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VALIDATING INDUSTRY 4.0 BASED COGNITIVE AUTOMATION APPROACH IN ADDITIVE MANUFACTURING SUPPLIER PROCESSES

VALIDATING INDUSTRY 4.0 BASED COGNITIVE AUTOMATION APPROACH IN ADDITIVE MANUFACTURING SUPPLIER PROCESSES

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ABSTRACT

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This thesis investigates the application of Industry 4.0 technologies, specifically Cognitive Business Robotics (CBR) and Business Process Automation (BPA), within the supply chain processes of metal additive manufacturing supplier. The thesis was conducted in Switzerland Innovation Park Biel/Bienne AG (SIPBB) in collaboration with the Swiss Smart Factory (SSF) as part of the CPS4Retail project. The research focuses on integrating these technologies into the operations of the Swiss Advanced Manufacturing Center (SAMC). The objective was to explore the potential benefits and implementation strategies derived from the CPS4Retail experiment, with particular emphasis on reducing non-value-adding time within the supply chain of 3D-printed metal parts.

The study began with an assessment of the information and requirements necessary for the autonomous operation of CBR. The solutions were then developed, implemented, and evaluated to determine their impact on the supplier's processes. The findings indicate a significant reduction in the time required for commissioning and manufacturing, especially in planning, communication, and scheduling tasks. The integration of CBR and BPA, facilitated by SSF, effectively streamlined these processes, leading to enhanced efficiency.

The results highlight the potential for small and medium-sized enterprises (SMEs) to leverage Industry 4.0 technologies, with substantial improvements in operational efficiency and supply chain management. The study also identifies potential areas for future research, including the integration of pricing and sustainability metrics, to further optimize supply chain processes This thesis contributes both a deeper theoretical understanding and practical insights into the deployment of cognitive automation in manufacturing supply chains.

Keywords: Industry 4.0, Supply chain, Business process automation, Cognitive business robotics, Process optimization

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LIST OF ABBREVIATIONS

AM	Additive Manufacturing
BPA	Business Process Automation
CBR	Cognitive Business Robotics
CPS	Cyber Physical Systems
DIH	Digital Innovation Hub
IoT	Internet of Things
LPBF	Laser Powder Bed Fusion
NVA	Non-Value Adding
OEM	Original Equipment Manufacturer
PVA	Process Value Analysis
VA	Value Adding

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1 INTRODUCTION

The focus of this thesis is the automation of supplier processes for producing 3D-printed metal parts for drones, within the context of Industry 4.0. This research stems from the CPS4Retail project, which aims to harness the untapped potential of small and medium-sized enterprises (SMEs) in Europe by integrating cognitive business robotics (CBR) into retail and supply chain processes.

The increasing demand for online shopping, exacerbated by the COVID-19 pandemic, has intensified the need for efficient supply chain operations that can handle highly customized products and shorter delivery times. CPS4Retail addresses this by developing a replicable model that combines cyber-physical systems (CPS) with CBR to achieve unprecedented levels of automation.

This thesis explores the implementation possibilities and impacts of CPS connectors in the supply chain of a metal additive manufacturing supplier, specifically within the context of producing parts for drones. The objective of this thesis is to study the implementation possibilities and effects of enabling Cyber Physical System -connectors to a supplier of metal printed drone parts.

1.1 Scope and limitations

This thesis is limited to the point of view of a supplier of 3D-printed metal parts to a drone manufacturer. Moreover, the focus is to explore the implementation possibilities and effects of embedding cognitive business robotics to the 3D-printed part supplier processes.

1.2 Overview of the company - Switzerland Innovation Park Biel/Bienne

Switzerland Innovation Park Biel/Bienne (SIPBB) is a private, non-profit organization focused on industry-oriented applied research and development (figure 1). As part of the Switzerland Innovation Foundation's national and international network, SIPBB aims to attract research investments from abroad, promote Swiss innovation and startups, and swiftly transform research results into marketable products. The park is centered around four key competence centers—advanced manufacturing, battery technology, health technology, and smart factory—supplemented by engineering services tailored to specific project needs. Approximately forty tenants, including offices, laboratories, clean rooms, and coworking spaces, are located within the park, fostering a collaborative environment for innovation. (SIPBB 2024a.)

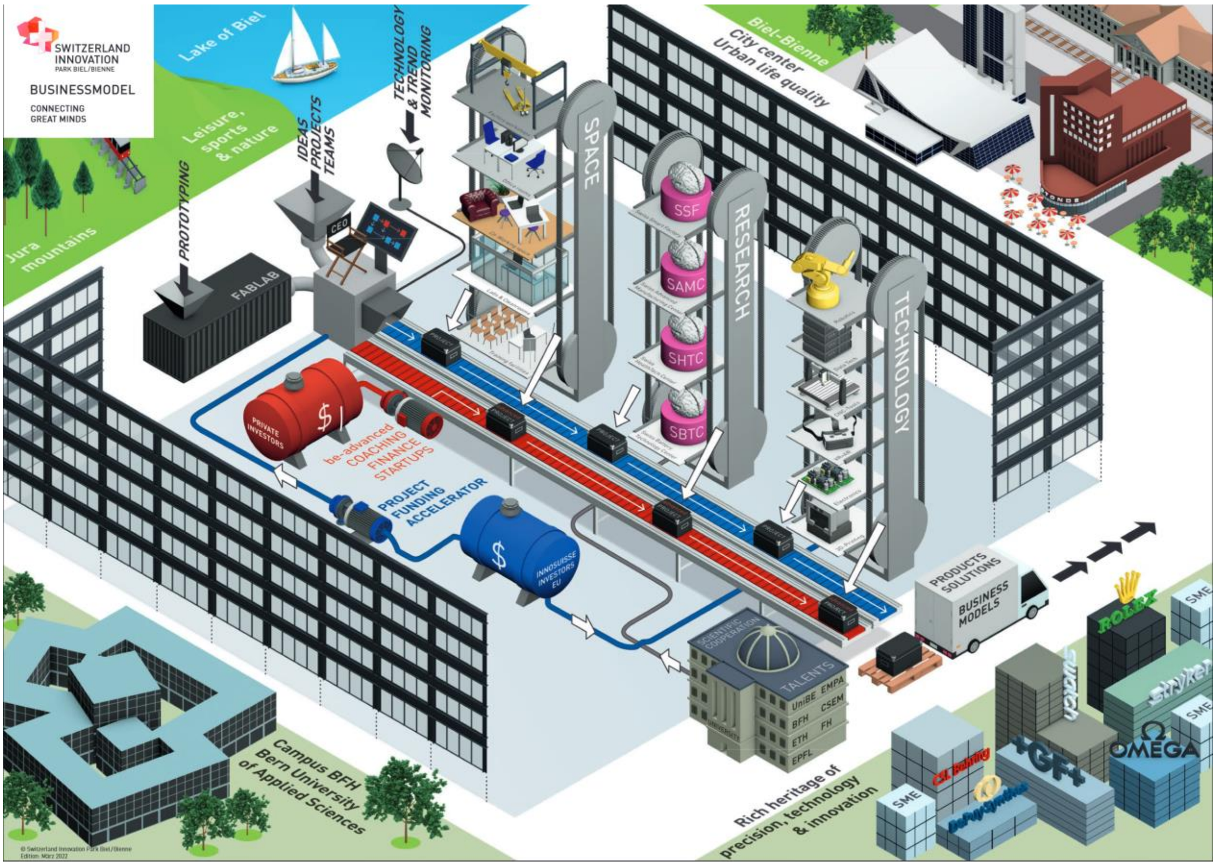

FIGURE 1. SIPBB Overview (SIPBB 2024a)

Competence Centers at SIPBB

The Swiss Advanced Manufacturing Center (SAMC) focuses on advancing manufacturing technologies through precision engineering, additive manufacturing, and automation. It serves as a collaborative hub for academic institutions and industry partners to innovate in areas such as machine tool technology and digital manufacturing. (SIPBB 2024b.)

The Swiss Smart Factory (SSF) is a research platform for Industry 4.0 technologies. It facilitates smart manufacturing by integrating IoT, cyber-physical systems, and AI, providing a space for collaboration between researchers and industry to demonstrate practical applications of digital manufacturing. (SIPBB 2024c.)

The Swiss Battery Technology Center (SBTC) specializes in battery technology innovation. It enhances battery performance and sustainability by focusing on material development, cell design, and management systems, supporting applications like electric vehicles and renewable energy storage. (SIPBB 2024d.)

The Swiss HealthTech Center (SHTC) is dedicated to advancing healthcare technologies, including digital health solutions and medical devices. It promotes collaboration between academia, healthcare providers, and industry to improve patient outcomes through innovations like telemedicine and wearable devices. (SIPBB 2024e.)

2 THEORETICAL BACKGROUND

This theoretical background introduces several key concepts essential for understanding the thesis. These concepts include several that are closely related to the ongoing industrial transformation. In addition to that the reader is provided insight into process automation, supply chain and the additive manufacturing method that constitutes the core process in this thesis.

2.1 Industry 4.0

Fourth Industrial Revolution is a concept to describe the ongoing transformation of the manufacturing industry through the integration of advanced technologies such as the Internet of Things (IoT), artificial intelligence (AI), big data analytics and robotics. It builds on the three previous industrial revolutions, which were characterized by the introduction of steam power, mechanization, electrization and assembly line production, automation and digital technologies (Figure 2). (Phuyal, Bista & Bista 2020.)

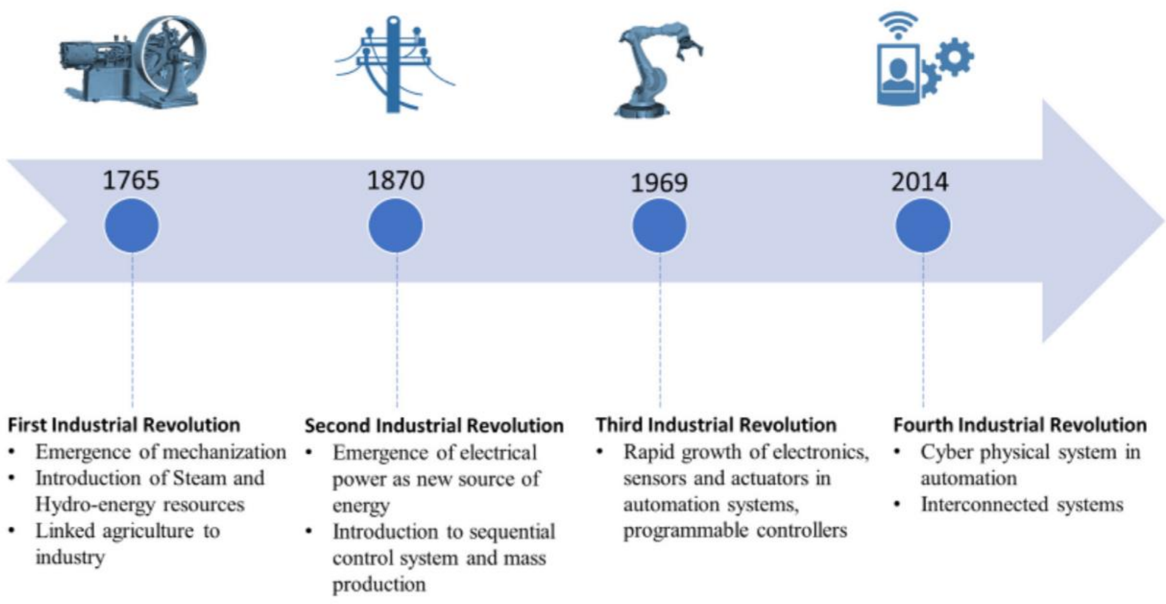

FIGURE 2. Industrial revolutions (Phuyal, Bista & Bista 2020, 2)

2.2 Cyber-Physical Systems (CPS)

> *A cyber-physical system (CPS) is an integration of computation with physical processes whose behavior is defined by both cyber and physical parts of the system. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa. As an intellectual challenge, CPS is about the intersection, not the union, of the physical and the cyber. It is not sufficient to separately understand the physical components and the computational components. We must instead understand their interaction. (Lee & Seshia 2017, 1.)*

The following example could help understanding what a CPS and its benefits could be: Imagine a massive factory or warehouse with lots of autonomous vehicles, each autonomously directing themselves using onboard sensors and pre-saved map. Consider humans and human operated vehicles in this dynamic environment. Then imagine this scenario: one high traffic intersection experiences sudden blockage, making it impassable to autonomous vehicles. This disruption could lead to significant delays, comparable to frustrating traffic congestion.

Traditionally these autonomous vehicles would attempt to reroute around the blockage using their sensors and path-finding algorithms. However, in the worst-case scenario, they might end up stuck, with each vehicle being blocked by one behind it. Now, consider the introduction of a Cyber-Physical System in this scenario. In this example CPS could refer to a collaborative network where vehicles and external sensors in the environment work together seamlessly. Here’s how CPS could be used in previous scenario:

1. **Cooperative communication:** Each vehicle, autonomous or not, sharing real-time position data and relevant information. This would ensure that vehicles are continuously informed about the overall traffic situation.
2. **External information:** Environment sensors and human-operated interfaces allow gathering of additional insights. For example, a human operator or a sensor might detect a blockage or maintenance and relay this information to the CPS.
3. **Smart decision-making:** Enabled with this collective knowledge, the CPS orchestrates the use of intersections or type of traffic. When faced with traffic-hindering events, it could dynamically reroute vehicles, minimizing the impact. Instead of the chaotic standstill, the traffic flow remains smoother. (Lee & Seshia 2017, 2.)

The scope of Cyber-Physical Systems extend far beyond traffic coordination. Potential applications are all around as shown in the figure 3.The applications in the discipline of embedded systems, CPS leverages computing and software embedded within non-computational devices, including cars, toys, medical devices, and scientific instruments. This technology seamlessly integrates the complexities of physical processes with software and networking dynamics. Through the provision of abstract models and the utilization of various design and analysis techniques, CPS offers a comprehensive framework for the unified integration of these components. (Lee & Seshia 2017, 2-4.)

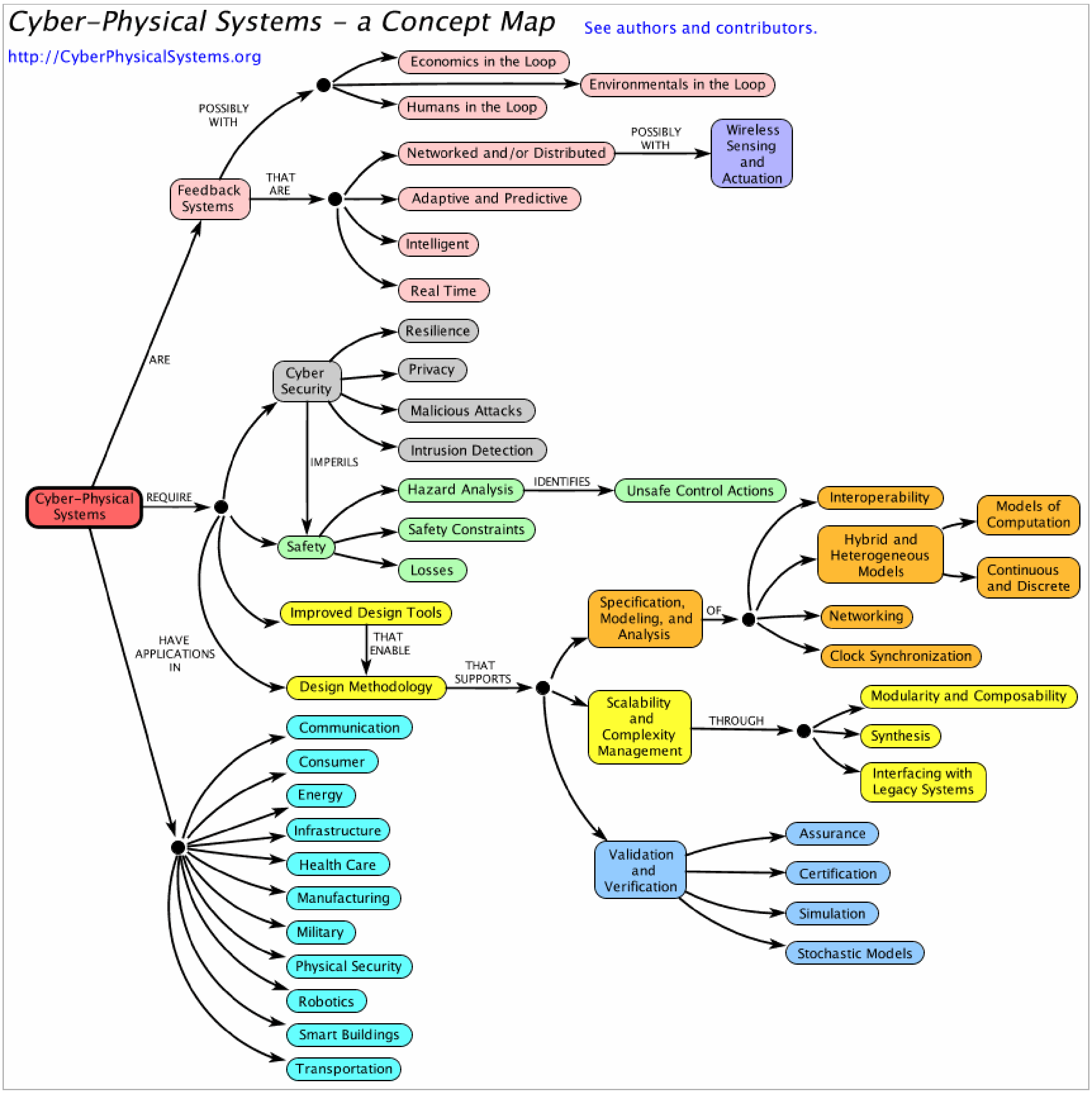

FIGURE 3. CPS Concept Map (The Ptolomey Project 2023.)

All in all, effective CPS facilitates intelligent decision-making by using data from both digital and physical realms. Cyber-Physical Systems have diverse applications and use-scale. Consider the following examples:

1. **CPS-enabled navigation:** Imagine a navigation application directing driver to the nearest store with the desired product in stock.
2. **Manufacturing Optimization:** In manufacturing, CPS dynamically routes orders to suppliers for each component based on factors such as lead times, price, or balance of these considerations.
3. **Supply Chain Resilience**: During a global supply chain disruption (such as a ship stuck in a canal), CPS can analyze and execute decision on alternative transportation routes and methods (figure 4). (Lee & Seshia 2017, 6 - 16.) (Hansa Tek Netics Corporation 2023.)

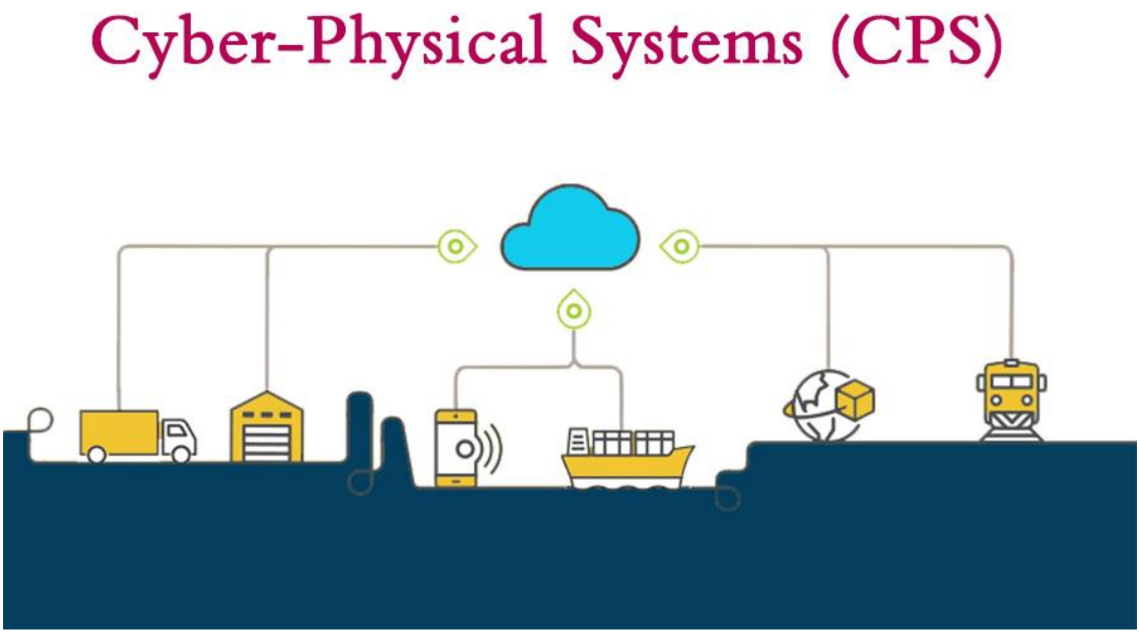

FIGURE 4. CPS and Supply Chain (Hansa Tek Netics Corporation 2023)

2.3 Business Process Automation

A business process can be defined as any set of activities that collectively contribute to achieving a specific organizational objective. In the realm of automation, a business process is typically characterized by repeatable transactions comprising a series of steps that interact with multiple IT systems. Examples of business processes include fulfilling and invoicing a customer purchase order, approving a loan application, completing data entry, onboarding a new employee, and various other tasks within financial services, human resources, and business operations. (Red Hat 2022.)

When these workflows are managed on an ad hoc basis, they often entail numerous email threads, documents, and handoffs. Such an approach increases the likelihood of human error, which can lead to inefficiencies manifesting as communication breakdowns, bottlenecks, and missed deadlines. These challenges are exacerbated as the scale of operations increases, further complicating the management of business processes. (Red Hat 2022.)

The introduction of automation software seeks to address these challenges by providing a reusable and extendable business automation strategy. By implementing such a strategy, organizations can regain control over their business processes, enhance communication, improve customer satisfaction, and minimize confusion. Automation of business processes liberates time and resources, enabling employees to concentrate on core activities rather than tedious, repetitive, and often frustrating tasks. This strategic shift not only enhances operational efficiency but also empowers the workforce to focus on activities that add greater value to the organization. (Red Hat 2022.)

2.4 Robotic Process Automation (RPA) and Cognitive Business Robotics (CBR)

Robotic Process Automation (RPA) is a software technology designed to automate repetitive, rule-based tasks that are traditionally performed by humans. It involves the use of software robots, or "bots," to emulate human actions within digital systems to execute business processes. These bots can interact with applications, enter data, and trigger responses much like a human would, but they do so faster and without errors. RPA is widely used across various industries to enhance operational efficiency. Common applications include data entry, invoice processing, and customer service operations. In finance, for instance, RPA is employed to automate tasks such as end-of-day calculations and account reconciliations. (CAI 2024.)

Key advantages of RPA include cost reduction, increased accuracy, and improved compliance. RPA can significantly reduce the time required to complete repetitive tasks, thus freeing up human workers for more complex and strategic activities as illustrated in figure 5. The technology is also scalable and can be deployed across various business units, making it a versatile tool for digital transformation. (CAI 2024.)

FIGURE 5. Robotic Process Automation (Morakhia 2023.)

Imagine automation as a spectrum. On one end, you have robotic process automation, which handles routine, rule-based tasks. On the opposite end, you find cognitive automation, which integrates advanced technologies like natural language processing, speech recognition, and artificial intelligence to manage tasks that require judgment and decision-making. Cognitive automation mirrors the way the human brain works, using context to make decisions, perceptions, and judgments. It processes unstructured data, identifying relationships and patterns to make informed decisions. This type of automation comes pre-trained and can efficiently automate various business processes with minimal data. This means there is no need for IT specialists or data scientists to develop complex models—the system learns and makes connections independently. Ultimately, cognitive automation operates autonomously, capable of performing tasks continuously without human intervention. (SolveXia 2022.)

2.5 Supply Chain

A supply chain is a comprehensive network that encompasses all parties involved in the process of fulfilling a customer request as illustrated in figure 6. This network extends beyond the core participants such as manufacturers and suppliers to include transporters, warehouses, retailers, and even the customers themselves, each playing a pivotal role in ensuring the seamless flow of goods and services from origin to consumption. (Chopra & Meindl 2016,13.)

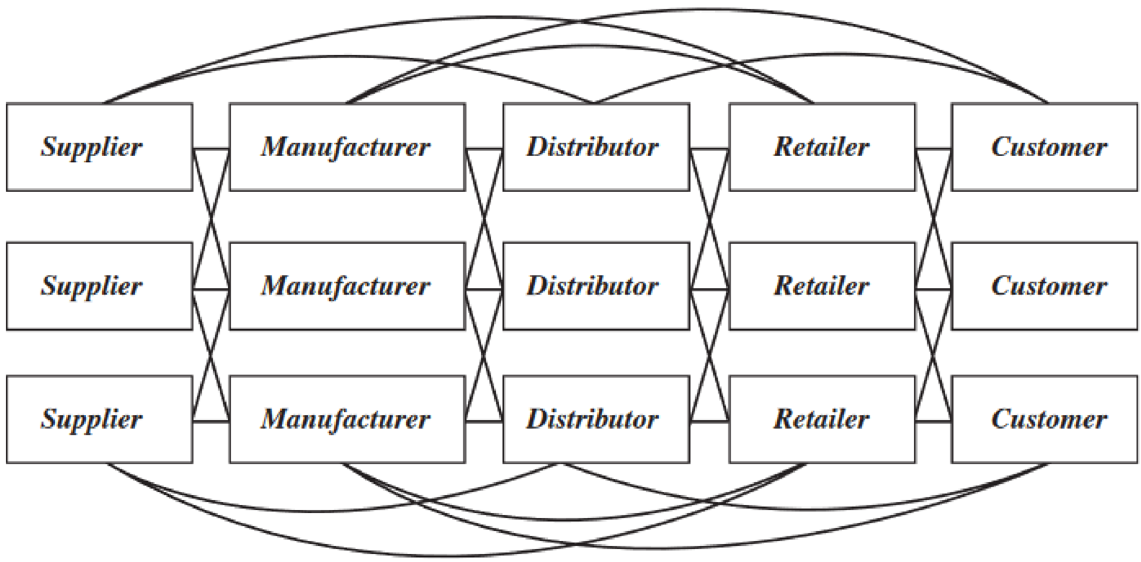

FIGURE 6. Main stages of Supply Chain (Chopra & Meindl, 2016, 15)

Manufacturers are responsible for transforming raw materials into finished products, while suppliers provide the essential inputs needed for production. Their collaboration is fundamental to ensuring that products meet quality and quantity requirements. Transporters are responsible for the logistics involved in moving goods between different points in the supply chain. This includes the transportation of raw materials to manufacturers and finished goods to distribution centers, retailers, or directly to customers. Warehouses serve as storage facilities that help manage inventory levels and ensure that products are readily available to meet demand. They play a critical role in balancing supply with demand fluctuations. Retailers are the final link in the supply chain before products reach the consumer. They are responsible for marketing and selling products to end users, providing essential customer feedback to other supply chain participants. Customers are integral to the supply chain as they drive demand. Like the figure 7 conveys, their purchasing decisions influence production and supply chain strategies, making them an active participant in the supply chain process. (Chopra & Meindl 2016, 15.)

FIGURE 7. Generic Supply Chain (CFI 2024)

Objective of Supply Chain

The primary goal of a supply chain is to maximize the overall value generated, known as the supply chain surplus. This is calculated as the difference between the customer value of the final product and the total costs incurred by the supply chain. The customer value is estimated by the maximum amount a customer is willing to pay for a product. The consumer surplus is the difference between the product's value and its price. The profitability is the difference between the revenue from the customer and the costs across the supply chain. A higher supply chain profitability indicates a more successful supply chain. Emphasizing the growth of the supply chain surplus benefits all members by increasing the overall value created, rather than focusing solely on profitability at individual stages. (Chopra & Meindl 2016, 17.)

2.6 Process Value Analysis

Process Value Analysis (PVA) is a method used by businesses to evaluate and optimize their internal processes by focusing on customer needs. It involves assessing each step in a process to determine its necessity in delivering the desired outcome for the customer. The primary objective of PVA is to identify and eliminate any superfluous steps and costs within the value chain involved in producing a good or service. By doing so, businesses can enhance efficiency, reduce expenses, and maintain or improve customer satisfaction. Ultimately, PVA aims to ensure that products or services are delivered to customers more quickly and at a lower cost without compromising quality or customer expectations. This approach not only helps in reducing waste and inefficiencies but also supports continuous improvement efforts within the organization. (Kenton 2022.)

The value-added process involves analysing business activities to assess their contribution to the enhancement of a product or service. "Value" in this sense refers to the price a customer is prepared to pay for a specific product or service. Consequently, the customer is crucial in determining the value of a process or activity. Companies implement the value-added process to ensure their operations meet customer expectations and support the overarching business goal of providing high-quality products or services. (Indeed 2024.)

Areas of value

Activities within an organization can be classified as either value-added or non-value added. Value-added activities directly contribute to fulfilling customer requirements and enhancing the quality or functionality of a product or service. In contrast, non-value-added activities do not enhance the product's value and often lead to unnecessary resource consumption, such as time, materials, or labour. (Indeed 2024.)

Companies need to establish criteria for identifying activities that add value. Common guidelines for assessing value include:

- **Customer Willingness to Pay:** Will the customer cover the cost of the activity?
- **Function or Form Alteration:** Does the activity modify the function or form of the product or service?
- **First-Time Quality:** Can employees perform the activity correctly on the first attempt?

Activity Efficiency: Is the activity unnecessarily complex, excessive, or not in line with standard practices? (Indeed 2024.)

Identifying non-value activities plays an important role in making processes more sustainable and efficient. Common non-value activities include:

- Defects: Services or products that fail to meet quality standards, leading to rework or disposal, thereby wasting resources.
- Waiting Time: Periods when employees or processes are idle, resulting in inefficiencies.
- Product Overproduction: Producing more products than needed, causing an inventory surplus.
- Inventory Storage: Holding excess inventory, which increases costs without adding value.
- Non-utilized Talent: Underutilization of employees' skills and knowledge.
- Needless Transportation: Unnecessary movement of materials or products, consuming time, and resources.
- Extra Processing: Unnecessary process steps that do not enhance the product or service.
- Excess Motion: Unnecessary movements that increase labour without adding value. (Indeed 2024.)

2.7 Laser Powder Bed Fusion (LPBF) – Additive manufacturing technology

Laser Powder Bed Fusion (LPBF) is a widely utilized additive manufacturing technique. Like the figure 8 illustrates, in the process, a laser is directed at a bed of metal powder to create each layer of a component, guided by a computer-aided design (CAD) file. After exposing each layer to laser radiation producing the needed shape in a layer, the machine spreads a new layer of powder over the part and repeats the process. This method is particularly well-suited for producing precise, high-resolution parts with complex geometries. LPBF employs a laser to heat and melt or sinter the powder material, eliminating the need for physical molds. The resulting components are characterized by high accuracy, excellent surface quality, and mechanical properties that are comparable to those of wrought materials. (All3DP, 2023.)

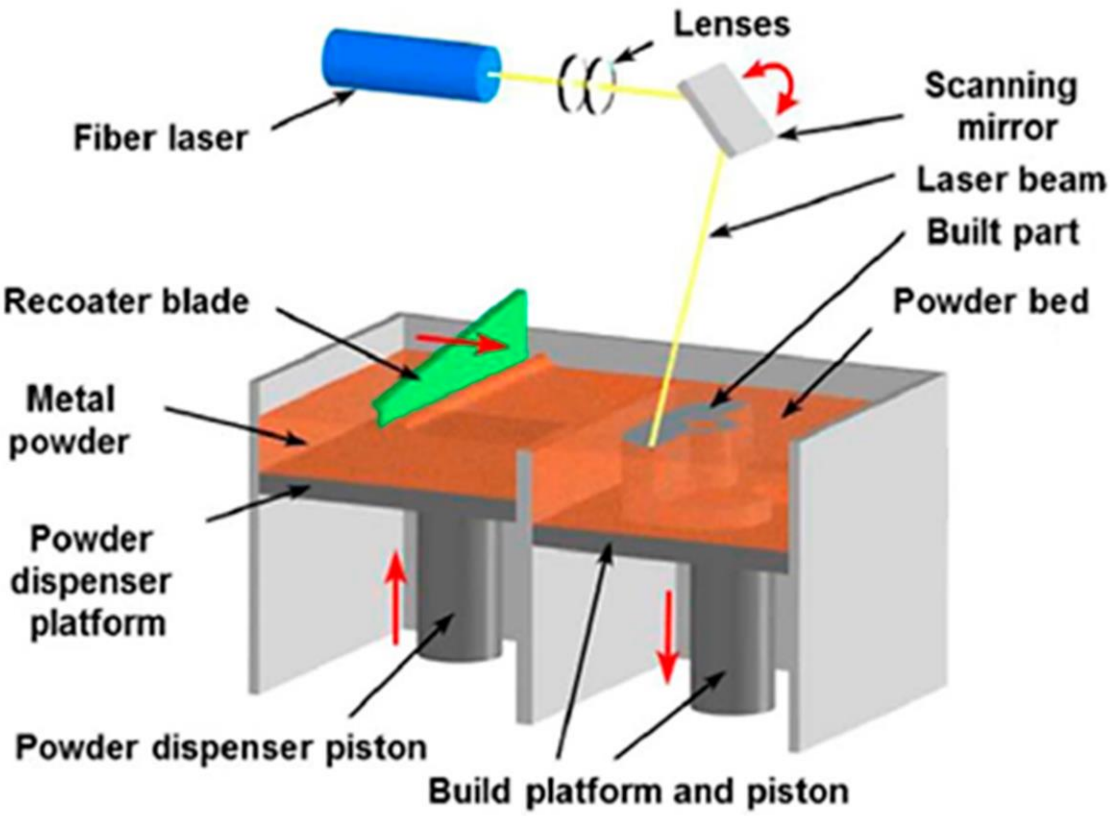

FIGURE 5. LPBF process. (Cabibbo, Santecchia, Spigarelli 2020)

After every layer has been finished the part needs post-processing. In this Additive Manufacturing method, the part remains surrounded by the powder material that was not targeted with the laser beam. Figure 9 shows how a part looks like after the job is finished and build platform is lifted to allow post-processing to proceed. The post-processing of LPBF printed parts involves several significant safety hazards. Inhalation of microscopic (< 100 µm) metal powder used in the process poses serious respiratory risks, potentially leading to an occupational lung disease. Proper personal protective equipment is essential. Additionally, certain metal powders are highly combustible and can pose a significant explosion risk when airborne. Furthermore, there is great potential for cuts, burns and other injuries when handling heavy objects and performing the post-processing, which can involve dangerous chemicals, heat treatment, polishing and cutting the parts away from the substrate and supports. (Nair, 2019.)

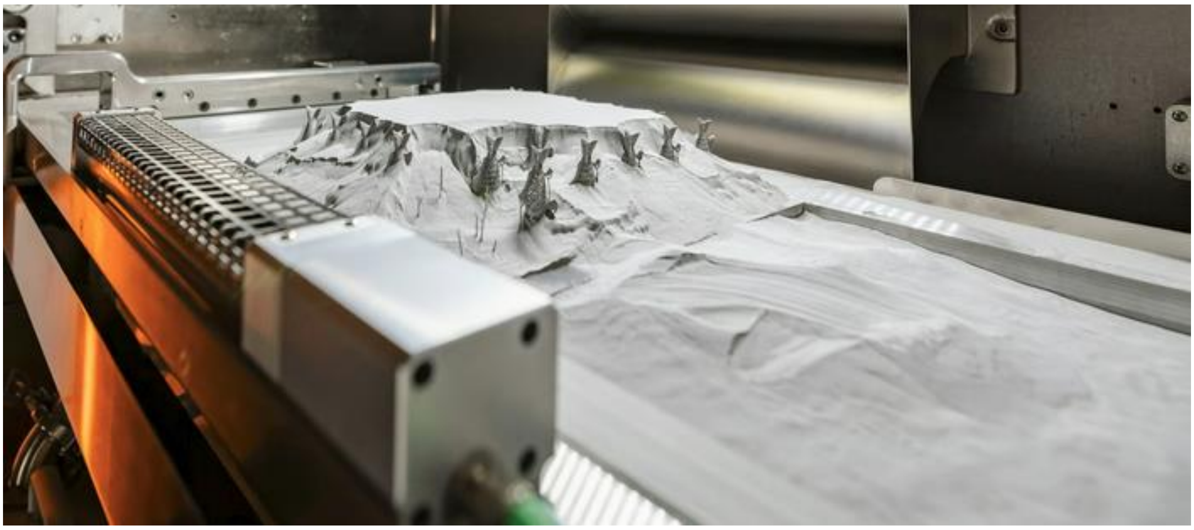

FIGURE 6. Powder Bed After Print (All3DP, 2023)

3 IMPLEMENTING CPS4RETAIL EXPERIMENT IN SUPPLIER PROCESSES

This chapter explores the automation of supplier processes for 3D-printed metal drone parts. Originating from the CPS4Retail project, which seeks to unlock the potential for European SMEs by integrating cognitive business robotics (CBR) in retail and supply chains, the objective is to examine the implementation and impact of Cyber Physical System (CPS) connectors for a metal-printed drone parts supplier. The tools and software used in this thesis were Python for coding and understanding the machine communication, PowerPoint for making presentations and charts and Word for making deliverable report.

3.1 Initial Condition of the Project

The work on the tasks for this thesis began when an individualized drone manufacturer, in this scenario the Swiss Smart Factory (SSF) needed a partner to act as a supplier to validate and demonstrate a project they participated in. They had developed a cognitive bot with a chatbot interface to cope with the complexity of supply chain optimization. Naturally close under the umbrella of Switzerland Innovation Park Biel/Bienne (SIPBB), the Swiss Advanced Manufacturing Center (SAMC) was seen to be feasible supplier of 3D-printed metal parts for drones.

At first the task was defined to figure out what processes this cognitive bot could handle. What information does this cognitive bot need to be able to function, where this information would be and how that could be extracted and communicated to the cognitive bot. It was mentioned as preliminary information that the Aconity-manufactured metal 3D-printer had a possibility to have application programming interface (API) installed. That was agreed to be a good point to start studying what information could be offered for the cognitive bot to use. Some understanding of Python language was a prerequisite to understand the installation process and the data the printer provides.

3.2 Using Python API for 3D Printer Data Analysis

The initial phase of the thesis focused on thoroughly understanding the process and data generated by the Aconity brand LPBF (Laser Powder Bed Fusion) 3D-printer. This involved breaking down the 3D printing process into its core components and analysing it from a robotic perspective: What information is essential for automation, and how can a robot interpret this data to make informed decisions? The objective was to identify and outline the key data points that would be relevant for a CPS-Connector, which enables the integration of cyber-physical systems in manufacturing processes. Specifically, the study sought to determine what information the Aconity LPBF 3D-printer could provide and in what format this information is available.

According to the printer's documentation, it is possible to integrate Python-based application programming interface (API) named AconitySTUDIOpy. A thorough review of the API documentation revealed that it offers sufficient data to meet the requirements of a cognitive business robotics (CBR) application, especially for a retail environment. Key information that can be extracted includes the printer's operational status (e.g., running, idle, no job, error) and the estimated time remaining for the current job. The availability of such detailed operational data suggests that the Aconity LPBF 3D-printer is well-equipped to support automated decision-making processes. The next phase of the thesis will involve developing a framework for how this information can be effectively utilized within a CPS-Connector to enhance the efficiency and intelligence of the manufacturing process.

3.3 Implementing CPS-Connector and providing documentation

Given that coding was a key strength of the colleagues at SSF, the next objective was to organize a meeting and develop a presentation that would illustrate the printing process and explain how to interpret the data stream provided by the machine. This information was essential for building functions that would enable automated decision-making and for clarifying the printer's operational aspects, thereby facilitating effective knowledge transfer (figure 10).

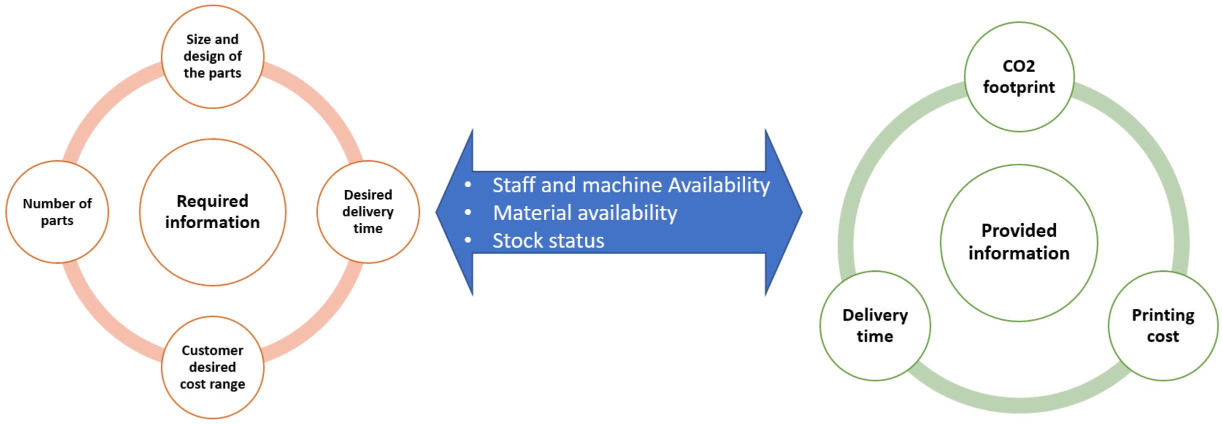

FIGURE 7. Information Communication Between Chatbot and SAMC

Before the meeting took place, the AconitySTUDIOpy API integration was successfully installed at the printer. Subsequently, the connection to the retailer's system was implemented and tested by SSF colleagues in collaboration with IT support. At this stage, all components necessary for cognitive robotics integration had been tested and confirmed to be viable. SSF confirmed that the printer state could now be observed and integrated to their system. With these foundations in place, the focus could then shift to the rest of the supplier related processes involved in additive manufacturing.

3.4 Analyzing Additive Manufacturing Supplier Processes

AM supplier processes (figure 11) surrounding the 3D-printing itself were inspected for their automation potential. Different processes of receiving orders all the way through to supplying the orders were broken into pieces and presented in flow charts. Then these pieces of processes were evaluated if they are value adding or non-value adding process and if they could be automated. Then the results were compiled and the work to research viable automation solutions to these were started. Most of the automation potential was seen in the communication and scheduling processes. Given that the CPS4Retail integration was already streamlining the communication, the focus was shifted to how to arrange the scheduling.

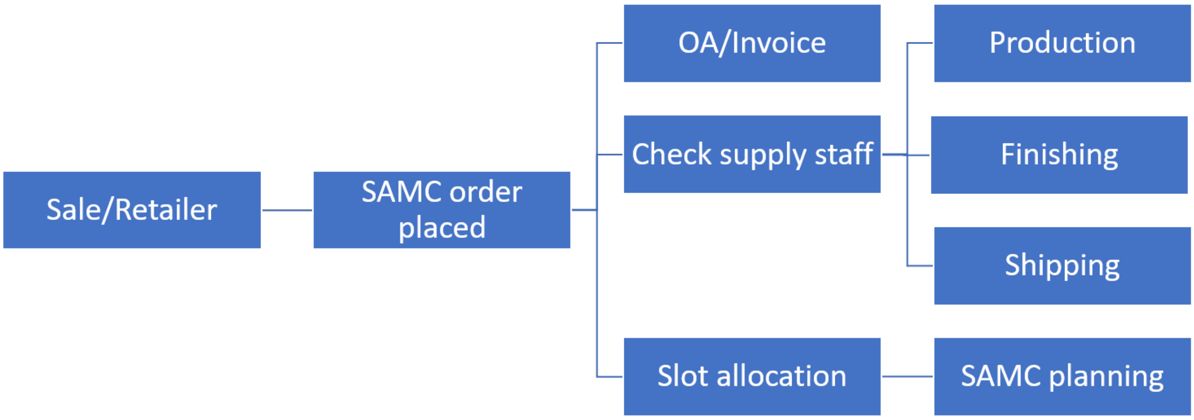

FIGURE 8. Supplier Process Flow at SAMC

In this case, there was considerable freedom to suggest scheduling methods. However, the specifics of the SAMC way of working were first outlined. These specifics included working exclusively during the day shift, the average material changeover time, and the print cost structure. The constraint meant that print jobs could only be initiated during day-shift hours. If a material change was required to print a specific job, the changeover had to occur within the day shift. Furthermore, delivery times were restricted to working hours. Pre-determined print job time and cost estimations were also provided for cognitive business robotics to assess the optimal scenario based on the number of parts and the estimated print job duration required to fulfill the order.

3.5 Deliverable Report Compilation

The project group designed four scenarios to technically validate the integration of the Cognitive Business Robotics (CBR) system, aiming to compare traditional supplier integration methods with the CPS4Retail solution, both under normal conditions and in the face of supply chain disruptions. These scenarios provided a structured framework to assess the efficiency and resilience of the CBR system.

Scenarios 1 and 2, as presented in the Table 1, focused on the standard ordering process for a custom, lot-size-1 drone. In these scenarios, a customer orders a drone from the OEM, specifying metal arms, which the OEM cannot produce in-house. Consequently, production is outsourced to a tier one supplier specializing in advanced manufacturing and metal 3D printing. For validation, this process was carried out twice: once using traditional methods and once with the CBR system.

The time required for each approach was recorded and analysed, highlighting the efficiency gains achieved through the CBR system.

Scenarios 3 and 4 addressed potential supply chain disruptions. In these cases, the OEM's 3D printer experiences a mechanical failure, preventing the in-house production of the drone part. To mitigate this disruption, an alternate part is ordered from a tier one supplier. As with the previous scenarios, the traditional approach was compared to the CBR system's automated process, showcasing the CBR system's ability to quickly identify alternatives and reduce potential delays.

#	Scenario Title	Description
1	**Baseline Integration Scenario**	Integration of a new supplier's data source in a traditional approach
2	**CPS4Retail Integration Scenario**	Integration of a new supplier to the supply chain network using the CPS4Retail solution (CPS Integration, Orchestration of CBR chatbot)
3	**Baseline Supply Chain Disruption Scenario**	Mitigation of supply chain disruption in a traditional approach
4	**CPS4Retails Supply Chain Disruption Scenario**	Mitigation of supply chain disruption using the CPS4Retail solution (automatic search for alternative supplier)

TABLE 1. Scenarios for the technical validation of the CBR system

All the work culminated in a compilation of written report that presented the technical validation scenarios, value analyses, and comparisons, providing a comprehensive overview of the project's outcomes and the impact of the CBR system on the supplier processes.

4 RESULTS AND CONCLUSIONS

This thesis is a study of implementation possibilities and benefits of an Industry 4.0 approach on automating supply chain related processes between supplier and retailer facilitated by interoperable systems in each end. The results of the study were provided in a deliverable report for the purposes of the CPS4Retail project. Goal was to study and analyse four different scenarios; baseline and CPS4Retail Scenario in normal supplier-retail scenario and in a scenario when there is a disruption, and the retailer needs to route the order to a different supplier.

Beginning of the efforts consisted of reading the documentation of the printer. This was accompanied by outlining what are the requirements to enable the retailer's system to understand the status of the printer. Even though the programming language skills were better on the understanding side compared to the applying those skill. The documentation provided information that it would be possible to allow the communication of the printer status, if it is printing, idle or error state, what is the progress point of the current print, and datapoints to estimate the time needed for completion of the current job. Somewhat diverging from the initial outline, there was not straightforward way to offer data about the current material inside the printer nor the printer schedule outside of the current job. Results were discussed with the SSF colleagues, and it was agreed that there was enough information to fulfill the requirements. The scheduling of printing along with the information about the material inside the printer could be solved with alternative approaches.

Early attempts to install the Aconity API were met with considerable difficulties. The process involved scrutinizing output logs, scraping data, and comparing these results against the documentation to diagnose and resolve challenges. With the help of SSF experts, we successfully installed the AconityStudio Python client. During this collaboration, it was discovered that there was a REST API available, this interface provided straightforward way to communicate with the printer API over the network. After that finding the IT support and SSF specialists made the necessary configurations, and the communication to SSF system was successfully tested, allowing data to flow seamlessly to the bot.

The challenge of scheduling was solved by integrating planning system to a cloud-based calendar which the cognitive bot could determine availability and book slots for 3D printing. The schedule was recognized as an effective tool for conveying information about the material being used at any given time.

The analysis of the additive manufacturing supplier processes revealed that only the steps involving printing, post-processing, and packaging directly add value to the customer. In contrast, the steps related to communication, scheduling, preparation, and cleaning do not contribute value. To address this, non-value-adding tasks were categorized into two groups:

1. Tasks that could be improved through automation, such as communication leading to purchase commitments, cost and time estimations, and production scheduling.
2. Tasks that have already been time-optimized but remain necessary manual activities, such as preparing the build job, setting up the printer, and cleaning it after printing. These tasks have fixed durations and cannot be further optimized by cognitive bots.

When comparing the baseline process to the process with CPS4Retail integration, both with and without supply chain disruptions, significant time savings were observed with the use of the CBR system. The time required from staff on the non-value-adding process in the group that had potential to benefit from automation was reduced to almost zero, as the staff only needed to check and follow the schedule if the CBR system would be fully implemented.

From the perspective of customers and retailers, the automated system showed potential for reducing delays in communication and offer preparation, as it operates independently of supplier staff availability, which can be affected by factors such as holidays, weekends, or workload. Although these edge cases were not included in the time savings calculations, the potential for increased customer satisfaction remains significant. Additionally, the reallocation of personnel from repetitive tasks to roles better suited to their expertise was positively received.

The thesis successfully achieved all the objectives set for it according to the planned schedule. As a result of the work, the commissioning party was able to validate its project outcomes from the supplier's perspective. It can be stated that the thesis has demonstrated significant potential for improving the operations of various small and medium-sized enterprises by integrating cognitive business robotics (CBR) into retail and supply chains. Therefore, the thesis has greatly benefited both the commissioning party and the author by enhancing personal expertise.

To further improve and build on this study would be to add more capability to the system. An idea that was considered, but not fully implemented in this study was the offering of a full-fledged pricing data to the cognitive robot. This could include not only detailed cost accumulation information but also sustainability metrics related to material usage, energy consumption and waste generation. Integrating this data could allow the CBR system to make and offer more informed decision that balance cost-efficiency with environmental impact, aligning with growing demands for sustainable manufacturing practices.

It should be noted that the study was constrained by the specific context of Swiss Advanced Manufacturing Center, which may limit the generalizability of the findings. Expanding the research to include multiple suppliers and diverse types of manufacturing environments could provide more comprehensive insights.

The practical portion of the thesis was completed successfully, aligning well with the personal goals of the thesis author. However, the writing portion of this thesis presented its own set of challenges. One of the main reasons for this difficulty was the unfamiliarity with intangible AI concepts that, due to the rapidly evolving nature of the field, have not yet become established and are constantly changing as new information and developments in AI emerge. Additionally, prioritizing the writing process did not align with the ongoing employment demanding significant part of the time and focus of the thesis author.

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