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Design for Industry 4.0

MSc Industry 4.0 Advanced Manufacturing

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1. Introduction

The world is currently experiencing the fourth industrial revolution, which is driven by the progress in artificial intelligence, robotics, the Internet of Things, simulations, and other disruptive technologies. This has dramatically affected industries worldwide. During this transformation, design has become critical in creating innovative solutions and business strategies, (Bai, Dallasega et al. 2020a). In this essay, we will examine the manufacturing process failures that a company is currently facing. These issues range from the development stage to the actual production of the products. Such problems have led to delays in deliveries and a noticeable decline in product quality. Therefore, we will explore whether virtual reality is a viable solution to these challenges.

2. Industry 4.0

The need for new manufacturing technologies and business processes has emerged due to globalisation, changing economic environments, customer demands, and increasing competition in the market. As a result, logistics constantly faces new challenges, and the industrial sector is undergoing a paradigm shift that is significantly changing production. The conventional centrally controlled and monitored processes are being replaced by decentralised control. This control is built on the self-regulating ability of products and workpieces that communicate with each other. The Industry 4.0 concept aims to introduce network-linked intelligent systems, enabling self-regulating production, which includes communication between people, machines, types of equipment, and products, (Gubán, Kovács 2017).

Industry 4.0 can offer numerous advantages to manufacturing companies, such as increased profitability, efficiency, quality, and better working conditions. Due to these benefits, it has gained significant attention from researchers and professionals. However, there are also drawbacks to consider, such as the need for understanding, expenses, modifications to legacy systems, and possible energy issues. These challenges make it difficult to decide whether to adopt and assess Industry 4.0, as demonstrated by the obstacles to blockchain technology. These technologies may be grouped into physical and digital technologies. Physical technologies mainly refer to manufacturing technologies such as additive manufacturing or sensors and drones. Digital technologies mainly refer to modern information and communication technologies like cloud computing, blockchain, big data analytics, and simulation.

Some of these technologies are known as:

Additive manufacturing, also known as 3D printing, uses layers of material to create solid objects. Its flexible process allows it to minimise weight and create complex shapes to reduce the number of parts.

Artificial intelligence, often abbreviated as AI, is an area of computer science that emphasises the creation of intelligent machines that work and react like humans. This is achieved through human intelligence, understanding natural language, making decisions, and recognising objects.

Robotic technology, specifically autonomous robots, is commonly used in manufacturing to perform repetitive tasks usually done by humans.

Augmented reality is a technology that enhances the real-world experience by overlaying computer-generated images and other effects onto the real environment through a device such as a smartphone or headset.

Blockchain is a decentralised database that uses encryption, authentication technology, and network consensus to maintain an unalterable and continuously growing list of records.

Big data and analytics are used when traditional data mining techniques fail to uncover meaningful insights from large data sets, such as customer preferences, market trends, patterns and correlations.

Cybersecurity entails operating measures to prevent theft, compromise, or attacks on information.

Cloud allows users to store, manage and process data and applications from anywhere with an internet connection through remote servers.

A *cobotic* system is a robot intended to physically interact with humans in a shared workspace once they have passed a specific safety requirement.

Industrial Internet of Things (IIoT) refers to the network of physical devices, vehicles, and other items embedded with sensors, software, and connectivity to enable the collection and exchange of data. These connected devices are used to optimise manufacturing and industrial processes.

Nanotechnology, also known as molecular nanotechnology, is a technology that controls individual atoms and molecules to fabricate macroscale products.

RFID refers to technologies that use wireless communication between an object (tag) and an interrogating device (reader) to track and identify such objects automatically.

Simulation refers to the use of computer technology to replicate a real-world system or process.

Sensors and actuators are devices that respond to physical stimuli such as heat, light, sound, pressure, magnetism, or motion. They transmit resulting impulses for measurement or control, (Bai, Dallasega et al. 2020b).

3. Quality Control and 4th Industrial Revolution

In any manufacturing industry, quality is a crucial aspect of both products and processes. It provides a strategic advantage for businesses and organisations in the global market. Throughout modern history, quality models and practices have undergone numerous evolutionary phases, including inspection, control, monitoring, quality assurance, management, and design quality, (Tambare, Meshram et al. 2021).

Quality control is essential in consistently delivering high-quality products or services. It helps identify and correct potential defects or errors before negatively impacting customers or end-users. By implementing quality control measures, businesses can improve customer satisfaction, reduce costs associated with rework or recalls, and increase overall operational efficiency. Prioritising quality control in any industry or organisation is essential to maintain a competitive edge and build consumer trust. Production systems are becoming more flexible with a more diverse customer base, higher customer demands, increased competition, and faster technology advancements. This has resulted in smaller batch sizes, higher product variety, uneven product sizes, constant tool changes and setups, and varying levels of precision.

Traditional methods like statistical process control (SPC) are less effective in creating control charts to monitor production processes. This presents many challenges in quality control due to uncertainty. However, with the rapid evolution of the industrial sector and Industry 4.0, potential solutions are ready to improve the existing quality processes, (Godina, Matias 2019).

4. Quality Control and Industry 4.0

In the era of Industry 4.0, which includes advancements such as smart factories, autonomous systems, IoT, and machine learning, Quality 4.0 aims to utilise new technologies to enhance quality management and organisational excellence. The objective of Quality 4.0 is to reduce expenses, enhance quality, simplify compliance, and improve the efficiency of quality operations. Forward-thinking organisations are exploring novel approaches to quality management in the digital age. It is important to understand that Quality 4.0 is not just about technology but also about transforming the culture of leadership and quality processes. Rather than creating new methods from scratch, Quality 4.0 aims to enhance and improve existing quality methods, (Tulip.co 2023).

I4.0 technologies and tools uses with Quality Management:

- Data Science and Statistics: Collecting and classifying data to drive critical thinking;
- Enabling Technologies: Advancements in sensors, mobile devices, networks, IoT, IIoT, integrated systems, VR, AR, and cloud computing. Managing documentation;
- Big Data: Analysing and managing massive data sets;
- Blockchain: Transactions occur if quality objectives are met;
- Artificial Intelligence (AI): Making complex decisions (computer vision, chatbots, and robotics);
- Machine Learning (ML): Utilising heuristics for decision-making, forecasting, and screening data;
- Neural Networks and Deep Learning: Forecasting and identifying difficult patterns, (Carvalho, Enrique et al. 2021).

5 Virtual Reality

Virtual Reality (VR) technology allows individuals to experience a computer-generated environment as if it were real. It typically involves wearing a headset that tracks the user's movements and displays images and sounds that simulate a 3D environment. VR can be used for various purposes, such as gaming, education, and even therapy. It could revolutionise how we interact with technology and each other.

The idea of virtual reality (VR) was initially suggested in the 1950s, and the Sensorama simulator is considered the first fully operational VR device that offers users an immersive, interactive experience. VR technology has the potential to simulate all human senses, including vision, hearing, touch, taste, and smell, to create a virtual world experience for the user. The VR engine or PC operates as the central hub of the VR configuration system. It receives information from user input devices and processes it, delivering suitable responses to the user in real-time through outcome devices. These input devices may include voice recognition, a 3D mouse and gloves, which transmit user input to the VR engine. Additionally, tracking sensors such as electromagnetic, optical, mechanical, ultrasonic and data gloves monitor the user's position. Virtual engines or PCs generate 3D models, object rendering, simulation and visualisation in real time. Output devices such as 3D sound, visualisation and haptic devices enhance the realism of VR-based applications, (Eswaran, Bahubalendruni 2022).

6 Case Study

This case study focuses on a sizable manufacturing and engineering firm located in South Wales. The company has approximately 650 direct employees, and it generates a significant number of indirect jobs by creating high-value components for the aerospace industry. To produce the final product, the company employs various manufacturing processes like machined, vac-form, sheet metal, composites, and additive manufacturing. Meanwhile, the engineering side encompasses several departments, including design, electrical, stress, flammability, certification, manufacturing, BOM, document control, and project management.

The company has expressed concern over the significant issues raised by customers and integrators during Critical Design Review (CDR) events. These events are used to present and agree on the final product with customers and integrators, and any concerns or issues raised are transformed into actions once approved by all parties. However, once the CDR event has been finalised, there is a short window to introduce changes, modify parts, and release the final products. In addition, the company must continue to work on cabin configurations, assembly tolerance, updates, and converting prototype parts into production ones.

The design department has identified a significant obstacle to achieving a faster flow process from New Product Development to the Critical Design Review (CDR) stage. During the product development phase, designers are responsible for product design and validation, which involves prototyping and physical tests in collaboration with the Industrialisation Department (IND).

However, the flow process is halted at this stage due to the long lead times required to complete prototypes and physical tests. The high costs associated with obtaining prototypes and required parts for testing are equally concerning due to the small quantities and short lead times requested. Since these test parts cannot be used in the production phase, a significant amount of waste material is another obstacle to creating an environmentally friendly company. During product testing, 40% of the focus is on analysing how passengers interact with the new product and its environment. Whenever changes need to be made to the original design due to space or structural limitations, the client requests these analyses to aid in decision-making, which can cause delays of up to 2 months. Unfortunately, this lost time cannot be added to the original project timeline, which can ultimately impact the quality of the final product.

7 Discussion

Effective management of a production facility in the manufacturing industry includes maintaining product quality, maximising machine efficiency, and improving overall performance, (Tambare, Meshram et al. 2021). In the presented case study, to remain competitive and satisfy customers, the company needs to focus on maintaining product quality and improving overall performance by improving its product development process.

There are multiple ways in which digital technologies can enhance the quality of various processes. Companies can monitor their operations through real-time data collection and analytics, predicting quality issues and required maintenance. Moreover, digital tools can

enhance the efficiency and effectiveness of work, resulting in faster and better outcomes while reducing costs.

(Küpper, Knizek et al. 2019), demonstrates that many companies are increasingly adopting or exploring Quality 4.0. The study reveals that the primary drivers for this decision were enhancing performance, responsiveness, and productivity. The most critical parameters for measuring these improvements were manufacturing quality (such as first-pass output, waste rate, and rework), the negative impact of insufficient quality on consumers (such as complaints, rejections, and warranty claims), and the financial costs associated with poor quality. Simulation testing is a powerful technology for improving design robustness. Introducing preventive quality in the early stages of product development can significantly reduce costs and time, resulting in a faster workflow process.

Designing a product is a crucial stage in the manufacturing process that requires creativity, drafting, market analysis, overcoming challenges in techniques, adapting to available resources, and ultimately producing the final product. To enhance the accuracy of the product design and avoid production cost increases, modern visualisation technologies such as VR can simulate the product's appearance more realistically. This allows for early error detection and evaluation.

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Equally important is to show the stakeholders the final product more realistically in an immersive environment, allowing them to provide feedback and suggestions quickly, decreasing rework costs and increasing productivity, (Eswaran, Bahubalendruni 2022).

Reducing production costs in time and money is a significant challenge for industries. It has been established that the design stage of the product life cycle determines over 70% of the final production cost. Assembly planning plays a crucial role in product design, as product costs are strongly linked to the assembly process. Considering time, cost, ergonomics, and operator safety is essential while planning the assembly process. Rapid physical prototyping and computer-aided assembly planning have contributed towards better assembly planning. However, physical prototyping requires time and materials, while computer-aided planning can only partially factor in ergonomics and operator safety, (R D M D Jayasekera, X Xu 2019).

8 Conclusion

Achieving a successful quality process involves a comprehensive approach that tackles various strategic, cultural, and technological concerns. Businesses that effectively handle these challenges will experience reduced defect and failure rates, giving them a competitive edge through enhanced customer satisfaction and operational efficiency, (Küpper, Knizek et al. 2019). For a complete quality transformation, people and skills must be the main focus - technology is just one part of it. To summarise, virtual reality technology can enhance the quality of products manufactured by this company, while also reducing costs and manufacturing time. This will result in higher customer satisfaction and a competitive edge in the market delivering quality products in a faster way.

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