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IMPLEMENTATION OF INDUSTRY 4.0

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Affidavit

I confirm that the bachelor's work was disposed by myself and independently, under the lead of my thesis supervisor. I stated all sources of the documents and literature.

In Prague ……………… ……………………

Tharusha De Silva

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Abstract

This bachelor thesis is focused on the implementation of Industry 4.0 into an existing well known refractory company. It begins with a brief history on the evolution of production and the concept of Industry 4.0 is introduced here. The thesis specifically discusses the ceramic industry and as a part of it, the refractory industry and evaluation models. In the practical part, an analysis of the current state in the model company is performed which is followed by the proposals which were made for the implementation of Industry 4.0 or in other words implementation of Smart Factory into the current state of the model company.

Keywords: Industry 4.0; sensor; Smart factory; refractory industry; manufacturing process; monitoring; data

Contents

1. Introduction

In recent years manufacturing processes have taken a keen interest in automating all parts of production to be more efficient as well as economical. With technology advancing every second, industries must also change their existing models to cope with the ever-growing competition and demand. This bachelor thesis deals with the manner in which Industry 4.0 can be introduced to an already existing production line in the model company which this thesis is based upon. An analysis of production will be performed on the basis of which the concept of elements of Industry 4.0 will be designed, which can be introduced into production in the refractory industry whilst finding solutions to the difficulties that occur in this industry.

The first part of this thesis is devoted to the history of manufacturing and its evolution through time and technology. It is also devoted to the theoretical part which is the paradigm Industry 4.0 and its characteristics. Furthermore, the ceramic and refractory industry, on which this work is focused, is analyzed.

The second part is devoted to the analysis of the current state of production and production processes in a model company. This section describes in detail the whole process of refractory production in this company. From the transport of raw materials through the storage of production raw materials, mixture preparation, mixture extrusion, drying and the end of production, which is the firing of the product and its final inspection and dispatch.

The third part deals with the design of conceptual solutions for production using elements of modernization in the field of monitoring and control of production itself so that based on these elements to monitor more parts of the production process and its management, which would increase product quality and production process efficiency.

The final part of the thesis is devoted to the evaluation of proposed implementation concepts. In conclusion, there is a proposal for the strategic implementation of conceptual solutions into the current operation of the model company.

2. Production Systems

A production system is a system that converts material, energy, knowledge, and monetary inputs into value-created outputs like fabricated or assembled products. A product's value is created through a series of processes that must be managed through organizational procedures. Technical operations such as machining, assembly, testing, handling, conveying, storing, collecting, distributing, sorting, and packaging make up the processes. [10]

As the market grows and changes new designs of production systems are required to sustain competitiveness. The manufacturing industry has gone through several paradigm shifts since its beginnings two centuries ago.

The first paradigm was Craft Production, which produced a high-cost product that the customer requested. This paradigm did not include any production systems. Manual processes were used by hand made by most of the manufacturing industries during this year. In addition, craft products suppliers were limited to geographically localized areas, which means that this production cannot be scaled.[9]

In the 1913s, a new moving assembly line was introduced after a certain century. This year marks the start of mass production, which enabled low-cost products to be produced on a large scale. However, such production had a very limited number of varieties to offer. Due to the highest rate of production, the year 1955 marks the peak of mass production. During this time, the production system was known as dedicated production line. Global competition and consumer demands for a wide range of products led to the development of mass customization in the late 1980s. [9][10]

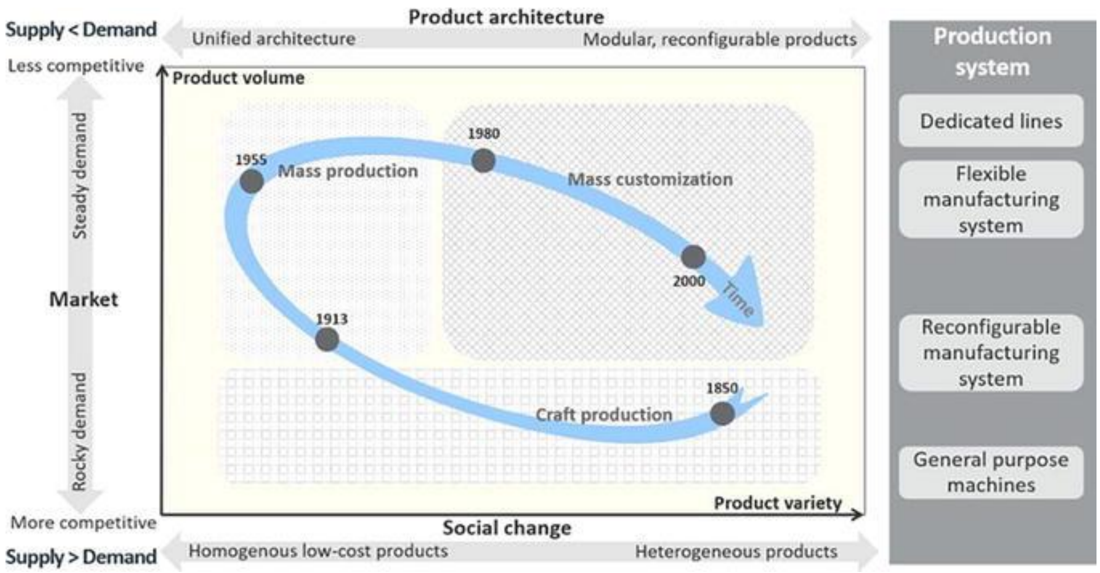


Figure 1:The evolution of production systems [2]

In the 1980s, computer numerical control (CNC) technology was developed to accommodate high-frequency changes in customer requirements. This manufacturing system is referred to as a flexible manufacturing system (FMS). In the twenty-first century, the manufacturing industry must contend with unpredictable, high-frequency market changes, as well as other challenges brought on by globalization. [10] Figure 1 above illustrates the evolution of production practices.

2.1 Dedicated production lines

The global system of production is characterized by the mass production of large quantities of standardized products. Dedicated production lines were a key paradigm in the manufacturing industry during this period. Dedicated production lines manufactured large quantities of a single component type in a cost-effective manner when demand was high.[9]

As long as the dedicated production lines can operate at full capacity, they are cost-effective. Global competition, however, is increasing market pressure, as is global overcapacity. Many dedicated production lines are required to maintain the variety of products. This has a significant impact on the overall factory cost. [10]

Dedicated production lines have their own set of drawbacks. A dedicated production line, according to Delorme et al., requires a large investment and must be used for a long time to be competitive. The dedicated line is difficult to change, and reconfiguring it if necessary, will be costly and time-consuming. To address these issues, Flexible Manufacturing Systems were developed. [11][12]

2.2 Flexible manufacturing systems

In the late 1980s, the demand for product variety increased, resulting in the mass customization paradigm. Since then, the number of product variations offered by manufacturers has increased dramatically. Due to the numerous component and accessory combinations available for each car model, the number of different car models in the United States of America increased from 44 in 1969 to 165 in 2006. Product market segmentation and international competition both resulted in the development of highly diversified and customized products that required the use of FMS as a manufacturing system. [14]

Within the context of the system's capabilities, the FMS concept allows production companies to predefine a variety of production processes. FMS enables production companies to activate a variety of product models quickly and easily on demand using a single system configuration, improving their competitiveness and profitability through a highly efficient system design. In the same system, companies can effectively manufacture a variety of product types. When an unexpected production requirement arises, however, FMS's adaptability is limited by limitations and synchronization issues. Because FMS are not designed to respond to structural changes, they are unable to respond to market fluctuations such as changing user needs and major equipment failures. An example of a flexible manufacturing system is shown in figure 2. [14][15]

Figure 2: An example of flexible manufacturing systems developed by FESTO group [10]

2.3 Reconfigurable manufacturing system

The widespread use of the internet, computational and analysis software, and the introduction of modern responsive production systems, such as 3D printing, have created an opportunity for a new product development paradigm: personalizing products to meet the needs and preferences of individual customers. Customers can design and manufacture their innovative products in collaboration with manufacturers and other consumers. Customers can participate in design, product modeling and simulation, fabrication, and assembly processes that respond quickly to their needs and preferences thanks to the open-product architecture, on-demand production systems, and adaptive cyber-physical system used in this co-development process. [15][16]

Because of the diversity of consumer demands, businesses have been forced to offer a greater number of product variants in smaller batch sizes. There has been a significant increase in product variety across all product ranges and sectors, and this trend is expected to continue.

The reconfigurable manufacturing system (RMS) concept was introduced to address the issues in the FMS as a result of the high cost of reconfiguring. RMS is distinguished from dedicated production lines and FMS in earlier definitions by their adjustable system structure adaptability and scalability to varying demands. The structural changes can take place at the system, machine, or both levels. When frequent changes are required, RMS is a cost-effective production system paradigm.

It lowers system costs by designing a production system for the entire part family, as well as providing the necessary custom flexibility to manufacture all of the part family's components. As a result, it can manufacture a wide range of components at various levels of production and in high-efficiency environments. RMS system as shown in figure 3. [17][18]

Figure 3:RMS system developed by FESTO [10]

The type of configuration and reconfiguration system is shown in Figure 4.

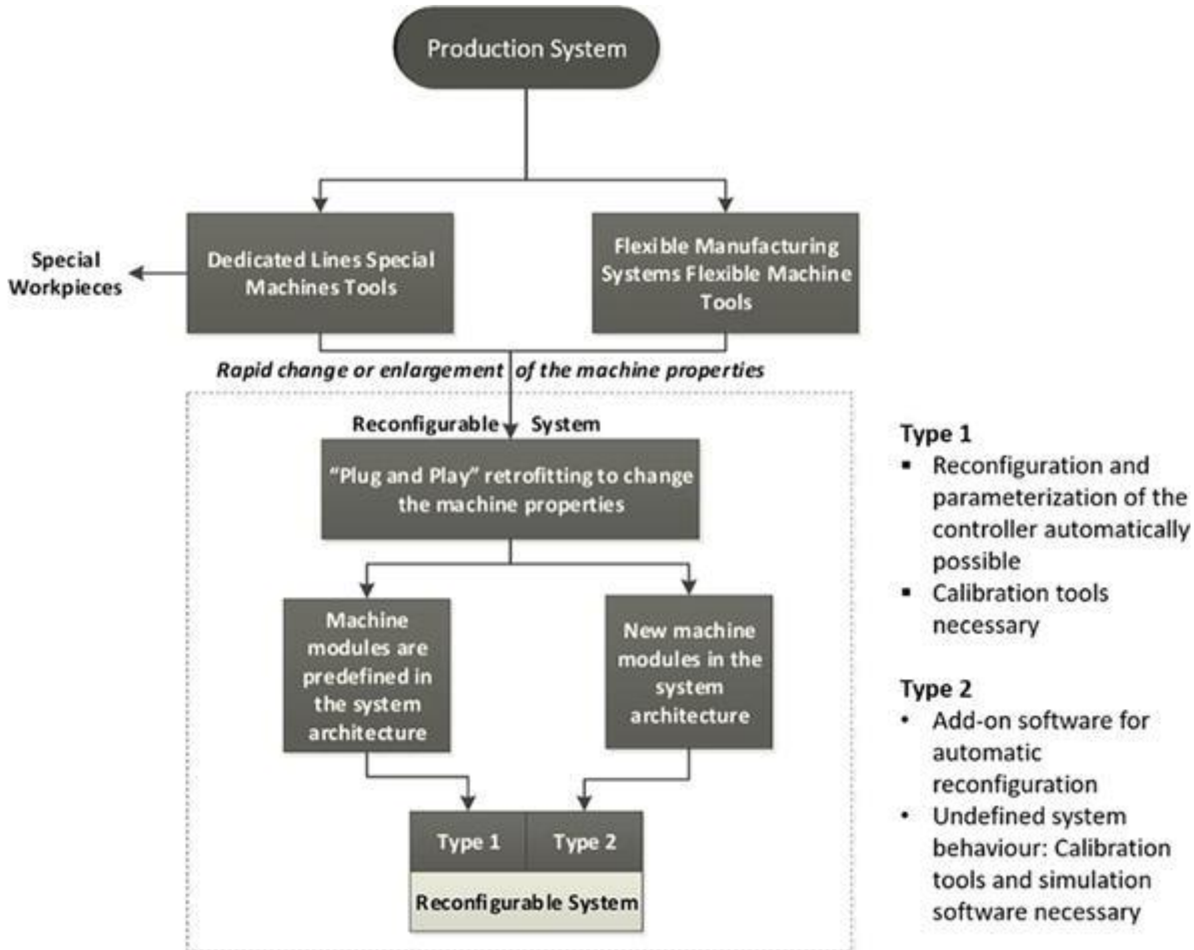


Figure 4:Configuration and reconfiguration system [13]

Convertibility (functionality shift purpose), scalability (capacity change plan), modularity (modular elements), integrability (quick integration interfaces), customization (part family flexibility), and diagnosability (easy diagnostic design) are just a few of the aspects that can be defined to fully comprehend the reconfigurable material handling system. Modularity, integrability, and diagnosability allow for rapid reconfiguration, while customization, scalability, and convertibility are critical reconfiguration characteristics. [20]

2.3.1 Transformation of Operational Processes

Continuing to improve operational efficiencies through traditional cost-cutting measures now only yields marginal results. Industry 4.0 refers to a significant shift in the way goods are produced and delivered, with an emphasis on industrial automation and the flexible factory. Factory and warehouses must use the industrial internet of things (IIoT) and digitalization to become much more agile and efficient in order to stay competitive. While many processes in industries have been automated, secure wireless connectivity enables factory automation, allowing for industrial automation on a much larger scale. Industrial automation will boost productivity and performance by laying a digital foundation.

Industries that cut the cord and go wireless stand to gain a lot. The business outcomes that industry expects from Industry 4.0 are supported by wireless cellular connectivity. It enables flexible production in manufacturing, for example, by allowing smart factories to quickly changeover production lines to reduce lead times. [21]

2.4 Process Digitization

To bridge and manage the gap between productivity and quality issues, the manufacturing industry was forced to shift production facilities to low-wage countries as global competition on product quality and production costs increased (Brettel et al., 2014). Buyers are also hesitant to pay high price premiums for minor improvements in quality, according to mature manufacturing companies (Brettel et al., 2014). As a result, businesses are constantly attempting to capitalize on the benefits of sophisticated production strategies such as lean manufacturing and mass customization. The next step in increasing competitiveness will be the virtualization and digitization of operational processes. [20]

Digitization is the process of converting non-digital data, information, and operations to a digital platform so that employees and customers can access them more easily. Manufacturing companies' digital transformation to Industry 4.0 has an impact on both local and global value chains (Deloitte, 2015). Manufacturing costs can be reduced, and companies can deliver customized products/services more efficiently as a result of the transformation. Furthermore, digitalization enables businesses to optimize not only individual production steps, but the entire value chain as well.

Companies can improve both their long-term competitive advantage and their ability to build capable organizations through digitalization (Rüßmann et al., 2015). This is also linked to a stronger connection between machines and products, which boosts industrial efficiency and helps businesses establish a competitive foothold. The ability to collect and analyze data across centralized machines tends to enable much faster, more flexible, and highly efficient processes for developing quality products at lower costs, which tends to increase productivity, economies of scale and scope, and trigger industrial growth in order to - establish a competitive advantage. [21]

What does digitizing operations and automating processes mean for businesses? The table 1 below points the major changes in each sector of a business.

Table 1: Digitizing operations

Management	• Incremental Business Model • Future-Proof Solution • Flexibility to Market Changes • Remain Competitive
Controlled Finances	• Efficient Resource Allocation and Utilization • Low Personal Costs • Reduced Investment
IT Infrastructure	• Scalable and Flexible Infrastructure • Short Iteration and Release Cycles • Reduced Development Effort
Sales and Marketing	• Automated Analysis • Personalized and Targeted Marketing • Increase Marketing Reach • Reduced Ad Spend • Increased Sales and Revenue • Enhanced Client and Customer On-Boarding
Production	• Automated Operations and Processes • Accessibility and Ease over Control

	• Precise Estimation of Production Quantity
Customer Service	• Efficient, Faster, and Automated Customer Care • Automated Knowledge Management • Central Customer Database • Automated Sales and Support

A survey was realized in 120 industrial companies in Czech and Slovak Republic (40% automotive, 30% mechanical, 20% external supply for automotive, 10% other industry). Figure 5 illustrates the survey. [21]

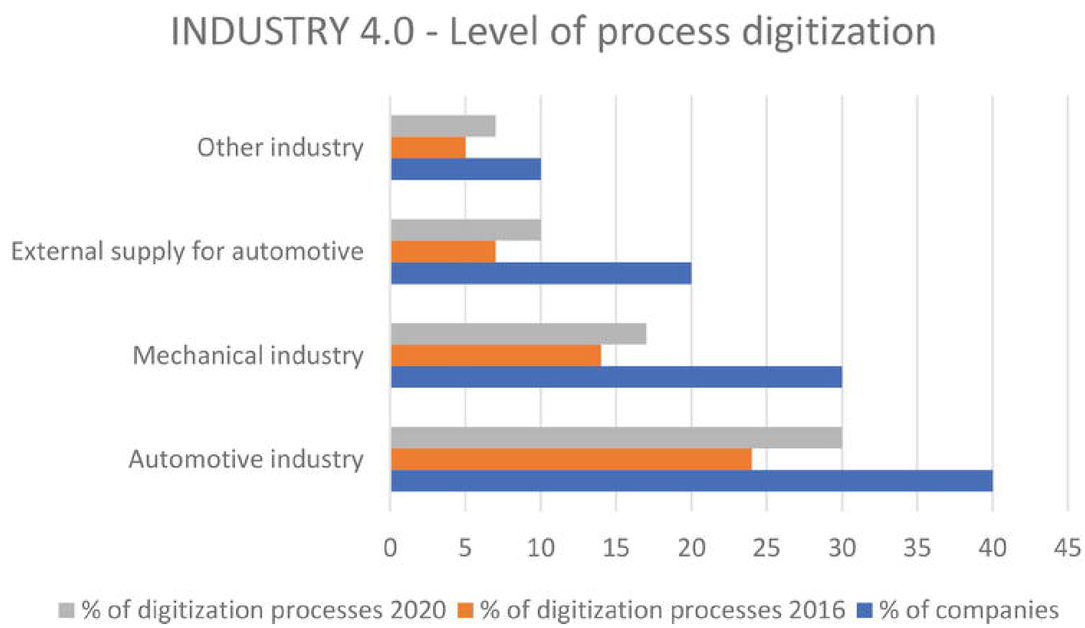


Figure 5:Level of Process Digitization [19]

2.5 Types of Manufacturing Automation

Industrial automation systems are classified according to the degree of integration and flexibility with which they can be used in manufacturing processes and operations. Manufacturing automation is a process of automating tasks, processes, and production through the use of technology. Its goal is to increase industrial output more efficiently and quickly than humans could previously. With fewer man-hours on the production line and more shifted to designing, operating, directing, installing, and troubleshooting automated systems, robots, software, machine algorithms, and equipment, manufacturers can increase productivity. It has changed the nature of manufacturing work by increasing productivity and the levels of expertise required to maintain it.[22]

2.5.1 Fixed Automation

Fixed automation manufacturing, also known as hard automation, is a method of producing a single product using automated production processes and assembly. The configuration of tooling, equipment, and machines allocated for high-production needs determines the sequence of production and operation. Fixed automation systems are designed to produce the same type of product. Once the system is in place, or fixed, it is impossible to change product styles without a great deal of difficulty. The integration and coordination of the many sequences and operations in the production of a single unit is where the system's complexity lies.

2.5.2 Programmable Automation

Using electronic controls, programmable automation systems enable changeable operation sequences and machine configuration. Reprogramming sequences and machine operations with programmable automation necessitates significant programming effort. Programmable automation systems are less expensive in the long run because production processes are rarely changed. This system is most commonly used in environments with limited job variety and medium-to-high product volume. It can also be used in large-scale manufacturing facilities such as paper mills and steel rolling mills.

2.5.3 Flexible Automation

Flexible automation, as the name implies, is a manufacturing method that can easily adapt and respond to changes in production needs, such as product type and quantity. Machines are controlled by computerized systems that are programmed and operated by humans using HMIs (human machine interfaces) (Human Machine Interfaces). The system can be set up, or programmed, to make multiple product types at the same time. A central computer system controls the production and material-handling systems. The system is well-suited to batch processes for businesses that produce a wide range of products in small-to-medium production runs.

2.5.4 Integrated Automation

Integrated industrial automation refers to the total automation of manufacturing plants, in which all processes are coordinated digitally and controlled by computers. It includes technologies such as:

- Computer-aided process planning
- Computer-supported design and manufacturing
- Flexible machine systems
- Computer numerical control machine tools
- Automated material handling systems, like robots
- Automatic storage and retrieval systems
- Computerized production and scheduling control
- Automated conveyors and cranes

A business system can also be integrated with an integrated automation system using a common database. That is, it allows for the complete integration of management operations and processes through the use of communication and information technologies. Computer integrated manufacturing and advanced process automation systems make use of such technologies.[22][23]

2.6 Benefits of automation in manufacturing

Following the effects of the global pandemic in 2020, we will see a steady increase in the use of automation in all aspects of the manufacturing process. The advantages of automation will be seen throughout the process, from production and assembly to tracking and monitoring. Physical distancing measures that cause supply chain restrictions are likely to increase demand for automation, allowing manufacturers to meet production demands with fewer labor resources.[23] Among the many benefits of automation in manufacturing, the three most beneficial outcomes are as following:

Increased Production Output

One of the most significant advantages of automation is the ability to perform tasks at a constant speed for longer periods of time. This means that by running your machines for longer periods of time, you can increase your overall production output. Furthermore, using machines can help you expand your production space by allowing you to add more workstations.

Increased Quality of Products

Machines can be programmed to perform highly skilled and precise motions, increasing product consistency and quality. When manufacturing processes are automated, you can rest assured that the quality of your products will not be compromised. This will save time and money by producing fewer scraps and requiring less rework to produce high-quality products.

Creation of Fulfilling Jobs

While it is true that automating operations can reduce the number of physically demanding and manual jobs, workers can now spend their time doing more fulfilling jobs that they would not be able to do if their time was solely dedicated to manual labor. Workers will have more time to do management, problem-solving, and complex critical thinking tasks as automation takes over the repetitive, time-consuming, and potentially dangerous tasks involved in production. Companies may need to invest in training in order to make the transition to automated processes go as smoothly as possible. [24]

3. Extent of automation in current manufacturing Systems

The trend toward automation is steadily increasing. Competition, regulation, security, quality, and cost effectiveness are all constraints that factories must work within. Factory automation can help to alleviate these constraints by providing practical and efficient solutions for a variety of tasks (that involve various types of output).

In 2020, the global industrial automation services market will be worth US$ 47.4 billion [27]. Many businesses are turning to automation services to reduce their reliance on manual labor and increase the speed of mass production. Furthermore, using industrial automation services speeds up production processes. As a result, it consumes less electricity and other resources, making the manufacturing process more cost-effective. The constant demand for efficient automated systems is another major growth-inducing factor for the market. As a result, several businesses are investing to help with research and development for these services. [27]

Recent advancements made my several key players have immensely helped automate manufacturing systems, although there is still a long way for the term “smart factories” to be used, there have been exciting advances in manufacturing automation. [27]28]

Cloud storage for wireless data

Cloud storage is one of the most significant advancements in automation, and it has the potential to benefit every industry. You can use cloud storage to store all of your data wirelessly. Almost any machine's data can be automatically uploaded, ensuring that all data is backed up over a wireless network. Furthermore, in the event that your computer crashes, your data is completely safe, accessible from any computer, and ready to be recovered from the cloud.

3D Printing in manufacturing for finished components

One of the most significant recent advancements in manufacturing and automation is 3D printing. Even though the technology has been around since the 1980s, machines were too large and the process too slow for widespread adoption. 3D printers, on the other hand, have progressed to the point where they can now produce finished parts. These machines now have improved accuracy as well as the capacity to handle larger sizes and production runs. As a result, they're being incorporated into processes across a wide range of industries.

Sensing, measurement, and process control

Additional sensing, measurement, and process control transmitters are now being added to industrial robots to aid in the navigation of increasingly nimble machines. These transmitters provide the data required to manage the factory's overall operations. From the moment a product is created until it is delivered, it can be tracked. Sensing, measurement, and process control transmitters make allowing machines to operate without human intervention even easier and more reliable. If something goes wrong, such as the humidity around an automated spray system being too high for the paint to dry, the sensor can detect the problem and send an alert to the machine operator right away.

3.1 Digital transformation in the ceramics industry

Because it is one of the industries that invests the most in R&D&I, the ceramics industry has been able to keep up with Industry 4.0. Private companies and public institutions such as the Institute of Technology of Ceramics (ITC) and the Spanish Association of Manufacturers of Tiles and Ceramic Pavements have expressed a desire to internalize the new smart manufacturing tools (ASCER). [29]

In terms of product handling and material processing, ceramic manufacturing processes are highly automated. However, in the traditional ceramic sector, one of the most common issues is that the machines and equipment responsible for each manufacturing phase are not interconnected, limiting the overall efficiency of the equipment (OEE). Although the sector's digitalisation has progressed in recent years, there is still a long way to go in terms of automating and optimizing data and information flow. [29]

3.1.1 Raw Materials

The handling and processing of raw materials, with the goal of homogenizing, mixing, and packaging them for subsequent inclusion in the manufacturing process, is typically the first stage of most industrial processes. These processes are characterized by their ability to run indefinitely. Enter the raw materials in bulk through various processes, and a steady flow of intermediate product is produced, ready to be used in the next stage of the manufacturing process.

The process typically entails the transportation of raw materials via carrier, worm, pumps, or pneumatic systems, as well as intermediate processing steps such as mixing, rolling, stirring, cooling, and so on. In terms of automation, these processes are controlled by a sophisticated PLC and HMI that allows the entire process to be sequenced. The following characteristics are common in these systems:

• Managing start and stop sequences

• Managing raw material processing formulas

• Reports for traceability of goods produced

• Advanced diagnostic information

• Managing personnel and equipment safety

• Automatic and manual control

3.1.2 Furnace and Burners

Furnaces play an important role in a variety of industrial processes. The furnaces are extremely sophisticated in terms of automation, as it is necessary to monitor various process parameters such as temperatures, flows, and pressures in order to maintain product uniformity and quality.

Advanced PLC, HMI, and SCADA systems ensure process control and parameterization, including valve and inverter control, reading of measuring instruments, and so on. [29][30]

In this process, case stands out:

• Parameterizations for each product type are separate and independent.

• Enhanced diagnostic information, such as temperature, pressure, and fan speeds

• Logs and reports

• Control is either automatic or manual.

3.1.3 Handling and moving

Many industries require the manipulation of intermediates or finished products. This manipulation is typically used to group or ungroup these products in order to progress through the manufacturing process. These operations are usually carried out by equipment that is highly automated and requires little human intervention.

In terms of automation, these machines are distinguished by the extensive use of positioning systems in a closed loop network for field collection of I/O (such as AS- Interface and Profibus/DP) and primarily movement speed changes.

Advanced PLCs and HMIs ensure control, allowing full control of the machines and parameterization of processes / sequences, such as:

• Placements and adjustable speeds

• Advanced diagnostic information

• Automatic or manual control

3.1.4 Dryers

The goal of drying processes is to keep temperature, humidity, and pressure at predetermined levels. These parameters are primarily responsible for the final product's quality, necessitating stringent control throughout the process.

As a result, specific algorithms or PID are used to investigate the entire process control system for temperature, humidity, and pressure. These aid in improving system performance by aiming appropriate responses to process disturbances while reducing fuel and electricity consumption.

Because of the process's requirements, PLCs are frequently used to integrate and control control and monitoring equipment. At the hardware and software levels, the platform allows for the control of proportional valves, variable speed drives, and burners, which act to control all process variables. [29][30][31]

In this case, the following stands out:

• Advanced diagnostic information for all instruments

• Automatic or manual control

• Logs and reports

• Separate and independent parameterizations and revenue management for each product type

3.2 Performance Management (monitoring and regulating)

Management and monitoring of plant operations plays a key role in the world of automation. To achieve optimal production management throughout its value chain, plants must increase the levels of control over its manufacturing process.

The need to connect the various parts of the process to standardize information and gain more control requires the implementation of the following measures:

Once integrated into the platform, a traceability system for each of the pieces of the multiple production lines is implemented, as well as tracking of each of them.

An extensive network of IoT sensors to monitor all production system information.

To obtain a more accurate and sophisticated overall equipment effectiveness (OEE) metric, a holistic database should be created to track all information and data flows coming from the global production system.

Design of a Digital Twin that provides production data in real time.

As a result, system automation ensures complete and high-performance management of all production steps from quality control to end-of-line and finished product transfer to the warehouse.[31]

The industrial revolution in the 18th century led to a new dawn in manufacturing. As demand for products grew exponentially with the increase in population, the usual go to domesticated methods of production became insufficient. The large-scale production of good meant different outcomes for the same product. With the advent of water and steam power saw to successfully automating processes for large scale production.

Continued technological advancements and the implementation of innovative technology such as IOT and automation have resulted in less strenuous working conditions as well as the creation of job positions that are not as labor intensive.

4. What is Industry 4.0

Gordon E. Moore a co-founder of Intel Corporation introduced what is known as Moore's law in 1970s. The law states that "The speed and capability of computers can be expected to double every 18 months, as a result of increases in the number of transistors a microchip can contain". Going back in history or at least until the 1970s, one can easily conclude that technology has taken a great big leap. We have come to an age of smart 'anything' phenomena. Which can be from smart grids, smart energy, smart buildings to smart cities. Given the exponential advancement in technology in the last decade, Moore's law can still be considered valid.

The evolution of digital technologies is undeniable, and society is confronted with challenges that come with it. It is important to emphasize and understand that Industry 4.0 is an information and digital revolution.

4.1 Industry 4.0 – The Concept

Industry 4.0 is a vision and concept in motion and puts together the two revolutions mentioned above. Firstly, introduced to the general public in 2011 at the Hannover fair this new manufacturing paradigm is characterized by intelligently connecting people, machines, objects and information and communication technology systems. Industry 4.0 is the information-intensive transformation of manufacturing (and related industries) in a connected environment of big data, people, processes, services, systems and IoT-enabled industrial assets with the generation, leverage and utilization of actionable data and information as a way and means to realize smart industry and ecosystems of industrial innovation and collaboration.[2]

The concept is mainly made possible by the bridging of physical industrial assets and digital technologies which is called cyber-physical systems. The core capabilities needed for smart factories are created using cyber-physical systems. Products and production methods become networked and can interact with each other allowing new production methods, value development and real-time optimization.

Before companies can exploit the opportunities yielded by Industry 4.0 and fully benefit from them, they need to implement Industry 4.0 in a targeted and adequate way. In management research, Industry 4.0, its implementation, and its economic, environmental and social implications represent a comparably young research field.[7]

Given the specific and complex nature of Industry 4.0, enterprises need to undertake appropriate implementation strategies tailored to the individual design of their institutional and process organization structure.[7] Yet, up to now, literature provides corporate practice with general and highly aggregated recommendations that are difficult to grasp and usually disregard company-specific characteristics.

4.2 Industry 4.0 as a fourth industrial revolution

Industry 4.0, as defined by Smart Manufacturing, is the fourth industrial revolution, which builds on the previous three. The first industrial revolution took place at the end of the 18th century, and it marked a shift away from agrarian production methods and toward mechanical production methods based on water and steam power. The second industrial revolution occurred at the turn of the twentieth century, and it resulted in mass production and consumption thanks to the invention of electricity.

In the 1960s, the use of electronics and information technology in industrial production signaled the beginning of a new era of optimized and automated production, which the fourth industrial revolution builds on. The Internet of Things (IoT) is at the heart of Industry 4.0, where the physical and virtual worlds collide, allowing intelligent ICT-based machines, systems, and networks to exchange data, respond, control, and manage industrial processes.

4.3 Cyber-physical systems and its place in the evolution of manufacturing.

Cyber-physical systems are networks of intelligent physical components, objects, and systems with embedded computing and storage capabilities that allow the smart factory concept of Industry 4.0. The cyber-physical systems serve as the foundation for new capabilities in areas such as product design, prototyping and development, condition monitoring, track and trace, structural health and systems health monitoring, innovation capability, agility, real-time applications, and others.

Cyber-physical systems effectively allow us to make industrial systems capable of communicating and networking with one another, thus expanding established manufacturing capabilities. “Industry 4.0 builds upon data models and data mapping across the end-to-end product life cycle and value stream. All the technologies in Industry 4.0 need to be seen in that perspective whereby integration is key.”

The first and one of the key integrations is that of information technology (IT) and operational technology (OT). “Without IT and OT convergence there is no industrial transformation, let alone modern building management and several other areas where the silos between different traditional systems disappear due to, among others, IoT on one hand and where IT and OT meet on the other, which is the case in close to all industries”

Since the integration of IT, OT, and their backbones (such as networks and infrastructure, to which we can also apply CT or communication technology) basically comes down to an evolved and improved use of the Internet, IT technologies, and IT infrastructure. Industry 4.0 is only possible because of cyber-physical systems.

4.4 Integrations in Industry 4.0

There are two key integrations in Industry 4.0 model that will be addressed in this chapter.

- Vertical Integration
- Horizontal Integration

4.4.1 Vertical Integration

The first is vertical integration, which affects all processes in the conventional automation pyramid, from the field and control levels to the manufacturing, logistics, and enterprise planning levels. In any form of industry, communication is a key factor for successful and efficient operation.

“Vertical integration will make the traditional automation pyramid view disappear.” The same is true for most the systems and applications across these various levels. Other systems such as ERP (Enterprise and resource planning) will change dramatically, whilst others will be replaced by rapidly emerging industrial IoT platform applications, particularly manufacturing platforms or vertical platforms for diverse tasks and using cases in many aspects of industry that are becoming increasingly functional and interoperable systems.

The essence of vertical networking comes from the use of cyber-physical production systems which enable plants and manufacturing plants to quickly respond to diverse variables such as demand, occupancy at warehouses, condition of machinery used and unexpected failures.

4.4.2 Horizontal Integration

This term refers to the real-time digital interconnection between entire supply chains and consumers. This approach facilitates data sharing and analysis, resulting in multiple benefits for all supply chain stakeholders as well as the consumer. Better process coordination across the supply chain, for example, will lead to improved resource efficiency in terms of material use, energy consumption, and waste processes, resulting in cost savings and increased productivity.

In a nutshell horizontal integration involves a complete value and supply chain digitalization, with a focus on data sharing and linked information systems.

4.5 DESIGN PRINCIPLES OF INDUSTRY 4.0

Technological advances in artificial intelligence, cloud computing and intelligent devices have led to transformative innovations for individuals and companies. This has been beneficial in assisting businesses begin the digitization process. “The successful integration of new technology relies on businesses developing well-designed systems that take into account how the technology will optimise departments to allow employees to do what they’re best at.”

The Industry 4.0 concept has several design principles that are used in the implementation of digitization or automation of production processes.

4.5.1 Interoperability

The ability of objects, machines, and people in a business to communicate, exchange data, and coordinate activities is referred to as interoperability. It is important to use this ability to connect everything to an enterprise everywhere and everyone to take advantage of data insights to improve processes and efficiency.

Because interoperability is impossible without connectivity, businesses must first digitise their operations by using cloud computing for software and data storage. The next step is the integration into business operations of software and open source platforms, such as Linux, Android, Apache OpenOffice, GnuCash, ADempiere, SugarCRM, Drupal, Wordpress, and OpenCart. [3]

Allowing open data sharing between systems helps companies reduce the costs of collecting and managing information, reduce unnecessary duplication, and leverage applications by third parties where necessary. Within interoperability, it is also possible to swap machines from different manufacturers with the same functionality. With the right choice of machines, production productivity can be increased, and machine life can be extended. At the same time, it will allow companies to use the latest technologies without having to change the entire production process. [3]

4.5.2 Virtualisation

Virtualization means that a virtual twin can be abstracted by the use of surveillance and machine to machine communication. Sensor data are connected with models and simulation models of virtual plants. A virtual copy is thus created of the physical world. A human being can be notified in case of failure. All required information is also provided, such as the following work steps and safety requirements. [5]

Digital twins, also known as 3D models, are used to improve machine performance by allowing users to run "what if" scenarios and assess the impact of new equipment. They can be used also for the purpose of viewing the machine's real time status, analyzing performance, testing solutions and identifying potential problems before they occur. This can help you extend the physical life of your company, reveal inefficiences in operation, reduce maintenance costs and improve your understanding of the equipment. [5][3]

4.5.3 Decentralisation

Decentralization is understood as the transfer of decision-making to local parts of the system, whether between human or mechanical operators, which will reduce the use of the central computer. Storing and transferring data in the cloud is a form of decentralisation, as is the automation of manual, repetitive tasks.[3]

Industry 4.0 decentralizes all technology, allowing for the creation of decentralized systems across all industries on a global scale. Moving decision-making to lower levels of the process corresponds to moving from the classical hierarchy to decentralized self-organization. A more flexible environment for production is created and it is possible to better adapt individual products to each client. [3][5]

4.5.4 Real-time capability

Real-time capability refers to the ability to collect and analyze data in real time, allowing decisions to be made instantly and at any time. It includes plants that can react to the failure of one machine by forwarding products to another, as well as a continuous link between the end consumer and the manufacturer, via social media or direct selling points, allowing for a faster response to demand changes. The use of real-time data and robotic systems is expected to disrupt current production methods and organizational structures. [3][4]

4.5.5 Service orientation

Businesses can better meet customer needs thanks to the real-time capability enabled by big data and the free flow of information enabled by interoperable systems. This enables businesses to respond quickly to changing customer needs and expectations, resulting in a more personalized service. [3][5]

As a result, across all industries, there is a shift in emphasis toward customers rather than products, and toward tailored services rather than mass production.

4.5.6 Modularity

This principle applies to modular systems that can flexibly adapt to different requirements by replacing or expanding single modules, thus facilitating the addition or removal of production modules. As a result, these modular systems can be easily adjusted in the event of seasonal fluctuations or changes in product production needs, such as when incorporating new technologies.[3][5]

Using modularity, many production processes, such as design, production planning, production, and services, can be partially simulated for multiple products at once. [3]

4.5.7 Concluding the design principles

The design principles introduced above are a generalized yet practical and important part of implementing Industry 4.0. All the principles overlap in the sense one cannot exist without the other. Each of the principles is a key part of the definitions of Industry 4.0's main components. The successful implementation of Industry 4.0 while adhering to design principles will have a significant impact on a company's supply chain.

4.6 Industry 4.0 main components

Some new technologies are important for the implementation of intelligent manufacturing and the Industry 4.0 concept. These technologies are interconnected or can be interconnected. The core technologies of Industry 4.0 include the Internet of Things, the Industrial Internet of Things, big data, data analysis and smart factory. These technologies are fundamental because they are contained in all dimensions of Industry 4.0.

4.6.1 Internet of things

While a precise definition of the Internet of Things has yet to be defined and embraced globally, there is broad consensus on what it stands for, what it entails, and how it should potentially operate. One definition according to Kagermann et al. is IoT is a manifestation that allows “things” (robots and machines) and “objects” (smart phones, laptops, and tablets) to interact with each other and cooperate by sharing information to reach common goals. Simply out IoT is a dynamic network that connects various objects. These objects can use standard protocols to communicate with each other and with the outside world. Because IoT connects all of the

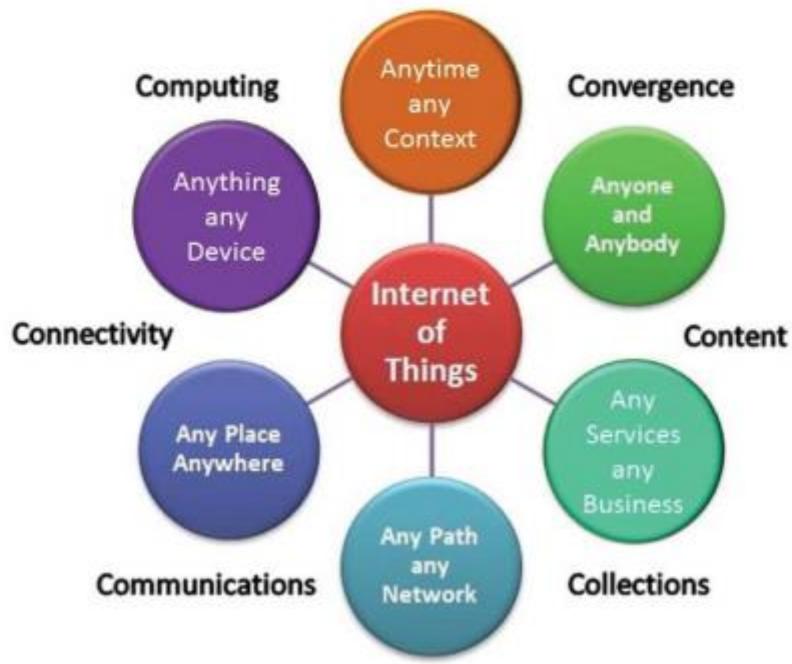


Figure 6: Chart of IOT [5]

subnets known as Industrial Internet of Things (IIoT), Internet of Services (IoS), Internet of People (IoP), and others, it is also known as the Internet of Everything. The figure 6 above gives a description of how vast IoT is and its importance in Industry 4.0.

4.6.2 Industrial Internet of Things

The Industrial Internet of Things (IIoT) consists not only of common network devices, such as mobile phones and other wireless devices, but above all it connects devices that appear in production plants, such as industrial sensors, from which data is loaded to the cloud and subsequently processed, production machines and more. [4]

After integration into the production plant, IIoT should make production monitoring available. IIoT can be used together with technologies dealing with Big Data, which can be used to variously optimize production processes using production data and their evaluation. The goal is to increase the level of automation at domestic and commercial levels.

4.6.3 Big Data Analytics

Collecting and evaluating data from many different production facilities and systems, such as production systems, will become common in real-time production decisions. Big Data Collection and Analysis has four main parameters: data volume, variation, collection rate, and data value.

Data can be collected during the entire production process and, according to the collected and evaluated data, follow-up production actions will take place. Data analysis is used to find out why certain problems have occurred in production or also to predict new inconveniences and to ensure that these problems do not recur or are completely prevented. [6]

4.6.4 Smart Factory

The smart factory is the next step forward in the evolution of automation. It represents a fully integrated and adaptable system that processes continuous data flow to improve and adapt to new demands. This phenomenon allows for the transition from sequential, linear supply chain operations to open, interconnected supply chain operations, i.e. to a digital supply network that integrates data from multiple sources and locations, processes it in real-time, and drives the physical act of production and distribution.

Smart factory is the center of all smart production processes. An efficient and agile system can be achieved through the integration of all data. It is also possible to achieve less production downtime and a better ability to predict and adapt to production changes as a result smart factory can have a productivity far beyond our expectations. [4]

4.7 Impact of Smart Factories on Production Processes

Each production process will have a different impact by the smart factory concept. Table below shows various production processes optimized with modern technology.

Table 2: Processes within a smart factory [14]

Process	Optimization

Manufacturing operations	Additive manufacturing – prototyping or low-volume spare parts Advanced scheduling and planning - to minimize time-consuming waste and cycle time by using real-time production and inventory data Cognitive bots and autonomous robots - to efficiently execute routine processes, with low cost and with a high accuracy Digital twin – digitizes an operation and transfers to predictive analysis beyond automation and integration.
Warehouse Operations	Augmented reality – assist personal with tasks Autonomous robots – perform warehouse operations
Inventory tracking	Sensors - track the movements of raw materials, work in progress and finished goods in real-time Inventory optimization on hand and signal for refilling automatically
Quality	Quality testing on-line using optical analytics Effective monitoring of equipment to predict potential problems of quality.
Maintenance	Augmented reality to assist maintenance operations.

	Sensors for predictive and cognitive maintenance analysis equipment.

4.8 Key Technologies

When a smart factory is created, IIoT is used to integrate basic elements in the production process. This allows the production system to perceive, interconnect and integrate data. Big data analysis is used to achieve the production plan, service the equipment and control the quality of products in the smart factory. Through human-machine interaction, a global process of smart factory cooperation with demand management is built. The smart factory is therefore a system that is characterized by three main aspects: interconnection, collaboration, and implementation. Smart factory consists of four layers: the physical resource layer, the network layer, the data application layer, and the terminal layer. [31]

4.8.1 Physical Resource Layer

All manufacturing resources that form the basis of intelligent production are part of the physical resources of the entire manufacturing life. New needs for equipment, production line and data acquisition are brought forward by efficient manufacturing of customized products. Therefore, current problems of key technologies should be solved to meet the demands of the smart factory. These physical resources must be changed so that it is possible to achieve the configurability of individual production facilities or entire lines and obtain data from these units. [32] Figure 6 shows the hierarchical architecture of smart factory.

4.8.2 Reconfigurable Manufacturing unit

Today's production facilities lack a high level of specialty and a relatively small range of applications due to a lack of flexible and configurable construction, causing poor adaptation to changing production environment. The production unit, modularized by production equipment (e.g., industrial robot, mechanical arm, and center of processing), enhances dynamic scheduling. In addition, the controller can be reconfigured and extended to other production facilities.

Modular Manufacturing Units

The level of intelligence of a smart factory is closely linked to modular production units, so it is important that their intelligence is as high as possible. There are several design proposals for modular production units.

Modular production units should cooperate with each other to achieve the main tasks, where the emphasis is on mutual perception and cooperation of the mechanism with intelligent modules.

The functions of different modular production units can overlap, so it is important to choose the right ones that will not duplicate their functions too much.

Each production unit must not only meet the production requirements of the product, but also improve the efficiency of production and self-organization. [32]

Configurable Controller and Reconfigurable Production Line

The configurability of the control system means that it is possible to add, replace or reuse hardware or software components of the system. Proper control system configuration can improve the configurability of the production unit, which expands the unit's ability to work with multiple applications. In this case, the production unit can adapt quickly to changes in operating conditions.

The reconfigurability of the production line can create a wide range of different products thanks to its variability, scalability and schedulability, which are the basis of production in a smart factory. The problem of current lines is in strong specialization. The aim is to replace these specialized lines with configurable ones, which can be changed and thus respond to changes in the market.[31][32]

4.8.3 Intelligent Data Acquisition

Basic information for workshop scheduling and intelligent service in a smart factory is represented by manufacturing resource data. In a smart facility, the wireless sensor networks (WSNs) are used to monitor, acquire, and log data. The production execution system can correctly implement production schedules based on data analysis and the use of an intelligent equipment for manufacturing scenarios. Radio-frequency identification (RFID), ZigBee and Bluetooth are the most common types of wireless sensor networks.

Near-Field Communication (NFC) has been studied as a means of accessing manufacturing resources since the development of RFID. Furthermore, both Bluetooth and ZigBee meet the cost-of-industrial-automation-of-wireless-communication-technologies requirements (e.g., low price and low energy consumption). In the manufacturing area, various types of special sensors are used to collect data, and the devices are all independent of one another. In a process visibility system, manufacturing resources should be able to support fine-grained data acquisition. [32]

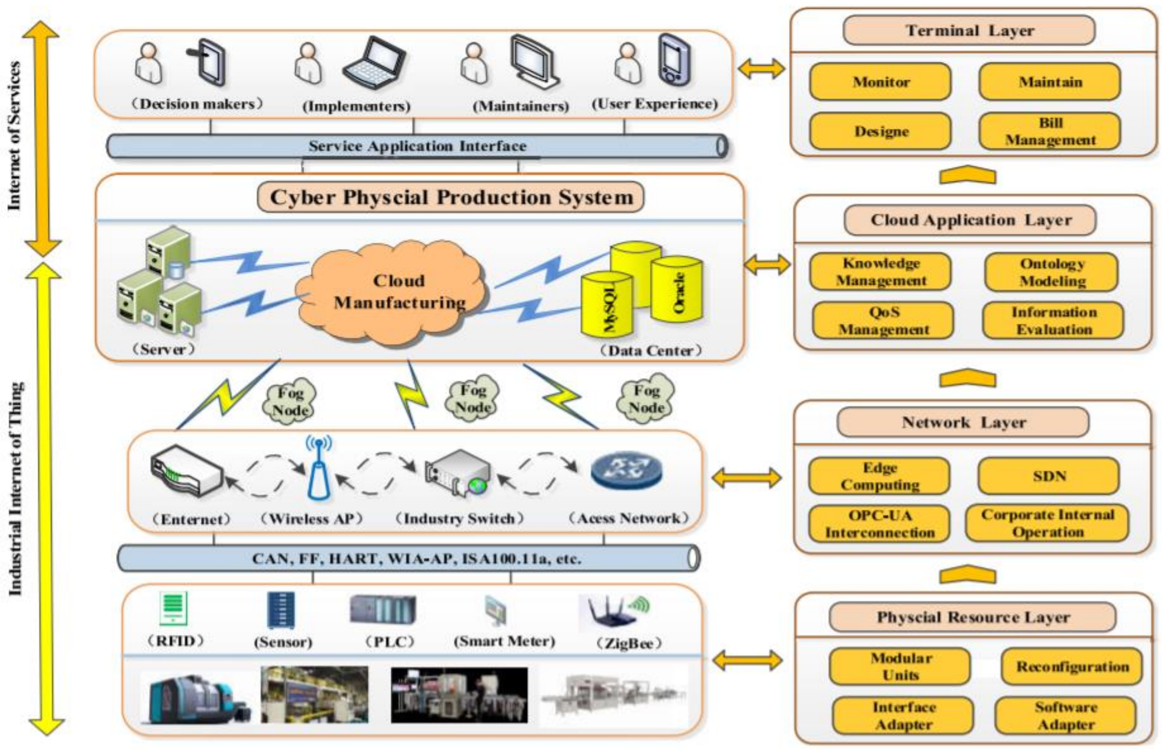


Figure 7: Hierarchical Architecture of smart factory [32]

4.9 Network Layer

Industrial networks are made up of a variety of network technologies, including field bus and sensor networks. In the smart factory, the network layer, which is characterized by perception and control, is critical. Data transmission, information sharing between intelligent equipment, and the manufacturing cloud platform all require real-time and reliable network techniques as cloud computing technology improves. Other technologies continue to improve to meet the demands of big data. But there are still a lot of problems with network technologies. Essential ones include data routing, congestion management, and error handling. IWSNs represent expanding wireless networks designed for industrial production. Wireless IWSNs should meet the highest standards in latency, reliability, baud rate, and low power consumption. [32]

4.10 Data Application Layer

The ontology model establishes the semantic association between manufacturing data. The goal of data application is to extract knowledge from data resources and create a value chain for industry. Structured and semi-structured data are the most common types of industrial big data. Data-driven innovation will continue to promote intelligent manufacturing as data mining technology advances.

4.10.1 Ontology-based Manufacturing Model

The ontological model of production resources is a new technical view of the construction of a smart factory. Due to the improvement of the production system configurations, the ontological model supports interoperability. This model is also able to apply optimized production resource management, as well as provide a semantic basis for consistent description between different applications. In addition, the ontological model should unify other criteria important for production, such as clarity, consistency, scalability and minimum deviations. In the smart factory, the ontology-based manufacturing model opens up new research opportunities in fault diagnosis, equipment health prediction, and active preventive maintenance. Figure 8 illustrates the model. [32]

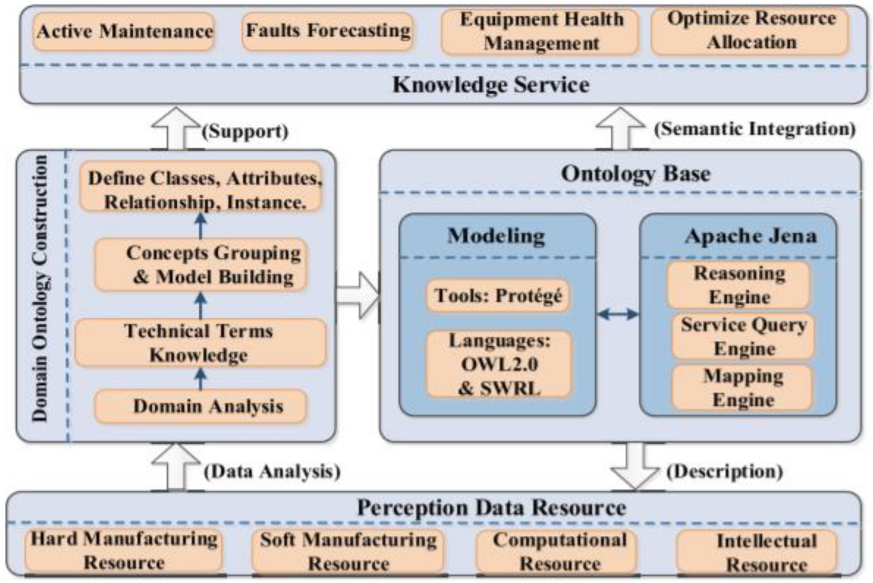


Figure 8: Ontology-based modelling method [32]

4.10.2 Applications of Big Data in Manufacturing

Real-time sensor data, machine logs, and manufacturing process data are examples of big data in smart factories, which have a large volume, multiple sources, and spare value.

Big data applications in industrial supply chain analysis and optimization, product quality control, and active maintenance are rapidly developing in the context of intelligent manufacturing. [32]

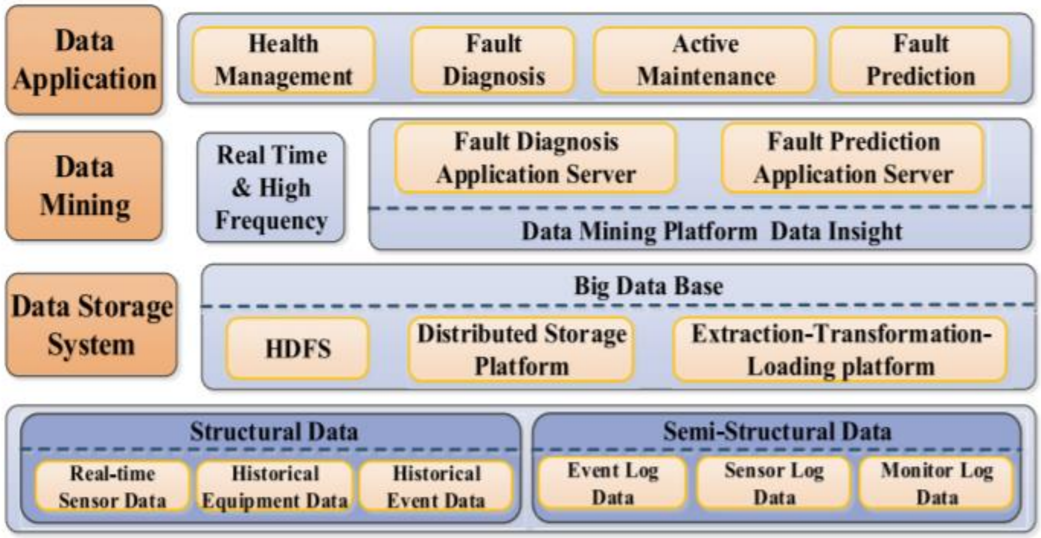


Figure 9: Open application architecture based on manufacturing big data [32]

The smart factory is an intelligent production system that combines manufacturing and service delivery. To meet the industrial demands, it integrates communication, computing, and control processes. The data-based virtual manufacturing mode will improve product quality, increase production efficiency, and reduce energy consumption as big data technology advances. Furthermore, the revolution of traditional industry will be fueled by intelligent manufacturing based on big data. Figure 9 summarizes the big data practices.

5. Analysis of the current state in PD Refractories

This chapter is devoted to the analysis of the current state of production in the model Czech company PD Refractories CZ as the company was selected to collaborate on this thesis, because it is one of the largest companies in its field in the Czech Republic and interested in continuous improvement of its own production, which would lead to to improve it, and also, as is the trend today, to minimize human labor. It describes the model company itself and how the production of refractory products in its production plant takes place.The analysis will also include all currently implemented elements of production monitoring and control. The whole analysis will take place in order to best select the production sites where it will be possible to introduce elements of modernization associated with Industry 4.0.

5.1 Analysis of current state of production

Earthenware and refractory clays, as well as slag, are used to make refractory products. Low water absorption, low gas permeability, and high compressive strength are some of their characteristics. All of these properties, of course, apply at high temperatures. They are used to remove any type of fuel's flue gases.

The entire production begins with the transport of the used production raw materials to the production plant premises, continues with their storage and then the fraction of production raw materials is adjusted to the required size. After the preparation of all production components, the production mixture is mixed. This production mixture is left to stand in a stacker. After the mixture has matured, the products are extruded on a press according to the required dimensions. From the press, the products are transported by means of drying trucks to the drying oven, where the heat treatment of the product begins. After drying, the products will be transferred from the drying wagons to the kiln wagons. These cars first make their way to the preheating furnace, where the products for entering the tunnel kiln will be properly preheated.

At the moment, the production of the model company is primarily dependent on the human factor. People determine all of the major parameters based on their prior experience, whether it's how much water to add to the mixer, whether it's sprinkled before the press, if inappropriate moldings emerge from the press, or shape control at the end or during production. The entire manufacturing process is divided into the following stages: mixture preparation, semi-finished product creation, heat treatment, and inspection and storage.

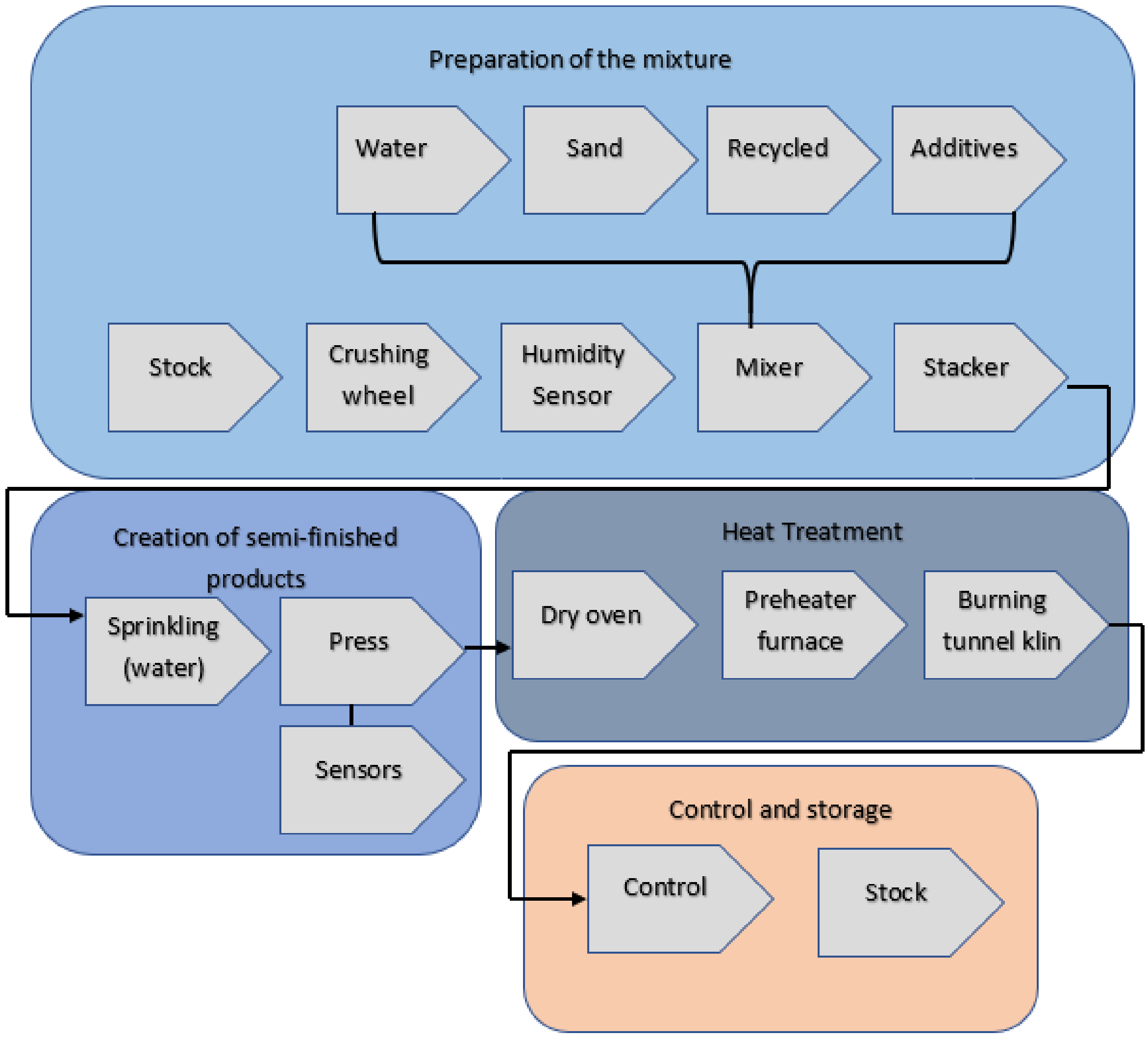


Figure 10: Production block diagram

5.1.1 Transport, storage and preparation of the production mixture

The input raw materials for the production mixture are transported to the production plant either by trucks or by train. The main warehouse holds the transported raw materials, which make up the majority of the production mixture. Clay, slag that is transported and stored in bags, and recycled material are among them.

All of these items are kept in a single warehouse that is divided into several sections. The warehouse is roofed, but there are no walls on some sides to support the handling of stored raw materials. Because one of the most demanding variables in production is the humidity of the production mixture, which can change significantly and affect the entire production process, and in the worst-case scenario, affect the quality of the final product, proper storage already has an impact on the final product. The clay is homogenized during this storage to make the entire production process as simple as possible. Other ingredients that do not require such a large amount of space are kept close to the mixer.

Figure 12: Burnt recycled material storage[38]

Figure 11: Clay and slag storage[38]

These primary materials are transported to the feedstock preparation plant by crane and conveyor from the warehouse. The individual components of the mixture are weighed and recorded to the required fraction size using two crushers. They are then transported directly to the mixer where a humidity sensor is mounted on the conveyor device.

Figure 13: Humidity Sensor[38]

In the mixture preparation room, there is also a control room where the recipe of the mixture is determined using a SCADA-based program. The weight of the individual raw materials entering the production mixture is determined by this program. These raw materials are water, slag and refractory clay. This program sends the required weights to the scales, where the weight of the given raw material is dosed and transported to the mixer via the mixture preparation plant. Here, a production mixture is formed from the input raw materials.

The mixer incorporates all of the production mixture's components, including water, clay, slag, and other additives. The raw materials are combined to create a homogeneous mixture. Due to a non-functional humidity sensor before the clay enters the mixer, determining the moisture, which is necessary for further processing of the mixture, is a major issue. The mixer is where the main humidification of the production mixture takes place. A basic production mixture is formed in the mixer at the same time.

From the mixer, the mixed production mixture already travels along the conveyor belt to the stacker. The production mixture is stored in the stacker for the time designated for the necessary homogenization of the production mixture. The homogenization time is approximately 24 hours. A new mixture is continuously coming into the mixture stacker and the one that has been here the longest is taken. After the desired homogenization of the production mixture for extrusion, the mixture is extruded from the stacker to a conveyor, which is directed to the part of the production where the extrusion takes place.

5.1.2 Creation of semi-finished products

After the specified 24-hour period, the mixture is gradually removed from the hopper and processed further. On the conveyor, the mixture travels from the hopper to the press. This conveyor has a sprinkler installed on it, which can be used to moisten the mixture if it is too dry. This is the last point in the manufacturing process where the production mixture can be altered. The press operator or technologist has the final say on whether to moisten the mixture.

The mixture is then sent to the press, as previously stated. The mixture passes through a pre-pressing chamber, which houses a horizontal screw press, before being extruded. A vacuum is used to deaerate the entire production mixture, which is important for the quality of the products and their compaction. The press, which is supported by an internal mandrel, extrudes an endless zone of products. The mouth of the press is determined by the extruded zone's outer shape, while the mandrel supporting the extruded zone determines the internal shape and dimension. The area behind the press is then divided into the required length.

The press has sensors in the pre-press chamber that monitor the press pressure, engine speed, press load, and vacuum value. On the press control unit, the values measured by the sensors can be viewed online. The press pressure parameter is the most important for the quality of the extruded insert of all the monitored parameters. The pressure at which the insert was extruded is represented by this value. To deaerate the mixture, the value of the vacuum in the pre-compression chamber is also important.

The selected product's pressure value and dimensions are recorded from the press. This is done in paper form on record sheets once per shift. All press components that meet the production mixture wear out quickly due to the high extrusion pressure and the highly abrasive nature of the mixture.

The cutting is performed using a wire saw. This wire saw works on the principle of the force of the wire acting on the infinite band, and thus individual products are created. If necessary, the product can be supported by the jig to prevent its deformation due to the action of the wire. The bed on which the product is divided has a shape adapted so as not to deform the product but, on the contrary, to support it.

Figure 14: Wire saw[38]

Afterwards, the product is moved away from the press on a conveyor. A manipulator picks up the product from the saw and transfers it to a conveyor, which moves it to the next step in the manufacturing process. A rolling mill is used here with the purpose of calibrating the shape of each passing product to the desired shape. The insert is grasped by a manipulator behind the rolling mill, which uses vacuum suction cups to transfer the product to a different location.

5.1.3 Heat treatment

Following loading into the drying wagons, the wagons are pushed along the rails to the drying ovens by hand. The products are heated for the first time in the drying ovens. The products are dried to remove any remaining moisture from the production mix. Moisture in the mixture is required for proper extrusion on the press, but moisture in the product is no longer an issue during the firing process. The drying process is carried out to protect the products from damage during the firing process. During firing in the firing furnace, the product would crack due to internal stress.

Figure 15: Drying oven[38]

The drying process takes about one day and takes place in a continuous multi-chamber drying oven at a temperature of 100 ° C. The amount of time it takes for a product to dry is determined by the type of product, its size, and the exact manufacturing mixture. On the other side of the drying ovens is an outlet where the drying wagons are transported for loading onto special kiln wagons. Temperatures are changed to maintain trade secrets, but the evolution of temperature changes is maintained, and the correct units of time are not listed. During firing, a gradual increase in temperature and its subsequent decrease is important to ensure proper firing and to prevent cracking of the fired products. A gradual increase in temperature is achieved in the kiln by means of several heat belts and a slow movement of the kiln wagons across the kiln as the products go through the firing process in approximately one full day.

5.1.4 Quality control and storage

The kiln car leaves the tunnel kiln, where the final heat treatment took place, after the products have been heat treated. The kiln car is driven to a location where the products are manually sorted. Inspection of all products is part of manual sorting. The products are first visually inspected for cracks and fissures, and then they are tapped to see if they collapse. Finally, a caliper is used to check the product's dimensions. Products that meet all the criteria are stacked on a euro pallet, which is then packed and transported to a specific location within the shipment. Non-compliant inserts are transferred to a container designated by them, then to a warehouse, where they are reintroduced into the manufacturing process as an admixture in the production mixture.

5.1.5 Production management and monitoring

During the whole production process there are several places where a certain type of production management and monitoring is manifested.

The first instance where production control takes place is right at the beginning of the entire production process, when determining the recipe of the production mixture. The SCADA program is used in the mixture preparation, which is connected to the dosing scales to the mixer, and with the help of this program the weights of individual components of the production mixture are determined.

Another place where regulation takes place are furnaces. All three furnaces are regulated to reach the required temperatures for firing the products. These furnaces are, of course, also monitored by temperature sensors so that the temperature inside the furnaces is known.

In front of the furnaces, monitoring occurs during production and in other places. The first place in the production process where the monitoring attempt has been blocked is the place where the input raw materials are transported to the mixer. A humidity sensor is installed here.

Another place where monitoring takes place in the production process is on the press. The press is equipped with several sensors that monitor its operating characteristics - press pressure, press load and vacuum value in the pre-press chamber. These values are displayed live on the monitor at the press line. The pressing pressure is recorded once per shift on a paper record sheet.

6. Proposal for the implementation of elements of the Industry 4.0 concept

After the analysis of the production line for refractory products, critical production points are identified, which are suitable for the modernization and introduction of elements of Industry 4.0. The quality of the production mixture creates the biggest problems in the production process of refractory products. The biggest problem with the mixture is its humidity. The raw material that has the greatest moisture instability is clay. Clay affects the mixture the most, because about half of the mixture is made up of clay. The moisture content of the clay is variable due to different outdoor conditions during mining, transport to the plant and different storage conditions. Mixing the right amount of water into the production mixture could stabilize the quality of the mixture and reduce the number of products that do not pass control. Furthermore, it is necessary to design an information system over the entire production, where data from its entire course will be recorded. Nowadays, it is possible to trace various production data, for example from a press. It is also possible to trace the time of entry and exit of the kiln, but no temperature is recorded here, which is also an important factor for proper firing. However, nowhere is this data kept complete. The data are kept in record books after the production plant. If they are recorded electronically, they are not in one program for the whole production process but are recorded in individual programs or files. which is also an important factor for proper firing.

This chapter proposal of implementation of elements of the concept Industry 4.0 proposes individual concepts that can be introduced into the current production of the model company. The draft concepts deal with four parts in which modernization can be introduced. Concepts for implementation into the production process of the model company will be described in subchapters. The concepts will focus on storage, mixture preparation, control, management of the production process and how they will be connected through the control system.

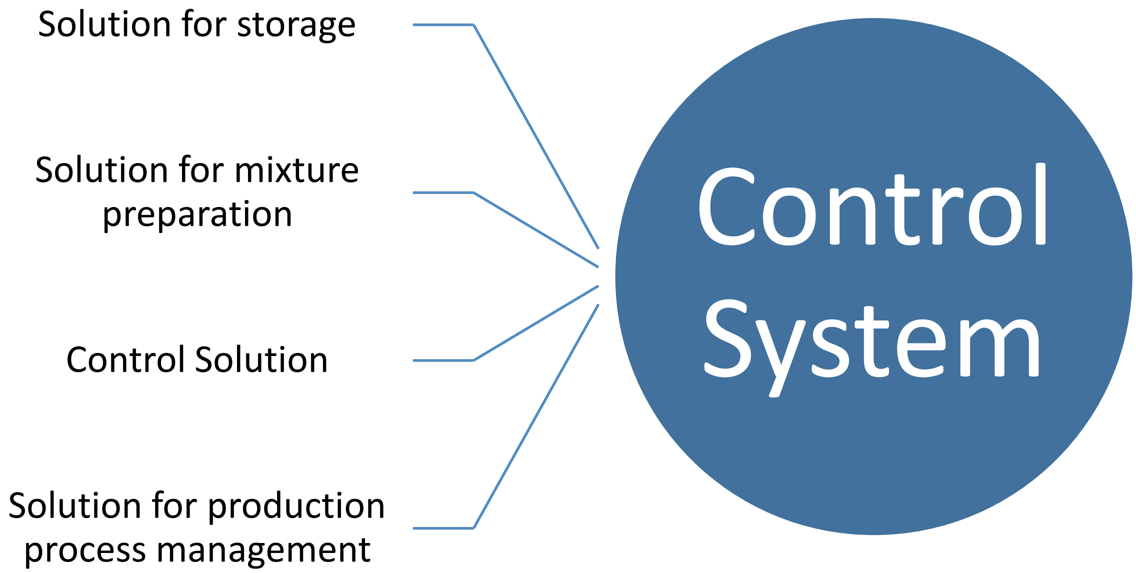


Figure 16: Proposal for implementation

6.1 Conceptual solution for the input raw material warehouse

In this part, solutions for storage of input raw material will be outlined. The conditions under which raw materials are received and utilized is one of the main important factors for the production. A slight change in condition can have drastic effects on all parts of production resulting in a higher number of finished goods that would not meet the minimum requirements in quality. The first instance where the input raw materials appear in the production plant is the warehouse. Until then, the input raw materials are under the supervision of suppliers and the production plant cannot influence the conditions under which they are supplied. All input raw materials are affected by the surrounding weather, especially air humidity and temperature. The environmental conditions cannot be influenced by the supplier either, as they are determined by the season. In winter the humidity is high and fluctuates, while in summer it is low and stable.

The main component of the production mixture is clay, which makes up about half of the ingredients depending on the recipe. According to the experience of the workers in the model company, the moisture of the clay is important during production. Another ingredient, which makes up about a quarter of the content of the production mixture, is the flake. The husk is a rock, but it is not very prone to changes in properties. The last main ingredient in the production mixture is the burnt recycled material from production, which is usually contained in one fifth of the mixture. Due to the fact that this material has already gone through the entire production process, the storage style is very similar and it is also enough to protect them from the fundamental effects of the weather. The warehouse should primarily protect the recycled material from direct sunlight and the effects of other weather such as rain, snow and drastic changes in the climate.

The properties of clay are affected already during its extraction, then during transport to the production plant, and finally also in the production plant. For the best possible work with the clay in the later stages of production, it is advisable that the production batch of clay is properly homogenized. Above all, this process ensures the same moisture content in the clay throughout the entire stored batch, as well as the same other properties. For the best possible conditions, the raw materials should be constantly monitored to know the state of which they are in. In the following subchapter I will talk about monitoring of stored raw materials and monitoring of storage conditions.

6.1.1 Monitoring of stored raw material

The best option is to monitor the stored raw material while maintaining the state of the warehouse and provide it with sensors. Since the state of the warehouse would be maintained the only cost would be that of the sensors and installation of the sensors. Due to the fact that the production depends mainly on the moisture content of the raw material, the humidity of the stored raw material would start to be monitored. In the future, monitoring could be extended to obtain more data of the state of the stored raw materials.

Given the fact that there is a lot of raw materials stored and used in a day it would be cumbersome for anyone to physically sit and monitor the dat. Therefore, it would be more efficient and precise to have a software with preset conditions that would monitor the data from the sensors. In this design, IoT sensors can be used, which would be installed in the floor and walls of the warehouse and would send information about the measured values at regular intervals. This information would be sent to the control system, which would continue to work with the data. The control system also could inform the person in charge about any unexpected fluctuations in the humidity.

The great advantage of this storage design is the knowledge of the moisture content of the clay in the production mixture. Knowledge of humidity is suitable for determining the water dosed into the production mixture. Determining the methodology for sensing such an amount of clay would be very difficult and due to the constant change in the amount of stored raw material. Therefore, it is necessary to consider the amount of raw material stored in a day before purchasing the required sensors.

6.1.2 Monitoring of storage conditions

The proposal for monitoring storage conditions is devoted to monitoring the ambient temperature and humidity in the warehouse during storage. Storage conditions have a major impact on changing the properties of stored raw materials. In the future, it would be possible to introduce monitoring of more parameters. The design can be applied in the previous variant of raw material storage. With the help of this design in combination with the monitoring of the stored raw material, it would be possible to monitor the influence of the state of the environment on the humidity of the stored raw material.

6.2 Conceptual solution of production mixture preparation

The preparation of the production mixture follows immediately after storage of the raw materials. Here, the first modifications of individual input raw materials take place, for the needs of the next production process.

In this part, it's about preparing the right production mix. Several different raw materials enter the production mixture. The amount of these raw materials is determined according to a recipe that is determined for production by a technologist.

The main task is to adhere to the parameters given in the recipe in the preparation of the production mixture. It is important that all elements of the mixture come into the mixer in the correct amount. If this is done, the mixer has the prerequisites to prepare a quality production mixture. In the current state of the production process, the ability to weigh the right amount of raw materials is fully satisfactory. However, it is not possible to determine the moisture content of the clay to calculate the weight of the mixed water.

As mentioned several times, the main factor that affects the quality of production is the moisture content of the clay. Therefore, this part is focused on the possibility of monitoring the moisture of the clay and the subsequent reaction of the mixer during the preparation of the mixture.

6.2.1 Check the humidity in front of the mixer

A moisture sensor is placed on the conveyor transporting the clay from the mixture preparation plant, which would be able to monitor the humidity of the clay entering the preparation of the production mixture. The sensor would also evaluate the data and determine the average humidity of the clay added to the mixer. Based on this average humidity, the required addition of water would be determined, which would be added to the production raw material.

Several types of sensors can be used, as one of the types suitable for the application of clay monitoring on the conveyor is microwave-based sensors.

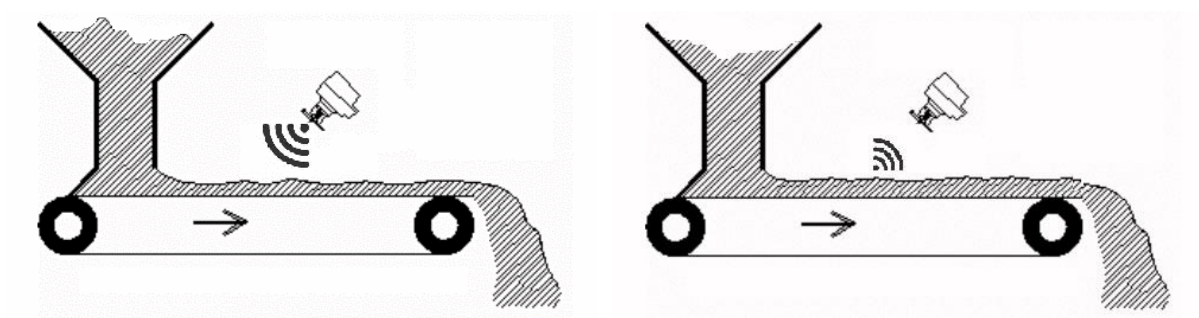


Figure 17: Microwave Sensor [29]

6.2.2 Checking the humidity in the mixer

As in the previous proposal, humidity is monitored here. The difference between this and the previous design is in the place of monitoring and also in the type of sensors. This system would monitor the moisture of the entire mixed mixture and be located inside the mixer. As a result, the mixer would have to be modified.

The main intervention in the current state would be the installation of hygrometers inside the mixer. Four sensors would be installed around the perimeter of the mixer and the values would be evaluated and averaged.

The mixing of the production mixture would take place subsequently. First, all input raw materials would be dosed and transported to the mixer by means of conveyors, where they would be mixed. After sufficient mixing of all raw materials, the humidity of the mixture would be determined using the installed sensors. Subsequently, the required addition of water to the mixture would be calculated. The water would be metered in and again the entire batch of production mixture would be mixed. The production mixture would then be sent for further processing.

The main advantage of the design of the sensors inside the mixer is the determination of the moisture of the mixture. However, a problem could arise if all the input components were insufficiently mixed and homogenized. This would not accurately measure the moisture of the mixture.

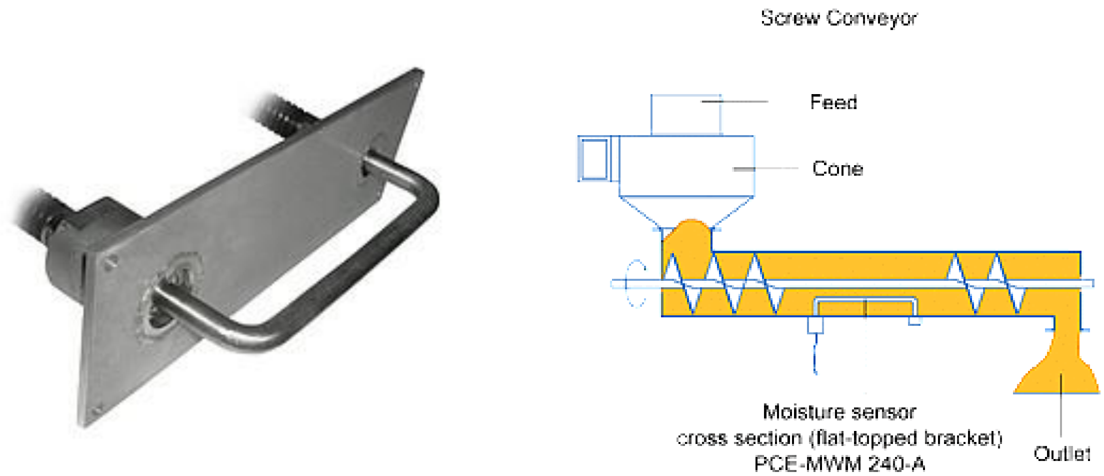


Figure 18: Humidity sensor [32]

6.3 Conceptual control solution

The inspection workplace comes next in the production process immediately after the fired products on the burning car leave the tunnel kiln. The car is taken from the furnace to a designated place for inspection. At the inspection workplace, the product is first removed from the kiln wagon. Then to determine the quality of the product, the conformity / non-conformity of the product with the caliber and the composition of the product on a pallet, on which the products are further stored and then shipped. In case of non-compliance with any quality parameter, the products are stored in a container for non-conforming products.

This process can be automated both in terms of evaluating the quality of individual products and handling them.

The control workplace is very important in the entire production process. The importance of this workplace lies in the fact that there is no shipment of low-quality products or that does not meet the guaranteed dimensions, because quality products are the main presentation of the company.

6.3.1 Robotic workplace

This proposal is to solve the entire control workplace using a robot, so there would be no human work during the control.

A product truck would be transported to the robotic control station. The car would be captured by an additional intelligent camera, which would be able to distinguish individual products and at the same time find out how the robot should proceed when removing products from the car. The robot would proceed by grabbing the product, placing it in front of an intelligent camera, which can evaluate itself whether the product is identical to the required dimensions and whether there are any defects on the product.

These cameras can process images and determine the dimensions of the scanned object, evaluate the images and determine the quality of the product. Based on the data from the cameras, the system evaluates whether the product meets or does not meet all quality requirements. Based on the evaluation, the beacon lights up either green or red at the end of the conveyor, depending on the evaluation of the product quality. At the end of the conveyor, the product will be stacked on a prepared pallet for dispatch if all conditions are met. If the product does not meet all quality conditions, then it will be moved to a container for non-conforming products. These products will again be included at the beginning of the production process as recycled. It is important to design the conveyor so that it is possible to transport all types of products that are manufactured in the plant. It is also important to position the cameras so that all products can be captured.

6.4 Conceptual solution of production process management

Conceptual proposals for the management of the production process consist in the information interconnection of individual parts of the production process. It is important to have a properly designed communication system for all the previous parts to work properly. It is also important that the individual sensors and devices send the recorded data to the control system or, if necessary, process it themselves.

The control of the production process is a very important part of it, without which no automation of the production process could take place. This section describes how the device should respond to data from sensors, from which sensor it should use the data, or send it to another device or database.

A good management structure is important especially for easy handling, scalability, and real-time response of individual devices.

The work proposes two ways of managing the production process. The first is control by means of the main control system, where everything is controlled by one control system. All devices send data to the control system, which consists in the fact that all measured data are sent to one control system. Here, the data is evaluated and then orders are sent to the device to modify the production process.

The second proposal is decentralized management, which works on the principle of individual decision-making of individual parts of the production system. Here are the individual subsystems that work with the sensors and devices they control. The subsystems obtain data from the sensors and based on the evaluation, issue commands for the device. The only shared part between all devices is the only database to which the individual subsystems send data for subsequent analysis. Based on the management and monitoring of production, it is possible to make an analysis of the production process.

6.5 Main control system

The main control system is based on one decision element. All devices and sensors operating in the production process are connected to the control system. At the same time, the control system has a database where it stores all data. All communication takes place only between the control system and the production equipment. Thus, in a normal manufacturing process, the sensors send data to the control system. The data system evaluates and sends instructions to all devices for which a change in the production process is to take place.

All data are stored in a database at the control system, where it is possible to view the data for operation of the entire production process. Furthermore, it is possible to use this data in Business intelligence tools that allow detailed analysis of production data. The value from all devices and the time when this activity took place would always be stored here. Figure 19 illustrates the process of the control system.

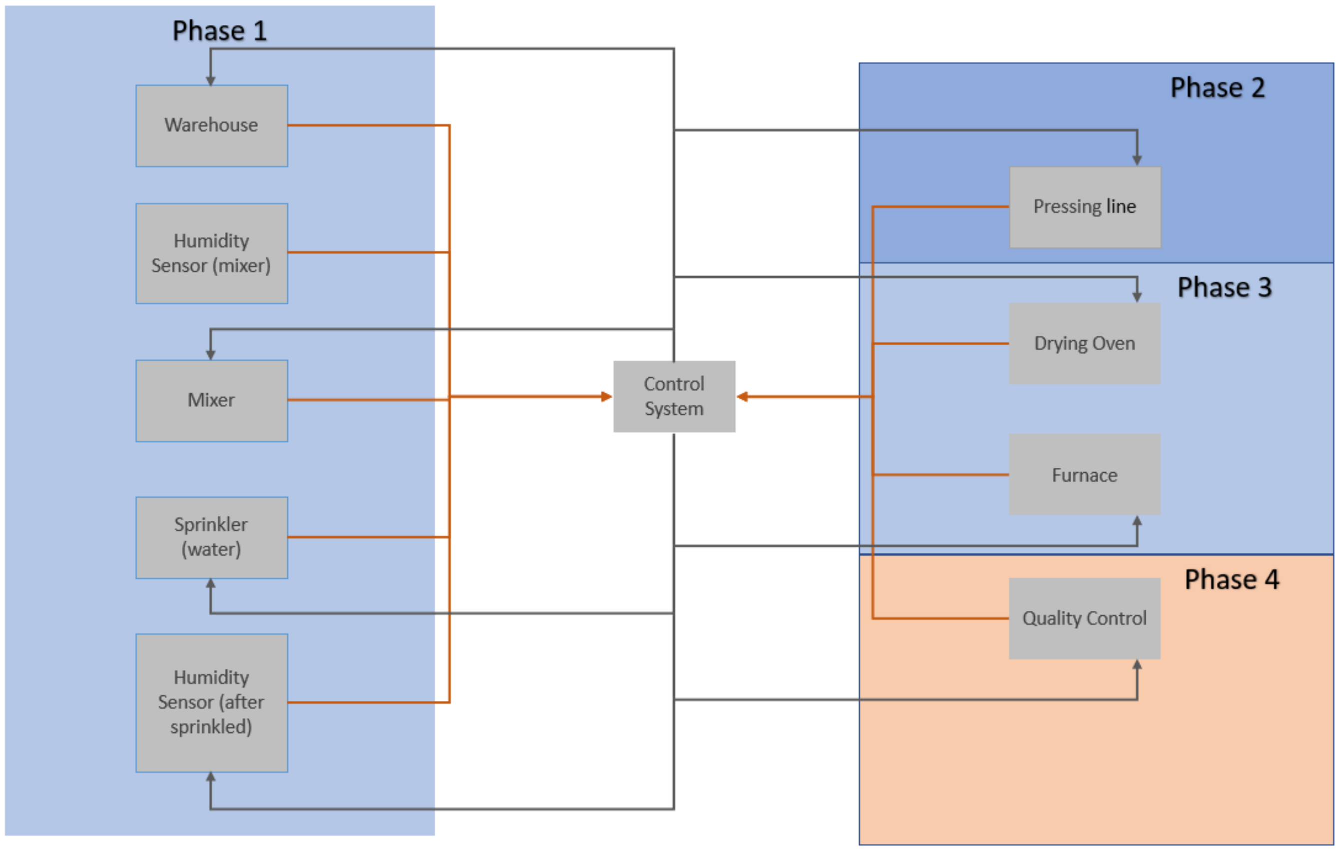


Figure 19: Diagram of Main Control System

Table 3: Functionality of control system

Phases	**Control System**	
Phase 1 – Production Mixture	**Receives**	**Sends**
Warehouse	• Actual weight of raw materials	• Recipe
Humidity Sensor (mixer)	• Measured humidity	
Mixer	• Request for real recipe	• Recipe and clay moisture
Sprinkler	• Dosed quantities of water	• Recipe of moisture mixture
Humidity sensor (after sprinkled)	• Measured humidity	
Phase 2 – Semi-finished product		
Pressing line	• Pressing conditions • Quantity	• Product Dimensions
Phase 3 – Thermal treatment		
Drying oven	• Time spent in the oven • Temperature	
Furnace	• Entry and exit time • Temperature	• Heat treatment
Phase 4 – Quality Control		
Control Belt	• Measured dimensions • Car number and Position	• Pass check or Fail

6.5.1 Technologist

The whole production process begins by entering the production data into the main control system by the technologist. Production data must contain all the necessary data for the entire production process, such as the number of batches, the recipe, the type and dimensions of the product and the heat treatment. The data control system processes and starts the production process. This is an important part of the production process, as all instructions throughout the production process depend on this data.

6.5.2 Warehouse

After entering all the necessary information from the technologist into the control system, the system sends the recipe and quantity to the warehouse and silo. Recipe information comes to the warehouse and silo. Here, the required amount of raw materials is weighed, which is ready to be sent to the mixer. Due to the possibility of inaccurate weighing of the weight of individual raw materials from the warehouse and silo, information is sent about the actual weight of raw materials, which will be used for the preparation of the production mixture to the control system.

6.5.3 Preparation of the mixture

When the mixer signals to the control system that it is free for a new batch, the control system sends a signal to the silo and warehouse to send the prepared feedstocks. The clay is monitored for moisture during transport to the mixer. The clay moisture monitoring sensor sends online data to the control system, which records them and based on the measured clay moisture, the control system calculates the required amount of water to be added during the mixing of the production mixture.

Subsequently, the mixed production mixture travels across the production process through the stacker, where it spends the required time for proper homogenization. From the stacker, the mixture travels to the press. In front of the press there is a humidity sensor, which sends the acquired data online to the control system. The moisture in the production mixture is processed in the system. Based on the comparison of the production mixture with the measured data, the system instructs the sprinkler to the amount of water that still needs to be added. This check is carried out to ensure that the production mixture is in the best possible condition for extrusion.

6.5.4 Extrusion of the mixture

At the beginning of the production batch, data from the control system receives the type and size of the product to prepare the mold for the correct product. During extrusion, the press sends all the collected data on the vacuum in the pre-press chamber, the press pressure, the pressure and temperature in the press chamber and the humidity of the mixture to the control system. If the system detects that the extrusion is taking place under unsuitable conditions, it will report the extruded product as defective, and the operator will remove it from the next production process.

6.5.5 Drying oven

The drying process is sent to the control system of the drying oven. This process is specific to each product and recipe and is determined at the beginning of the process by the technologist. At the same time, the oven sends the actual course of the drying cycle together with the time data on the beginning and end of the drying process to the control system, which stores it.

6.5.6 Firing furnace

After drying, the products are transferred to burning wagons. Here, a process similar to that of drying takes place. The control system sends to the kiln the required course of firing the products. The furnace sends back the temperature profile during firing as well as the time of the beginning and end of the firing process.

6.5.7 Control line

At the end of the production process, the products are inspected. The output of the burning furnace is followed by a control line. Individual products are placed on the conveyor belt of the control line. Smart cameras are installed on the conveyor belt of the control line, which can measure each product and check for signs of damage. The required product size plus the tolerance field in which the product can move must be sent to the cameras by the control system. Based on this data from the control system, the camera evaluates whether the product meets all the required criteria or not. They send information about the measured dimensions of the products, as well as the surface quality checks of the camera to the control system. Here it is evaluated whether the product has met all quality criteria. Based on the evaluation, the control system sends a signal to the traffic light at the end of the control line, if the product meets or does not meet the requirements and the green or red indicator light comes on accordingly.

6.6 Technology needed and steps to implement

This aim of this chapter is to talk about the technology needed to implement such a proposal mentioned above. The goal is to implement the conceptual solutions without having to stop the entire production process. This chapter will also talk about steps that should be taken to implement the given proposal. Technology needed is a main factor in implementation of industry 4.0. As it is a technologically driven paradigm.

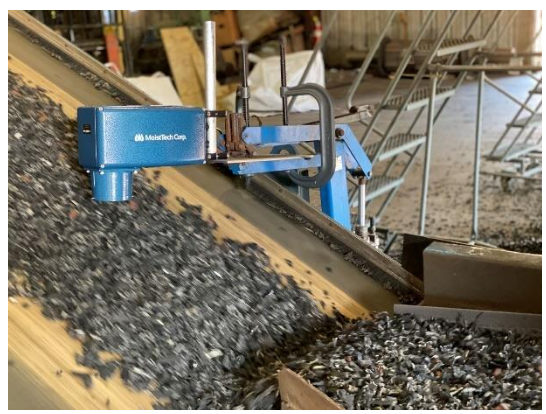
6.6.1 Humidity sensors

The need for precise clay moisture levels has become a critical component during production. Being such a porous material, clay can easily become either too wet or too dry wasting manufacturers time and money. To monitor the storage conditions and as well as the condition of the stored materials humidity sensors should be placed around the warehouse to measure the moisture content of the clay in the storage room and on the belt during mixture preparation.

There are two sensors that I have come across that is suitable for our needs.

Table 4: Moisture sensors

Absolute Moisture Sensor PCE-MWM 240	**IR3000 On-Line Sensor**
Designed specifically for use in humidity measurement of bulk material, this moisture sensor is installed in bins, silos, troughs,	The IR-3000 uses the most advanced components allowing installation in multiple locations and is equipped with product loss

bunkers case, distributors, screw conveyors and on conveyors. **Variant 1 (PCE-MWM 240-A)**: Bow sensor (length 200 mm) The bow shape makes it extremely robust against shocks and mechanical abrasion. It is fastened by means of adapters on the wall of tanks and silos. **Variant 2 (PCE-MWM 240-B)**: Rod sensor (length 500 ... 1500 mm) It is attached like a connecting strut between two container walls.	software capability where small gaps, inert material, foreign objects, belt or screw conveyors are removed from the measurement calculation, thus providing the most accurate true moisture reading. Depending on the application, the IR-3000 can be placed in numerous areas of the process. • Belt Conveyors • Screw and Drag Conveyors • Down Chutes • Storage Bins • Fluid-bed Dryers
	

6.6.2 Robots

Industrial robots are being used in a range of sectors and applications because they can be taught to execute dangerous, dirty, and/or repetitive jobs with consistent precision and accuracy. They come in a variety of models, with the most frequent distinguishing qualities being the reach distance, payload capacity, and the number of axes of travel (up to six) of its jointed arm.

A robot uses an end effector or end of arm tooling (EOAT) attachment to hold and manipulate either the tool performing the operation or the component on which the process is being performed in both production and handling applications.

A mixture of programming software and controllers direct the robot's actions. Their automated functionality enables them to work around the clock, on weekends, with dangerous materials, and in difficult environments, allowing employees to focus on other responsibilities. Robotic technology also improves efficiency and profitability by removing labor-intensive tasks that could cause physical strain or harm to employees.

Robotics adds speed, flexibility and consistency to any production line making it more efficient and cost effective. The leading manufactures of industrial robots are ABB, KUKA and FANUC with years of experience in the field of robotics they have solutions for almost any production process in any industry. There are also lesser known but emerging companies that specialize in industrial robots, one such company is YASKAWA. The HC-series by YASKAWA are ideal for a variety of tasks including machine tending, material handling, material inspection, packaging and assembly. They are designed to work safely with or in the same workspaces as humans. With the use of a smart camera such as ISC 1783 [35] the robot could perform a dimension analysis for quality control.

Figure 20: HC20XP by YASKAWA [36]

6.7 IT Structure and Hardware

Due to the complete linking and communication on all levels of the production process it is sure that a reliable transmission of increasing data volumes due to the steadily growing linking and communication of machine parts even under the most difficult conditions have to be ensured. As a consequence, cables especially for construction are subject to extreme torsional stress and very high temperatures. To ensure there is a stable transmission of data at required speeds it is necessary to invest in high speed I/O cables which could be copper based ethernet cables or optical cables. Figure 21 shows the making of an optical fiber. There is also a need for workstations to monitor the production process in each part. Although a decent workstation with a Microsoft Windows Server operating system is relatively cheaper it is the portal for communication between humans and machinery so it is of the utmost importance. Some of the operating systems that can be used for our purposes are:

- Windows 10 x64
- Windows 10 IoT x64
- Windows Server 2019 x64

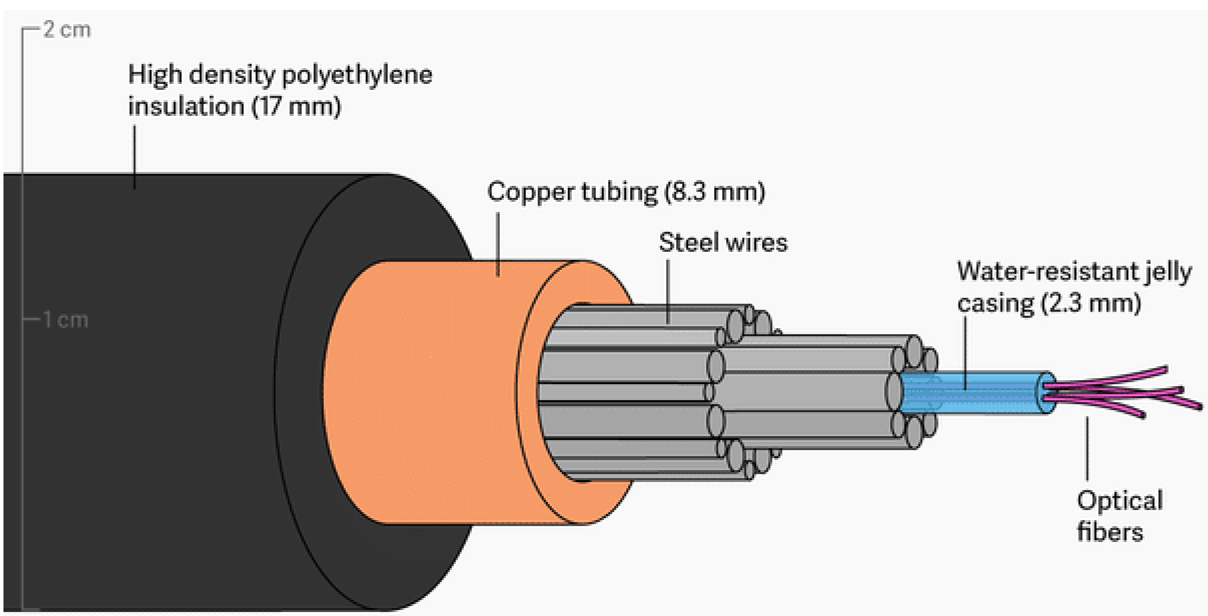


Figure 21: Optical fibers [32]

6.7.1 Data Storage

Modern computers, often known as terminals, link to storage devices directly or via a network. Users tell computers how to access and save data from various storage devices. However, there are two fundamental foundations to data storage: the form that data takes and the equipment on which data is collected and stored.

Users require storage devices to store data in any format. Direct area storage and network-based storage are the two basic types of data storage equipment.

Direct-attached storage (DAS), also known as direct-area storage, is exactly what it sounds like. This storage is frequently close by and directly connected to the computing equipment that needs to access it. It's often the only machine hooked up to it. DAS can also provide adequate local backups, but sharing is limited.

Network-based storage allows several computers to access it across a network, improving data sharing and collaboration. It is also more suited for backups and data protection because to its off-site storage capability. Network-attached storage (NAS) and storage area network (SAN) are two typical network-based storage configurations (SAN).

For enterprise applications, computer memory and local storage may not be sufficient in terms of storage, data protection, multiple users' access, speed, and performance. As a result, most businesses use a SAN in addition to a NAS storage solution. In is necessary to have a stable data storage platform for any company that in the future will benefit from machine learning. [37]

6.7.2 Backup software and appliances

Data loss is prevented by backup storage and appliances in the event of disaster, failure, or fraud. They back up data and applications on a different, secondary device on a regular basis and use those backups for disaster recovery. Backup appliances range from hard disk drives and solid-state drives to tape drives and servers, but backup storage can also be provided as a service, known as backup-as-a-service (BaaS). BaaS, like most as-a-service solutions, offers a low-cost way to protect data by storing it in a remote place and allowing for scalability.

6.8 Software

To implement industry 4.0 in the model company, management has to be both decentralized and centralized simultaneously.

Decentralized management works to redistribute management competencies to lower levels of production. This type of control does not work on the basis of one control system, but that there are other subsystems under the main system. Decision-making for individual parts of the production process is transferred to individual subsystems.

In the case of refractory production in the model company, I divided parts of production, which will themselves respond to the influences of the production environment. Each of these parts will have to have its own control unit, which will control its operation based on the data obtained from the sensors.

There is a need to gather data in real time and analyze so the production is as efficient as possible to achieve this the model company should invest in a SCADA system which would gather, analyze and evaluate the data gathered using the sensors and machinery. SCADA or supervisory control and data acquisition is a hardware and software system for monitoring and controlling industrial processes. Manufacturers can gather and analyze real-time production data, monitor and manage alerts, and implement automatic control reactions triggered by certain events or system characteristics using a SCADA system.

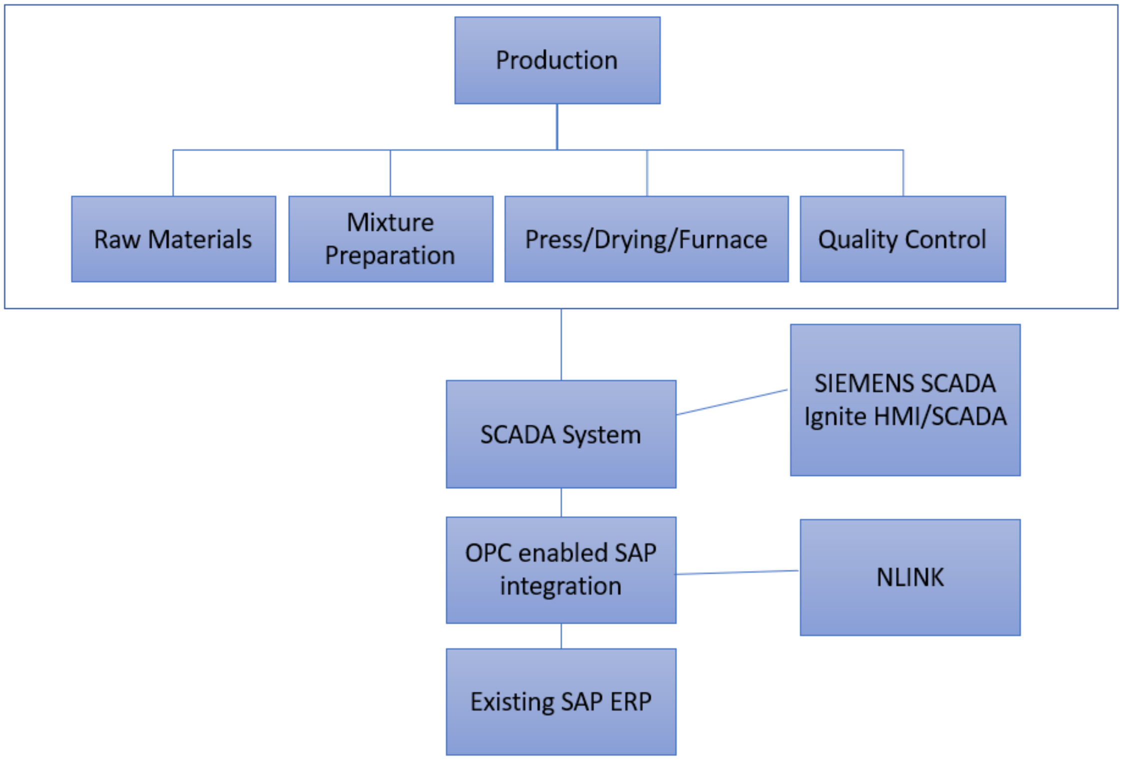


Figure 22: Integration of softwares

The SCADA system then can be integrated into the existing ERP system within the company. The model company already has an existing ERP (enterprise resource planning) software by SAP which can be easily integrated with the above-mentioned conceptual solutions. Connecting SAP systems to production systems (SCADA) enables the implementation of industry 4.0. An ERP system helps processes in a single system for departments such as manufacturing, HR, finance, supply chain and logistics among others. The figure below shows the integration between SCADA, SAP and ERP.

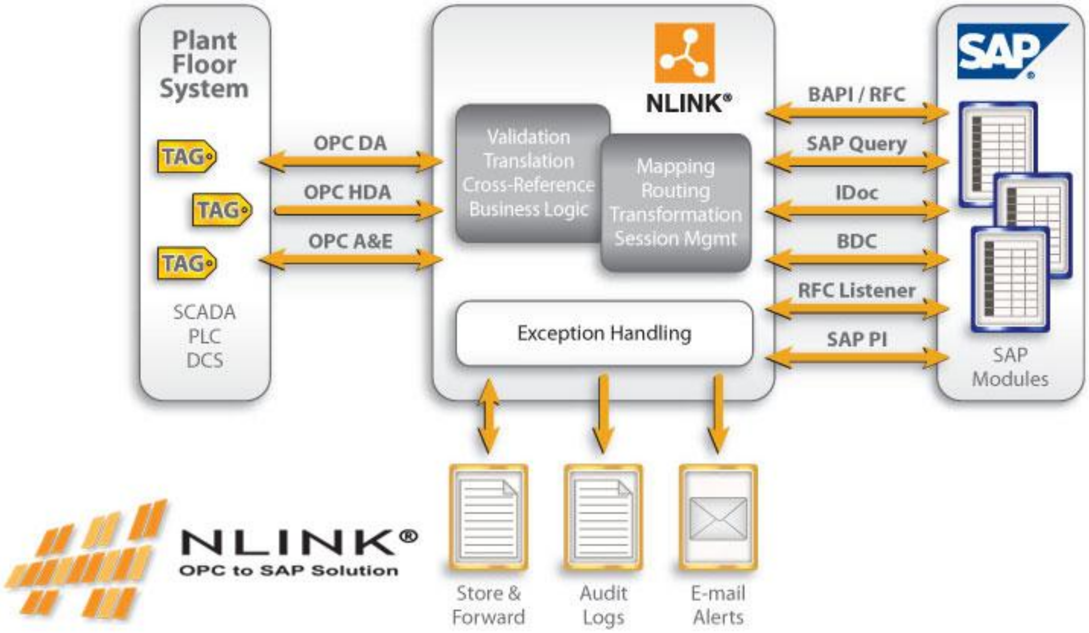


Figure 23: Connectivity through an OPC server [36]

SCADA systems come with an OPC server, to connect the SCADA system to SAP the OPC server of SCADA should be connected using a provider of OPC servers such as NLINK which is a SAP certified server. Once the data is being provided via OPC, SAP can be used for many different applications through-out the entire process from production to logistics. Some of these applications include:

- SAP PM Module – Preventive Maintenance
- SAP PM Module – Predictive Maintenance
- SAP PP-PI Module – Production Planning
- SAP QM Module – Inspection readings in assembly and testing.

The pricing is merely based on the business requirements and ERP systems are unit priced on a per-user basis.

6.9 Strategic implementation proposal

In the following part of the work will be a proposal for the gradual implementation of the individual best evaluated elements of modernization. The process of implementing the proposals will depend primarily on the greatest possible contribution to the production process.

The best approach is to introduce proposals into the production process systematically, so that in the current time they can benefit as much as possible from streamlining and improving production. The chart below describes the systematic implementation of the proposal. It starts off with the introduction of the control system into production. The implementation of the control system would be important for the existing equipment that would be connected to it.

Second comes the installation of sensors as the main problem in current production is the humidity of the clay. Therefore, the most important thing for production is to gather as much data and stabilize its humidity.

Third comes the analysis of the data gathered. Once the sensors have been calibrated for the production needs, data analysis can begin. That is using the now known humidity content of the clay and proposing recipes for production mixture accordingly. Although it would take much more data and analysis for the system to propose almost perfect recipes, knowing the humidity will gradually help improve the production mixture. In this step it is also necessary to connect the SCADA system to the existing SAP ERP of the model company so the gathered data can be used to manipulate the production.

Last is the automation of quality control, as this has the least effects on production system it can be done once the more important parts have been completed. By introducing robots to quality control human error can be eliminated as well as having a more efficient and reliable quality control checks.

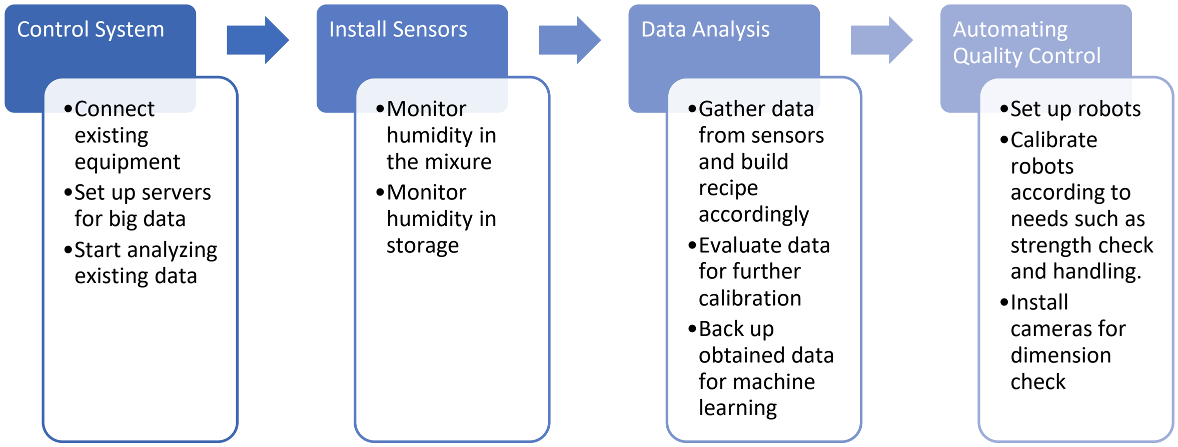


Figure 24: Strategic proposal for implementation

Implementing industry 4.0 in the model company is a long and expensive process. The above-mentioned conceptual solutions and strategic implementation proposal is expected to take 4-10 years for completion once started. That is for the model company to be completely digitized. The term complete digitization stands for when the production system is able to be self-sufficient. To reach a self-sufficient production system there would have to be enough data for the machine learning to process, in other words it is almost a process of trial and error.

It is important to plan strategically and precisely when implementing the mentioned proposal. There always is the question of what if a certain step would go wrong, it would mean the model company has to halt the whole production system which adds to millions of crowns in losses. Therefore, each step should be gradually introduced to the production system and monitored for any risk of failures before moving on to the next step.

7. Evaluation of proposals

In this chapter, the proposals from the previous chapter will be evaluated. Variants will be assessed according to the benefits and ease of implementation in the model company and the benefits of implementation in the production process.

7.1 Raw Materials

The proposed conceptual solution for storing raw materials will be assessed in this subchapter.

Table 5: Evaluation of Raw Materials

	Benefit	**Ease of implementation**
Monitoring of stored raw materials	Knowledge of clay moisture	Install sensors and connect to the control system. The only costs involved would be that of the sensors and the cost of installation.
Monitoring of storage conditions	Knowledge of storage conditions and steps need to be taken for proper storing of raw materials	Similar to the above mentioned

7.2 Production Mixture

The production mixture is of most important as the whole production process and results depend on a stable mixture of the raw materials. By improving the mixture, the company can also increase the return on investment which is very beneficial for the model company. There are still some factors that cannot be controlled such as the condition of the clay received from the suppliers as it depends on factors that is impossible for humans to control. So, the steps taken to control the condition of the production mixture therefore is very important to the model company.

Table 6: Evaluation of Production Mixture

	Benefit	**Ease of implementation**
Checking the humidity infront of the mixture	Knowing the moisture content before the production mixture enters the mixture is of great benefit to the company as you can know precisely how much water needs to be added. Which would give a better end result.	The design can be easily implemented to the current design state. Once the sensors are installed it is necessary to connect to the SCADA system.
Checking the humidity in the mixture	Calculation of the water added to the mixer based on the measured moisture of the production mixture, which would result in stabilization of the quality of the production mixture. This method can have a defect in insufficient mixing of the	It is possible to make the design on the current state, but it will be necessary to make changes to the mixer in order to be able to introduce a humidity sensor that would sense its internal content.

	production mixture, which results in the risk of incorrect water dosing. In case of poor measurement, the unwanted mixture would be mixed.	

7.3 Quality control

The quality of the final products is of the utmost importance for a highly reputed company like PD refractories. There comes a point where the experience of the employees in charge of quality control would not matter as there is always a margin for human error. It is unavoidable. Using an automated system would mean consistency in quality control checks, consistency leads to a higher conversation rate and products being of the desired quality which in turn would increase ROI for the company.

Table 7: Evaluation of Quality Control

	Benefit	**Ease of implementation**
Robotics	Automatic product inspection process. Introduction of automatic control of all products. No need for human labor. Furthermore, palletizing products. The flexibility of robotics means one purchase can be used for multiple needs. However, one arm can only work on one given job at a time.	It is necessary to precisely determine the correct parameters for the selection of the robot in order to handle the line cycle and be able to operate the entire kiln car before another fired car leaves the kiln.

7.4 Production process management

As mentioned earlier to implement industry 4.0 it is necessary to have both centralized and decentralized management within one company. That is using a designated software to a specific part of production. A software made to handle manufacturing processes; gathering data from sensors and machinery, real-time monitoring of production process would do a much better job in terms of precision and reliability than using a software that is not specifically made for this purpose. The efficiency would also not be limited by the performance of the control system.

SCADA systems have proven to be effective and beneficial in the past and present to many companies in a wide variety of industries. The chapter “software needed” speaks about which software can be used and how to implement into the existing ERP system. However, some employees would have to be trained on how to use the software and how to read data for analysis. The work force needed to handle the control system is significantly less than what would be needed for manual labor. It is a benefit for the company in terms of cost of labor.

7.5 Cost Involved

The strategic implementation envisages the possibility of investing a million of crowns per year. Furthermore, it wants to introduce proposals into the production process systematically, so that in the current time they can benefit as much as possible from streamlining and improving production.

Every day, conversations about Industry 4.0 take place in a variety of industries. Some companies are deploying existing and emerging technologies in the hopes of seeing a return on investment that justifies the initial investment, while others are waiting and seeing. Spending what the model company can today to create a solid foundation of Industry 4.0 technology, in my opinion, is well worth the investment, as long as it's done strategically and intelligently. All departments will benefit from the infrastructural work, which will help them work more efficiently and effectively.

8. Conclusion

The aim of this thesis was to propose the implementation of Industry 4.0 into the production line of the model company PD Refractories CZ. The proposal made is to transform the production line by monitoring, automating and management of the production process to increase its quality and efficiency within the Industry 4.0 concept. The first four chapters was devoted to the paradigm Industry 4.0, its principles, characteristics, technologies used and the concept of smart factory which is the ultimate goal and end result of implementing Industry 4.0 in industrial production.

In the fifth chapter which is the practical part, an analysis of the current state of the production process in the model company was done. Based on the analysis of the work, it identified suitable places for the implementation of Industry 4.0 elements. The elements were designed for the following areas of production: storage of input raw materials, preparation of the production mixture, control and management of the production process.

The proposal is focused on gathering and analyzing as much data as possible from each part of the production. A very important part of the production process is the processing of input raw materials and their moisture content. The proposal suggests ways to monitor the moisture content which subsequently would improve the production mixture and the end result.

The thesis also focuses on automating the current process of quality control to achieve a more consistent and efficient process of quality checks. Last but not least, the work focuses on proposals for the management of the production process, without which no monitoring and regulation of the production process could work.

The strategic implementation of designs into the production process depends primarily on the impact of the design on the final product. The best approach is to introduce proposals into the production process systematically, so that in the current time they can benefit as much as possible from streamlining and improving production.

Lastly an evaluation of the proposal was done. The evaluation was based on the benefit and ease of implementation of the proposed solutions into the production line.

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10. List of Pictures

11. List of Tables