

ASSESSMENT 2- INTRODUCTION TO INDUSTRY 4.0 ESSAY

Industry 4.0 technologies: Requirements, Impacts,
Challenges by SMEs in smaller countries – Case Study

MSc International Innovation Management

Module: Introduction Industry 4.0

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Introduction

SMEs (Small-to-Medium size Enterprises) are now and have, historically, been defined as LARG (lean, agile, robust and green) companies (Amjad, Rafique et al. 2020), normally spear-headed by entrepreneurial figure-heads/ management teams with innovation capabilities that are suited for adopting new technologies in order to increase their stature or even to remain competitive. (Ahmad, Iqbal et al. 2020) (Matt, Modrák et al. 2020) Comparing SMEs to large companies, this inherent leanness, due to the organisation size, is seen as an advantage in favour of SME's. On the other hand, the challenges that come with limited cash-flows, availability of sufficient SQEP (Skilled, Qualified, Experienced Personnel) and other shortcomings must be overcome with the help of external resources: clients, government organizations, universities etc. Maier (2017) quoted in Chavez (2021), concludes that 'the countries where SMEs have been most successful in adopting new technologies have coherent government strategies in place to support them, for instance, Germany (Industrie 4.0), China (Made in China 2025), and the USA (America Makes).' (Chavez, Hauge et al. 2021) With this in mind, the SME presented in the following case study operates in Scotland in the Lifting Industry and has recently – starting in 2018 – engaged with industry 4.0 technologies both in manufacturing and in its products semi and fully automated operation methodologies. The following content aims to identify such technologies IIoT, Digital Twins, Smart Operators and PLC programming as they are being used to produce a high quality 50t capable CHC (container handling crane) for a client in the Nuclear Industry along with the need for implementing organizational procedures relating to cybersecurity.

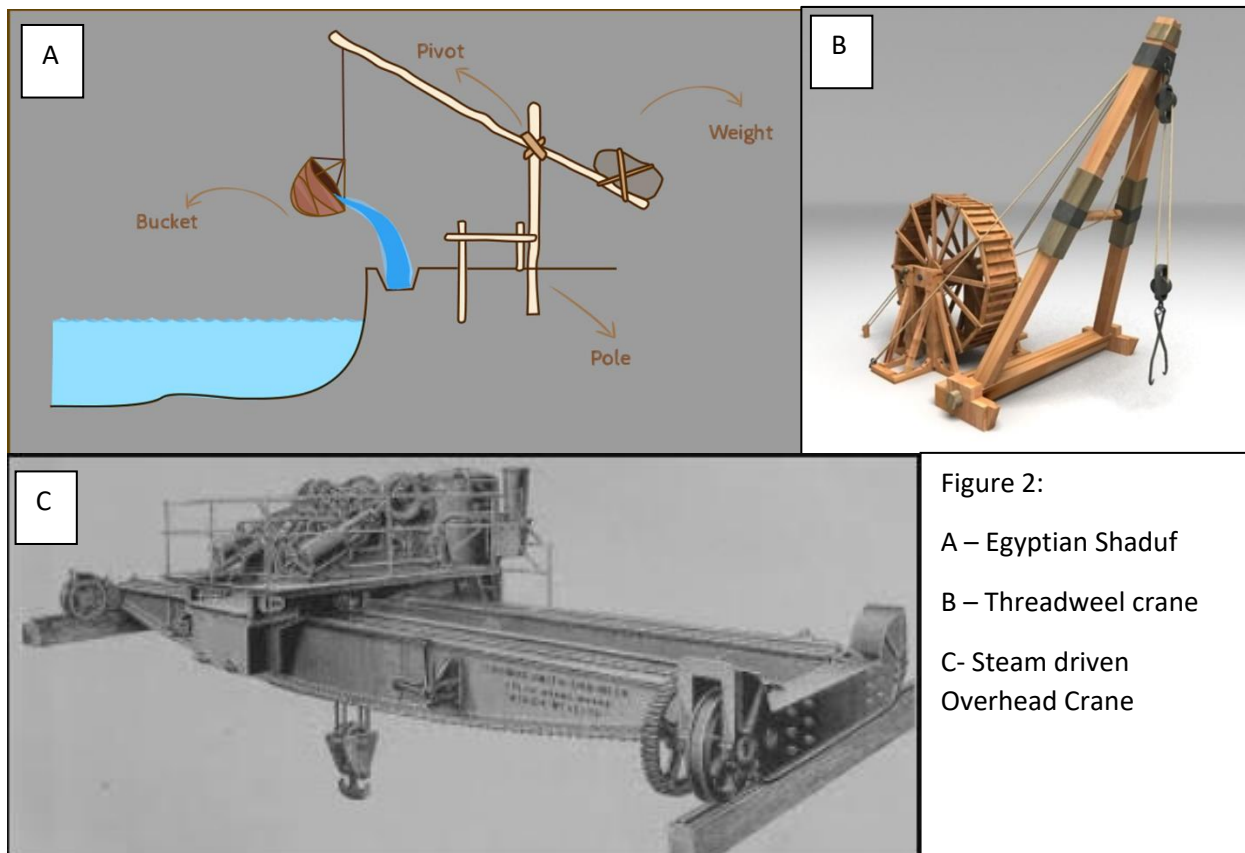
Along with this, specific challenges are continually encountered, mainly with the humanistic elements of the company and due to the culture. It is important to realize that the concept of cranes has been around since antiquity and lifting devices are commonly used across all industries, with many competitors manufacturing hoists and cranes as standard products. Knowing this, it is easy to understand why an SME that has found a niche in this oversupplied industry – in this case, manufacturing lifting gear for explosive and hazardous environments since 1972. Furthermore, due to the decline in the oil and gas industry with the global push to eliminate fossil fuels dependency, PCT was forced to expand its area of supply to other energy sectors, such as Nuclear and Renewables. To this effect, PCT enrolled in 2018 in a Nuclear Decommissioning Cohort arranged by Scottish Enterprise, the first one of its kind in Scotland, as one of 8 SMEs looking to become 'fit for Nuclear'. PCT was the first of these companies to win a contract in Nuclear Decommissioning due to this innovation programme and was awarded a 1.5 million £ purchase order for the design, manufacture, testing, installation, and commissioning of a CHC for the storage of low to medium radioactive waste containers.



Figure 1: Fit For Nuclear Logo

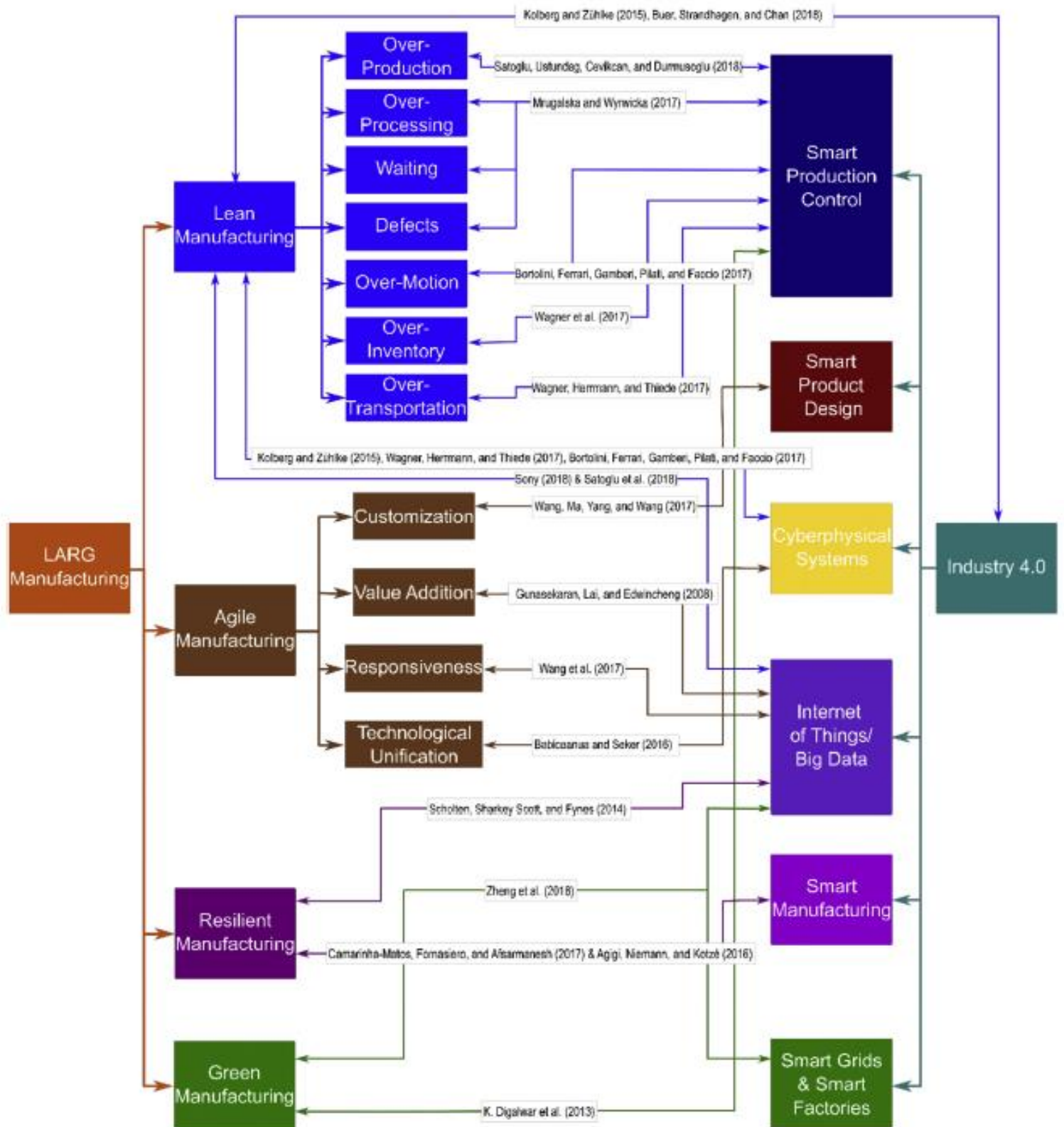
Brief history of cranes

Firstly, it is important to understand the need of adopting industry 4.0 technologies in the lifting industry and specifically applying this technology to an SME operating in this trade. Hoists, cranes, and other lifting appliances have been used since ancient times, with the first records being available from the Egyptians and Mesopotamians, that used a device called a shaduf (BBC Teach 2022) to offer a mechanical advantage in moving water for irrigation and daily use. Later, the Greeks (circa 500 BCE) and the Romans invented cranes for constructing the ancient temples, buildings and erecting their famous column segments using systems like the trispastos. There is a gap in progress during the dark Middle Ages due to the lost knowledge of the Greek and Roman empires after their downfall and subsequent pillaging by barbarians. (*The History of Lifting Equipment*. 2020) The fourteenth century marked the next big technological advancement by the invention of the stationary port crane and the resurgence of the treadwheel cranes. (Loganx 2019) The industrial revolution cemented the role of the lifting appliances in society as being an integral part of the progress; the introduction of steam powered cranes made it possible to lift significantly larger loads than in the previous mechanical advantage with human interactions. This period is also (*The History of Lifting Equipment*. 2020) Fast-forward to today's cranes, we find that technological advances in the wider industry world can also be identified within the lifting equipment developments.



Based on the historical development of the crane industry as presented above, the only logical advancement would be the transition from traditional manufacturing to the concept of intelligent manufacturing. (Shi, Xie et al. 2020). The next step in cranes manufacturing is to take advantage of the existing and emerging technologies. To this effect, PCT has analysed its own capacities with regards to the requirements of the client and the technological opportunities that would give the company the necessary support not only to complete the contract for the CHC but also to enact a systemic transition to Smart Factory technologies and to bring PCT into the fourth industrial age.

Figure 3. Conceptual LARG implementation Framework (Amjad, Rafique et al. 2020)

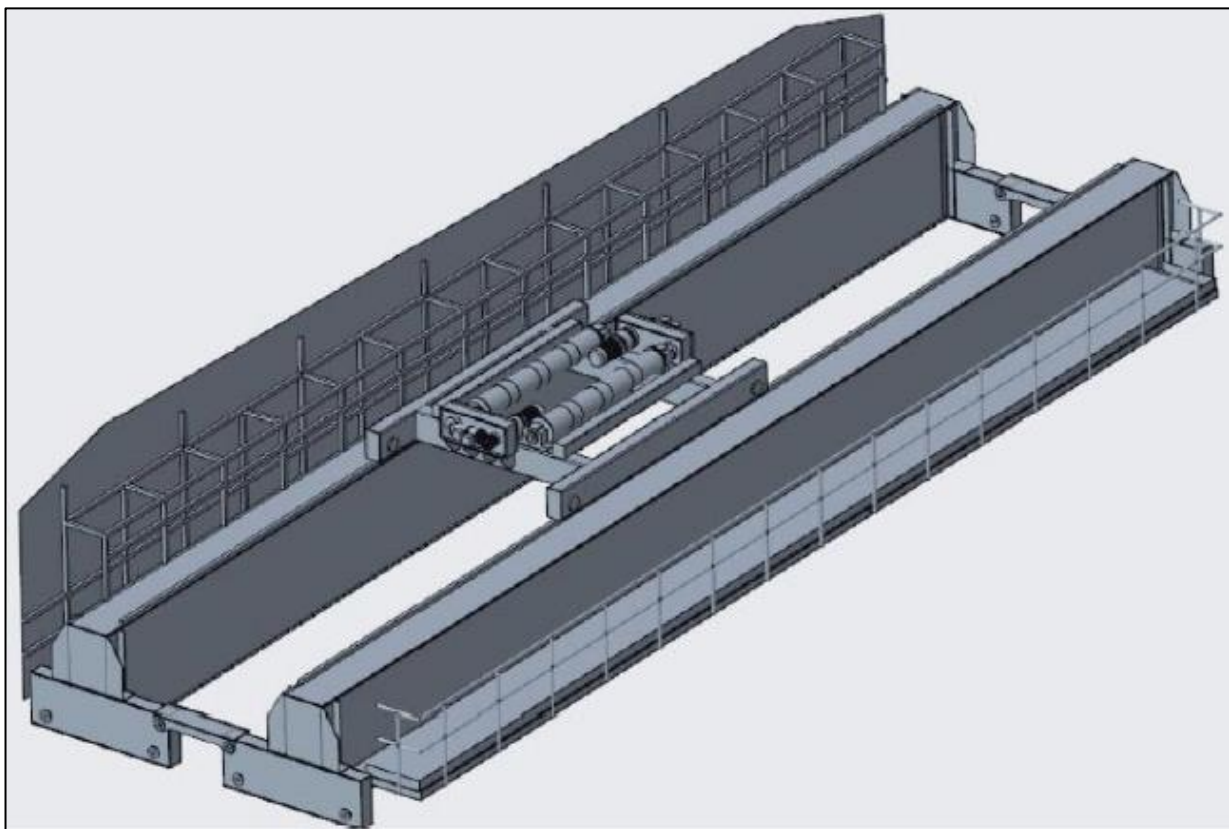


Innovative technologies

Smart product design

The first step in the manufacturing of this crane was the design. The purpose of the Container Handling Crane (CHC) is to enable the safe lifting/positioning of designated waste packages (containers) over the full area of the Waste Store. There are two types of packages to be stored within it. The Radioactive Waste Management (RWM) approved Rigid Concrete Box (RCB) and the half-height ISO freight container (HHISO). The new CHC in the Waste Store is a top-running, double girder electric overhead travelling crane (EOTC), with a 50T safe working load (SWL). The crane will have long travel, cross travel, hoist raise/lower and grapple plate locking motions. The CHC hoist will be a twin-barrel design with recovery motors fitted to each barrel. The grapple plate twistlocks will directly interface with the lifting features on the top surface of the RCB. A further lifting attachment (spreader beam), capable of interfacing directly to the grapple plate, will be fitted with twistlocks to interface with the lifting features on the top surface of the HHISO containers. The CHC will also be used to shuffle containers around within the CSA. Once the methodology and order of operations was established, the smart operators (Longo, Nicoletti et al. 2017) of Scottish Advanced Research Centre created a Digital Twin for the new CHC.

Figure 4. 3D CHC overview



Process Sequence Overview

PCT have a unique relationship with the Scottish Advanced Research Centre in Glasgow as some of PCT's former staff have taken up positions in the research and education organisation (NMIS, Bittleston 2020). The SARC supports the project and have built a Virtual Reality (VR) model of the CHC. The VR model assisted PCT and the client by developing virtual environments to support iterative product design, assembly process design and training, maintenance simulation, and remote support. A Digital Twin of the CHC also being created to semi-automate the assembly process - incorporating augmented reality, 'Just in Time' information and intelligent/smart workbenches through fixed, mobile, and wearable platforms. These self-teaching systems supply detailed assembly instructions allowing inexperienced operators to successfully complete complex tasks (Longo, Nicoletti et al. 2017). 'More integrated systems simultaneously capture data from intelligent tools and sensors, which is then used to validate processes and ensure traceability. In-line quality checks provide early detection of manufacturing problems and decrease the number of defects at the end of the process' (AMRC, The University of Sheffield 2020).

Following this principle, and in line with the agile manufacturing philosophy adopted, (Amjad, Rafique et al. 2020), the Digital Twin of the Container Handling Crane (CHC) is parked above the Vehicle Loading Bay's (VLB's) hatch, with the appropriate Container Lifting Frame attached. The transporter and load are parked in the VLB. The hatch is opened to allow the lifting attachment to be partially lowered through the hatch and the control is switched to the CHC Operator Pendant. The CHC Operator Pendant and camera systems are used to collect the load and lift to the fully raised position. The hatch is closed, and the control switched back to the CHC Operator Desk. The storage location is selected, and the load deposited in the store. The CHC is parked above the hatch, in the maintenance position (LT West limit & LT North limit) or above the spreader cradle position in the store. This industry 4.0 approach allowed PCT, as an SME with limited resources, to minimise any potential envelope clashes or misalignments during commissioning – which would have resulted in delays and commercial penalties.

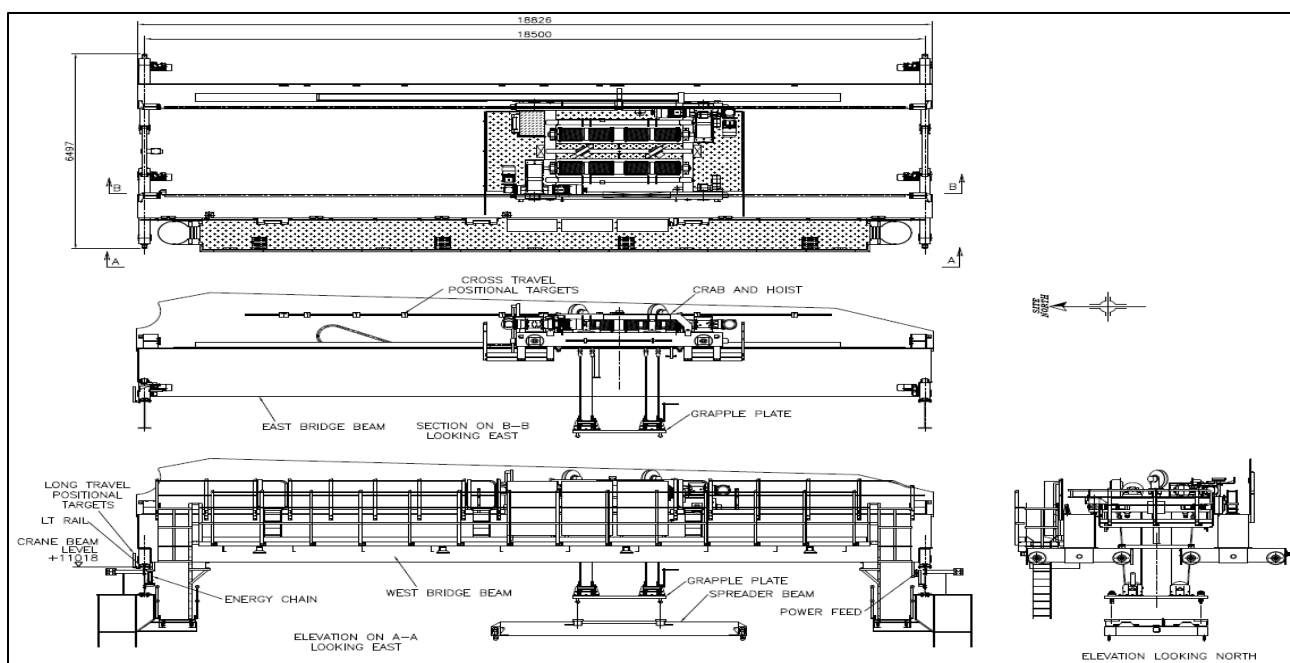


Figure 4.
2D views
of the
CHC crane
in-situ

Smart Manufacturing and Smart Production Control

Unlike all the other processes and technologies presented in the case study, where PCT had to find and establish a network of companies to subcontract parts of the job that were unfamiliar to the Lifting Appliances Manufacturer, this is what PCT are set up to do – make cranes. The company has been doing it for 5 decades by this point and had in its IP (intellectual property) frozen designs by chartered engineers that went back 100 years. Even so, due to the size of the CHC components, contractors were identified to weld the bridge beams, end carriages, drums, and spreader beam. This endeavour was made easy using PCT's Smart Factory system - Bitzlist (NMIS, Bittleston 2020). Using its Revision controlled document management made tracking any changes in design easy. Bill of materials management, Automated Procurement and outsourced operations management made it easy to engage the many subcontractors in the supply chain and automatically fed into the scheduling and capital resource management. In addition to these features, the MRP system is highly customizable to incorporate IIoT technologies.

One of the challenges posed by using a highly efficient programmed system that offers many automated processes for the data inputted is the training and proficiency of the operators (Longo, Nicoletti et al. 2017). As mentioned in the previous topic, smart operators that worked for PCT had departed for new challenges. Although it benefited the company for this specific project to be able to subcontract an organisation that now has former employees of PCT's, familiar with the modus operandum of the company, in the long run, valuable knowledge had left the company and would only be accessible for use as consultants (Matt, Modrák et al. 2020) with the associated higher cost and longer lead times. In chapter 8 of their book, Matt, Modrák et al. (2020) identified various states of organizational capabilities of SMEs for customized mass production. Applying their graph to this study, it is evident that PCT fall under the starting level of organization. This needed to be supplemented by external resources to achieve the required level of optimised state the project required.

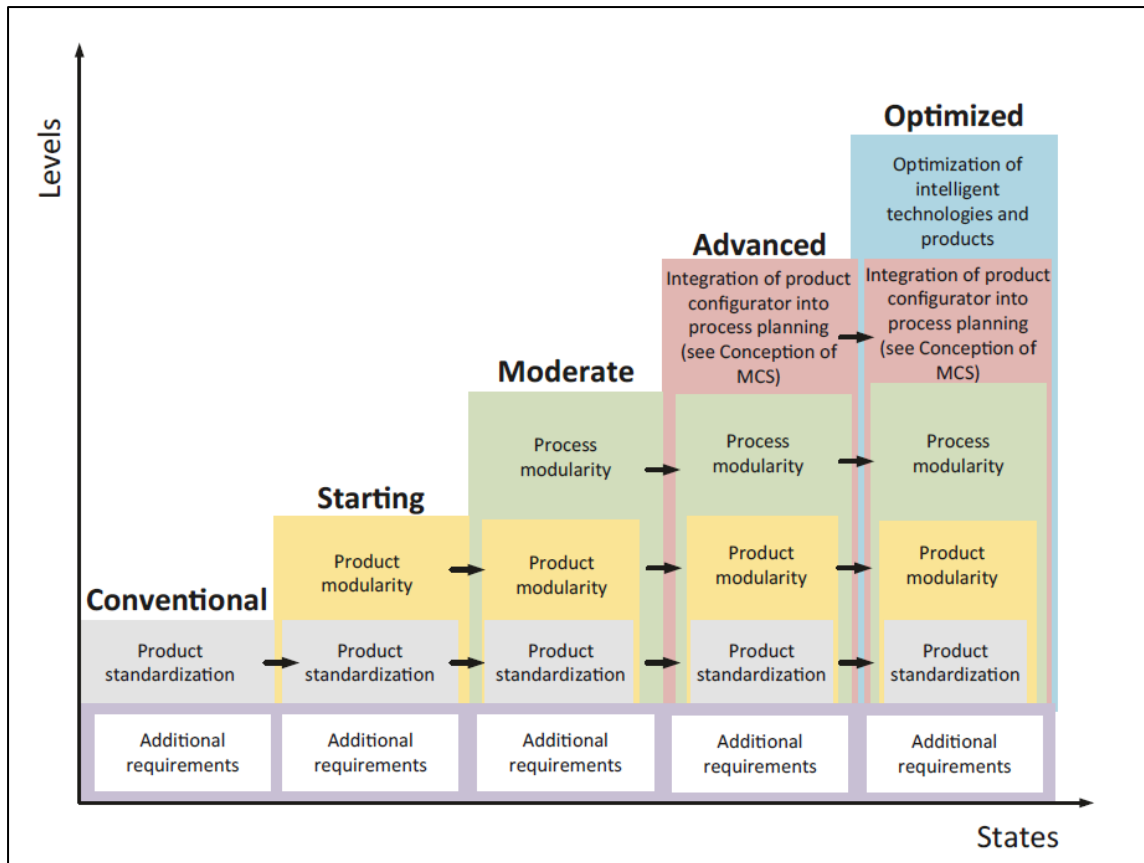


Figure 5. organizational capabilities for mass customized manufacturing (Matt, Modrák et al. 2020)

Cyberphysical Systems

The most important operational technology used in the crane is the automation of the movements and controls and it is a prime example of practical applications of Industry 4.0 advanced technologies in a real-life scenario (Kiangala, Wang 2018). The following description of the control methodology is illustrative of the big role played by PLC's and augmented IIoT systems in the operation of the lifting appliance, and paramount to the success of this project.

Crane Controls

The CHC is provided with an electrical control system, comprising the following equipment:

- CHC Main Control Panel (MCP), located on the crane bridge
- CHC Operator Desk, located on the upper floor of the VLB (CMB)
- CHC Operator Pendant, located on the lower floor of the VLB
- Crane-mounted field instrumentation and controls
- Cabling system, including junction boxes for marshalling and segregation.
- CCTV system controller, monitors, joystick and audio speaker
- Interface to other systems

The CHC will have two modes of operation: manual and semi-automatic (British Standards Institution 2011b). The CHC will have two points of operation; from the CHC Operator Desk

(CMB) and from the CHC Operator Pendant on the lower floor (VLB). Operation will be from either position or will be used for all movements. The CHC Operator Pendant will be provided with pushbuttons for all manual operations. The CHC Operator Desk is provided with joysticks and pushbuttons for the same functionality, as well as controls for the selection of operating position. Semi-automatic operation will be from the CHC Operator Desk. Semi-automatic operation allows positioning to a pre-selected long travel (LT) and cross travel (CT) location. The desk will be fitted with a touchscreen display (HMI) to allow the operator to select the target long travel and cross travel positions. Movement will only occur by operation of the joystick and only if the joystick is pushed in the direction indicated by the HMI. The crane will semiautomatically slow down and stop once at the target LT or CT position.

PLC/HMI Hardware

All normal crane manual and semi-automatic functions will be controlled by a PLC. The PLC central rack will be installed in the PLC / Safety Controls section of the MCP and will be fitted with the PLC CPU and local I/O cards. In addition, a remote I/O rack will be installed in the CHC Operator Desk, fitted with all necessary I/O cards, and connected to the PLC CPU by means of a control network connection. The control network cable length from CHC Operator Desk to CHC MCP will be in excess of 100m, and therefore fibre optic cables will be utilised. A touchscreen HMI will be installed in the CHC Operator Desk for selection of semiautomatic operation positions, visualisation of the crane speed and position, alarm functions and data logging.

PLC/HMI Software

A Software Design Specification (SDS) was produced, detailing the methodology of the software design, coding, validation, and verification process. The SDS also the functionality of the software. The PLC software is broken down into structured blocks of code, documented within the code and generally written in ladder logic to aid maintenance. No protected blocks of code will be used.



Figure 6: Image of PLC and associated programming software

Internet of Things in the Crane Instrumentation

Again, as was the case of the digital twin, PCT had to interact with the wider supply chain to secure the required knowledge when it comes to all the different systems (Gilchrist 2016) that are performing different tasks and measuring separate attributes during the crane's operation over the 60 years lifespan. Furthermore, the challenge to be overcome was programming the PLC to read all the different signals (Butun 2021, chapter 10) coming from

all the different types of instruments(British Standards Institution 2011a) (British Standards Institution 2011) (both analogue and digital) attached to the CHC.

LT and CT Position Transducers

A measuring sensor will be provided to allow accurate and contactless distance measurement using laser beam reflection. The sensor will be mounted on the crane and pointed at the west wall of the building, providing a constant position output of the crane in the LT and CT axis. The fixed positions will be derived from this measurement to control slowing and stopping in the normal course of operation. The sensor will be connected to the MPC PLC by means of a control network cable. The measured position will be displayed on the CHC Operator Desk HMI. If the signal is lost during operation, then the crane will come to a controlled stop.

Hoist Height Encoders

Two heavy duty wire draw encoders will be fitted to the crab unit and connected to either end of the grapple plate. The signals from the wire draw encoders will, by means of a control network cable through the CT energy chain system, be taken to the MCP PLC. The signals will be used to display the working height of the grapple and spreader beam on the HMI units at the CHC Operator Desk and loading bay.

The signals will also be used to monitor the tilt angle of the grapple. The amount of acceptable horizontal displacement from one side of the grapple to the other will be settable, through the HMI. If the acceptable displacement is exceeded, the PLC will stop the vertical operation and display an appropriate fault notice on the HMI's. See maintenance section for resetting to horizontal.

Loadcell System

The CHC balance beam assemblies will be fitted with loadcells connected to a loadcell amplifier to determine crane load, detect slack rope / load landed conditions and determine load centre of gravity. The loadcell amplifier will be connected to the PLC by means of a control network connection through the CT energy chain system. The PLC will use the measured load to inhibit raising of the CHC hoist in the event of an overload or snagged load. The PLC will use the measured load to inhibit lowering of the CHC hoist in the event of a negative load (ledging). The total measured load will be displayed on the CHC Operator Desk HMI. If required by the operator, the HMI can display the load on each corner as well as the total load. A visual indication/ representation of the centre of gravity in relation to the sheaves will be displayed on the HMI units.

Safety Related Controls

All safety and protection systems will be managed by a safety controller (British Standards Institution 2008). The status of the safety and protection systems will be communicated to the PLC via a control network connection to the safety controller. The safety controller will remove motive power from the motor controls by means of two sets of safety contactors.

Fault Finding, Alarms and Warnings

The PLC logic will alert the operator of a process problem or failure via the HMI units (British Standards Institution 2008). Many of the components within the MCP are provided with an additional contact or signalling via control network connections which will be used to monitor status and output information if 'tripped'.

Examples:

- Main contactors not releasing when de-energised
- Thermistor relay actuated
- Circuit breakers tripped
- Ultimate limit switch activated
- VSD fault
- VSD resistor overheated
- Overspeed detection
- Overload detection
- Leding (underload detection)
- Out of synchronism (hoisting motion)

As described above, the instrumentation communicates with the robustly constructed PLC which is programmed to be reliable in analysing and predicting the behaviour of the CHC in all situations (Sehr, Lohstroh et al. 2021) and will ensure the safety of operators. As shown previously, this technology was necessarily implemented due to the conditions of operation – handling of nuclear waste material – in a hazardous environment that would prove to be an unnecessary risk for a human operator. As was the case with the digital twin interaction, PCT had subcontracted this part of the contract to a company that has an expertise in working with and programming PLCs.

Blockchain and Cybersecurity

To continue the discussion of emerging technologies that must be implemented, Cybersecurity and the Blockchain are part of an overarching need to protect sensitive information not only for the duration of the manufacture of the CHC, but in perpetuity; especially as it relates to interactions with the nuclear industry, albeit low level nuclear waste storage because of plant decommissioning. The threat of ransomware (VICE News 2022) and the risk of disaster caused hackers leaking information is of great concern to PCTs clients. Although the Company servers are protected by adequate cybersecurity, due to the new hybrid style of work (home and office) that came about with the Covid Pandemic, the company has been slow in adopting all the possible measures that would make it difficult for malicious intent to gain control of one of the remote workers laptops and gaining access to any information that employee has been working on from home. While regular prompts from the responsible IT specialist are received on this matter, the challenge of sharing and securing important data is the responsibility of the individual. This matter is an active discussion between company, PCT and all the supply chain partners, and it is forecasted that a solution already used in the industry will be implemented within the coming period.

Conclusion

In final analysis, manufacturing SMEs in small countries require Industry 4.0 technologies being implemented to ensure they can survive and be competitive in the ‘Smart’ World of today. At the same time, bringing these technologies within the organisation, or owning the processes is not always required or indicated (Ahmad, Iqbal et al. 2020), as it can put a strain on the limited resources like capital or staff that come with the size of an SME. In addition, following the LARG manufacturing methodology (Amjad, Rafique et al. 2020) and applying it to the case study of the CHC being supplied by PCT, it is evident that processes like the smart product design (digital twin) and the cyberphysical systems (IIoT, instrumentation and PLCs) would have been impossible to buy in and integrate into the company, while still remaining on track to meet the client’s schedule for manufacturing of the crane. As both systems are integral to the success of the crane, the best approach was to sub-contract them to the relevant experts on the two subjects, while still maintaining the oversight of their activities through the Smart Factory System present within PCT.

Being part of a supply chain with partners comes with a few inherent risks, all related to the humanistic factor and all solvable by targeted management. Firstly, there is the risk of over-dependency on external sources with no guarantee for repeat business or availability. This can be mitigated by maintaining a good working relationship, with regular communication and ensuring that payments and deadlines are adhered to. Secondly, the level of knowledge cannot be allowed to drop in quality with the departure of key personnel due to the slowing down effect on operations and the increased financial cost required to replace said knowledge. The solution for this challenge is to put in place procedures for internal information transfer and put emphasis on succession planning. Finally, having a reactive rather than proactive approach to client and industry requirements will put unnecessary pressure on the entire process and on the project team, ultimately leading to rushed and poor decision making. This too can be addressed with the identification prioritisation of smart factory investments (Dreyer, Egger et al. 2022) to benefit the company in the long term, such as adopting blockchain and cybersecurity solutions.

All in all, PCT and the CHC project is an illustrative example of an SME that faces challenges in implementing all the technologies applicable and available to Industry 4.0 manufacturing, while being LARG enough to interact with them on a casual, case-by-case basis.

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