virtual representation of the elements and the dynamics of internet of things devices and analyse how it works and operates throughout its lifecycle (IBM, 2017). The digital twin displays real time data and running conditions of physical assets, data can be used to optimise existing production systems, look for bottlenecks or potential faults. Simulations could also be used by SMEs as a training tool. The digital twin offers trainers the ability to interrogate a virtual system and introduce fault scenarios, at no risk to production. As with many other Industry 4.0 technologies, the cost of developing and maintaining simulation concepts may slow adoption amongst SMEs, with other technologies such as System Integration, IoT devices and Big data providing a greater return of investment (ROI) for firms with lesser Industry 4.0 maturity.

Vertical and Horizontal System Integration

For SMEs system integration could be considered as the first step in the industry 4.0 journey, described as 'the Cooperation between machine and internet, machine and person and machine to machine on the chain of value, in real time, is the basis of the production cyber system' (Chukalov, 2017) systems integration is the foundation on which industry 4.0 is built.

Erboz suggests that vertical integration refers to the flexible and reconfigurable systems inside the factory and the extent to which they are fully integrated with each other for achieving agility (Erboz, 2017). Vertical integration spans from procurement, supply chain, manufacturing to logistics and can be understood as the integration of information technologies in IT systems in various hierarchy levels in production and automation equipment (Chukalov, 2017). Vertical data flows help SMEs create interoperability, connecting sensors, IoT devices to Systems Control and Data Acquisition (SCADA),

Enterprise Resource Planning (ERP) and Manufacturing Management systems (MES) that provide 'big data and help create smart factories. Through vertical integration of data and information directly from the workplace by controlling and operating on a production and corporate level (Chukalov, 2017), data is processed, allowing SMEs to gather information about how efficiently equipment or processes are being managed. System integration may be complex and disruptive.

In smaller countries SMEs may face the challenge of training or hiring skilled workers to undertake such a task. The book, *Challenges and Opportunities for SMEs in Industry 4.0* suggested 'one of the biggest problems of SME's related to digitalisation, is the lack of specialised personnel in information technologies' also adding 'most SMEs do not have the skills to operate and maintain their systems' (Ahmad, Iqbal and Halim, 2020, pp.222–223). This may force SMEs to consider costly IT integration consultancy firms to carry out work.

Horizontal integration incorporates external parties such as suppliers, customers and key stakeholders into the ecosystem. Integrating with systems outside their organisation, allows SMEs to share real time data with firms across the value chain, resulting in greater transparency, better planning, communication and reductions in manufacturing time. For SMEs in smaller countries, the acceleration of horizontal integration could be inhibited by the number and digital maturity level of local or regional stakeholders in the value chain and may deliver poor ROI.

Considerable time, resource and investment may be needed as legacy systems, processes and hardware may require updating or replacing. SMEs should assess their IT infrastructure to influence decisions about future effort and investment required. Numerous Industry 4.0 maturity and readiness models, with different perspectives, have been proposed since the term Industry 4.0 was introduced in 2015, Including PwC's digital operations self-assessment for Industry 4.0, which provides a tool for SME's to assess their organisation's current state against maturity model, comprising of four stages and seven dimensions (Matt, Modrák and Zsifkovits, 2021).

The Industrial Internet of Things (IIoT)

The Internet of Things, described by IBM, is the 'concept of connecting any device (so long as it has an on/off switch) to the Internet and to other connected devices. The IoT is a giant network of connected things and people, all of which collect and share data about the way they are used and about the environment around them'. In the context of Industry, McCarthy et al., (2022) defines the Industrial Internet of Things (IIoT) as "the application of instrumentation and connected sensors and other devices to machinery and vehicles in the transport, energy, and other critical infrastructure sectors". For SMEs, especially those in smaller countries, implementation of all pillars of industry 4.0 may not be feasible. The IoT however, provides the means to

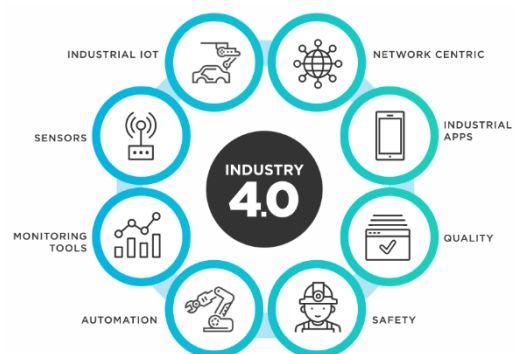


Fig 3. Visual illustration of the IIoT concept (TIBCO Software, n.d.)

communicate data between man, machine and process to decision makers. In a recent study Moeuf *et al.* (2021) found that many experts agree, for SMEs, the implementation of data exploitation technologies such as the of Internet of Things, is key to improving the industrial performance. The study also noted that experts consider the exploitation of data within a company as the first step for SMEs towards Industry 4.0 (Moeuf *et al.*, 2019) and one that reduces the risk of failure, as implementation of IoT concepts progresses.

Hansen ang Bøgh (2020) draw on work by Xu *et al.* (2014) to describe IoT in 4 layers. The first layer is hardware in the form of sensors, which need to be selected for correct application and positioned sufficiently for SMEs to yield relevant, reliable data. The second layer is communication from devices where SMEs could use platform such as OPC-UA, which is designed for industrial communication. The third layer is data bases and interfaces such as the cloud, which store the data produced by IoT devices. Forbes suggest IoT can improve systems and processes, increase efficiencies and could even help create new products, services and business models accordingly and SMEs could benefit from operational efficiency gains, improved safety and cost savings. Manyika et al. (2015) highlights the dramatic difference faced by SMEs to traditional working practises, with the flood of data generated by IoT writing, “for companies to make the most of IoT technology, their organizations must embrace data-driven decision making and capabilities and create environments in which relevant information is made available to the right decision makers in a timely manner”.

The Cloud

The definition of cloud computing by the National Institute of Standards and Technology (NIST) is described as a model for enabling ubiquitous, convenient, on-demand network access, to a shared pool of configurable computing resources (e.g., networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction (Mell and Grance, 2011). Cloud computing plays a vital part in industry 4.0 for firms needing to process, store and analyse vast volumes of data generated by cyber-physical systems (CPS).

For SMEs, the benefits of cloud computing are vast. Traditional physical IT infrastructure comprises of servers, licensed software, hard drives, uninterrupted powers supplies (UPS), security software and a team of IT workers. SMEs are faced with the challenge of hardware obsolescence, server capacity, system failures and the ever-growing risk of malicious cyber-attacks.

Cloud computing removes the requirement for SMEs to design, purchase, install and upgrade physical infrastructure and reduces the number of IT workers needed to support, monitor and maintain systems, thus reducing cost. Cloud service providers offer firms, scalable computer resources meaning SME's are not limited to specific internal server capacity, allowing for expansion and long term strategic vision. Storing large scale data provides less space and cost with Cloud technologies (Ahmad, Iqbal and Halim, 2020, pp.195).

SMEs could benefit from the increased cyber security provided by cloud service providers and could also improve resilience and uptime, as most cloud providers are heavily focused on system monitoring, reliability and preparation for disaster recovery. As SMEs matured with industry 4.0, IoT devices would

operate using cloud computing, to provide access to data without boundaries or time restrictions, improving management and decision making.

The cloud computing approach remarkably decreases the cost of entry for SMEs which are trying to benefit from computer-intensive business analytics that were normally only available to the largest of companies. As SMEs lack the necessary resources and also cannot afford the intensive expenses, Cloud Computing can provide numerous opportunities for them. Moreover, it can enable developing countries through a good cost reduction structure to compete more, in a business world and to propose new IT solutions globally (Ghaffari, Delgosha and Abdolvand, 2014).

Despite the obvious benefits, cloud computing does however still present challenges for SMEs. The full realisation of Cloud Computing is dependent on the availability of high-speed access (Ghaffari, Delgosha and Abdolvand, 2014). For SMEs in smaller countries with poor infrastructure, particularly in rural demographics, this could inhibit progression. Regarding uptime, SMEs planning to rely solely on the cloud provider, should carry out adequate due diligence during vendor selection of providers, to check reliability, security and recovery protocols are robust.

Additive Manufacturing

In traditional design and manufacturing, prototypes were produced using machining methods such as machining, grinding, drilling and casting into molds (Pereira, Kennedy and Potgieter, 2019). The process of subtractive and formative manufacturing is inherently wasteful, this is further compounded with the cost of heavy metal materials used and increased transportation costs to deliver them. Where complex prototypes are required, the use of different machines to produce specific parts maybe required. Once manufactured these parts will also require workers to assemble them. For SMEs, purchasing, installing, maintaining and operating large numbers of machines to produce goods, requires considerable investment and hire of a skilled team. The labour and time intensity of the traditional manufacturing does not only impact cost but could increase product time to market, reducing competitive advantage.

Additive manufacturing uses 3D printing technology, that offers a sustainable alternative to traditional manufacturing methods. Using a single machine, complex designs can be created layer by layer using the exact material required to manufacture the



Fig 4. 3D printer and printed prototype at Duraflex window profile manufacturer

component, something that would be difficult to achieve using subtractive methods. The clear advantage for additive manufacturing vs traditional manufacturing, in terms of environmental impact, is the reduced wastage of material and resource efficiency (Pereira, Kennedy and Potgieter, 2019). SMEs can increase operational flexibility, reduce lead times, reduce inventory, and increase product customisation, improving performance and competitiveness (Onu and Mbohwa, 2021).

Careful consideration is required by SMEs to determine if additive manufacturing is a viable application for their process. High volume mass manufacturing would require large production lines and the high capital investment to create assembly and production lines. Using additive manufacturing does not make it a financially feasible investment for manufacturers (Serope Kalpakjian, Schmid and K S Vijay Sekar, 2018). Pereira, Kennedy and Potgieter (2019) also concluded that current cost models for high production volumes are better suited for tradition manufacturing methods. However, manufacturing or prototyping requiring high complexity or customization, additive manufacturing is better suited. Figure 4 Shows 3D printer used at Duraflex which allows designers to print prototypes from CAD drawings, to see how potential window profiles designs will fit and function. It also allows sales team to show prototypes to customers and make quick modifications without the need for using material that requires long machine times.

Augmented Reality (AR)

Santi *et al.*, (2021) Suggests there are three combinations of realities: AR, Augmented Virtuality (AV), and Virtual Reality (VR).

AR can be summarised as a computer graphic technique where an artificial “virtual” object (CAD model, symbol, picture, writing) is added to a real-time video streaming of the external real environment (Santi *et al.*, 2021). Using devices such as smart glasses or smart phones, AR combines real life environments with virtual objects or information. SMEs could benefit from this technology, in maintenance instruction applications. Santi et al., (2021) suggests superimposed writing and animations showing assembly and disassembly procedures can be useful to solve complex engineering problems by unskilled operators. For SMEs, the fact that every modern smartphone or tablet can execute augmented reality applications, makes the technology much more accessible and a more affordable option to virtual reality, which always requires additional and specific hardware and training (Brassea, 2021). SME’s could also utilise AR, in product development. Virtual product models could be positioned in real world environments to check aesthetics and to verify real-life dimensions. General spacing and layout questions can be answered immediately without providing physical and costly product examples (Brassea, 2021). This could also extend to sales, offering a unique, personal customer experience. An example where this has been used effectively is in the sale of

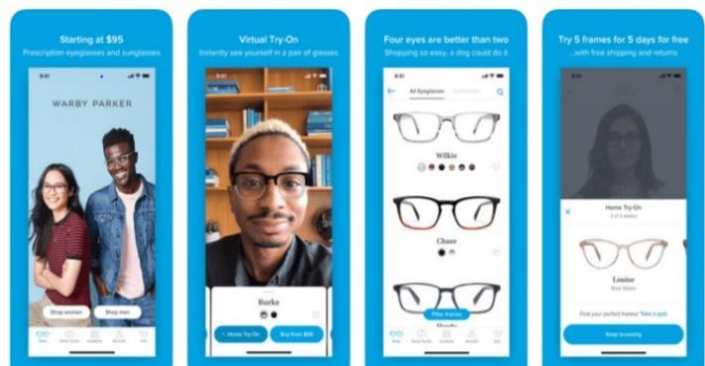


Fig 5. Example of AR spectacle virtual try on application (Kwiecień, 2019)

spectacles, where, using a smart phone, customers can select glasses from a website and visualise themselves wearing the virtual product on their face, removing the need to physically try on at a store.

AV could be viewed as the reverse form of AR, where real life objects are added to a virtual setting. As with AR, product development is an area where the technology could be used to save SME's cost and product time to market. An example of this could be inspecting how a picture of real product such, a piece of furniture could look in different virtual living spaces or office environments this could also be used in sales applications. Another AV use case is training. SMEs could benefit from conducting 'in-house' training



Fig 6. AR hydraulic training rig (Neges, Adwernat and Abramovici, 2018)

using real life machines, which could be created in a variety of virtual settings to suit their working conditions. An example of this is the work by Neges, Adwernat and Abramovici (2018) who created a training simulation using a physical hydraulic circuit in conjunction with AV technology, to modify the environment or object to create different stress scenarios for the trainee such as escaping steam or water, black outs, flickering emergency lights and alarm sounders.

VR immerses the user in a fully virtual environment. The use of goggles or headsets such as Oculus Quest, transports users into virtual setting. Ecorys and Sethet al., (2017, 2011 cited in Amuso, Poletti and Montibello, 2021) write that in product development, designers could visualise 3D or computer aided design (CAD) models, which could increase SME's ability to respond quickly to changing needs in the market and client's preferences. In addition to training and design applications, VR has also proved successful for maintenance teams. Using digital twin technology, SMEs could create digital copies of machines or production lines, displaying real time data for field engineers. Inspections and diagnostic could be carried out remotely to check equipment conditions of help diagnose problems. Digital twin technology gives engineers or Original Equipment Manufacturers (OEM's) the ability to stand in the first person, in completely virtual environments (Santi et al., 2021), mimicking smart factories to interrogate systems remotely from any location at any time. For SME's in smaller countries, especially those with multiple sites, this could reduce the need for a larger skilled maintenance team, as engineers could be shared across sites. This would help decrease the need for larger workforces and reduce field technician travel costs, speeding up reaction time and increasing productivity.

It is clear for SMEs, AR applications have great potential for the assembly, monitoring, and maintenance of machines in smart factories (Ekren, Oberer and Erkollar, 2017). AR can potentially simplify a worker's tasks and improve their decision making by introducing real-time virtual information into their environment (Reljić et al., 2021), nevertheless SME's will incur increased costs in purchasing hardware such as video-See-Through (VST) and Optical-See-Through (VST) Head Mounted Displays (HMDs), software and creation of virtual platforms, as well as marker or marker less technology for tracking virtual objects. Although many studies suggest there are many benefits using AR in a training and maintenance

applications, the dramatic contrast between traditional methods and in AR technology could also prove an inhibitor, as workers embrace to new technology.

Cyber Security

As industry 4.0 continues to grow, the vast number of interoperable, interconnected devices that create today's smart factories, help improve productivity, quality and reduce costs but also pose significant security challenges. Servers, mobile devices, cloud computing and IoT end devices are just a fraction of technologies that add cyber security complexities for SME's embarking on Industry 4.0. Hacktivists, cyber criminals, nation states and inside persons (Eliacık, 2022), are some of the potential bad actors that threaten IT infrastructure. Serror et al. (2020) suggests the seven most common types of attacks targeted against industry 4.0 systems are:

- **Physical attacks** – physical attacks on hardware and infrastructure.
- **Impersonation attacks** – Attacker uses fake identities to gain access or information.
- **Man-in-the-Middle (MitM)** – Attacker eavesdrops on sensitive information.
- **Routing attacks** – Attacker attempts to disrupt communication networks.
- **Malicious code injection** - attacker injects malicious code exploiting a vulnerability, to gain control over the infected device.
- **Data leakage** - Attacker attempts to access personal information.
- **Denial-of-Service (DoS)** – Attacker overloads a machine to render service unavailable.

To evaluate the threats posed by bad actors to their organisation, SMEs could use an 'Attacker model framework'. Serror et al. (2020) write that using this framework firms can formally model different security threats and resulting risks and evaluate the extent potential countermeasures address identified challenges, risks and threats. Potential high-risk factors with industry 4.0 technology include number of interconnected devices, cloud storage and large networks and correct countermeasures such as encryption, firewalls, physical security and data protection measures should be employed by SMEs to mitigate or reduce risk.

Conclusions

The potential opportunities Industry 4.0 technology could bring to SME's operating in small countries is unquestionable. As with all three revolution that came before, the technological advancements industry 4.0 provides will help shape the world for generations to come. Through the use of IoT, Big-Data and cloud

computing, SMEs have the ability to analyse vast data sets helping identify trends, streamline processes and effectively communicate with stakeholders to optimise supply, production and distribution chains. Where industry clusters are smaller and skilled labour and recruitment proves challenging, robotics and automation provide human to machine collaboration that reduce workforce sizes. This technology also helps SME's improve safety, significantly reduce costs and increase productivity. AR, simulation and additive manufacturing provides SME's with the means to improve design and customer experience, with digital design capabilities that are quick to prototype and offer a reduction in waste and improved product to market time. AR and Simulation create digital environments where SME's can offer workers enhanced training experiences and engineers predictive maintenance platform.

However appealing the benefits of Industry 4.0 technologies may seem, it is imperative that SME's first establish what technologies best suit the needs and budget of the business and set aside short term profits for long term sustainability. A staggered approach laying the foundations with vertical and horizontal systems integration, cloud computing along with IoT devices will pave the future innovation. SME's must also consider the effect new technology may have on workers. Correct training and recruitment campaigns will be vital to ensure that employees embrace the dramatic changes in process, technology and culture. "Ultimately the digital transformation will change the way SMEs do business and organizational structures, and those who cannot adapt to change will accelerate and gradually disappear" (Ahmad, Iqbal and Halim, 2020, pp.222–223).

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