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# Production Systems Performance Optimization through Human/Machine Collaboration

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## Abstract

The growth of enterprises is a constant source of research and development of new technologies. Indeed, to stand out from the competition and optimize their production, companies are moving toward the centralization of information and the implementation of machines. This dynamic requires a significant investment in terms of organization and research. Industry 4.0 is therefore at the heart of this reflection, as shown in the literature. It brings together many technologies, such as Artificial Intelligence (AI), the Internet of Things (IoT), and Big Data. This chapter focuses on company performance optimization through a sustainable Industry 4.0 framework involving methodologies such as lean manufacturing and DMAIC, new technologies as robotics, in addition to social, societal, and environmental transformations. This chapter will present robotic displacement solutions adapted to the industrial environment for improving production systems performance. Solutions for human-machine interaction problems such as human-machine interface or flexibility 4.0 will be shown.

**Keywords:** Industry 4.0, performance optimization, robotics, artificial intelligence, big data, human-machine collaboration, internet of things (IoTs)

## 1. Introduction

Faced with increasing competition, companies must develop new ways of optimizing their production, and this involves the use of new technologies such as robotics, artificial intelligence, internet of things, big data analytics. Even if these technology implementations in large companies have shown their efficiency for increasing the company supply chain performance, most SMEs are not willing to exploit them. Some of the reasons for these breaks are the technologies costs, human fear, employees' knowledge or education on technologies, and resistance to change. For instance, the problem of artificial intelligence or robot acceptability in companies could be pointed out.

The robotic implementation requires the writing of very precise specifications to answer the problems of the company. Robotic solutions are not well known by all companies, and some of them have difficulty visualizing the benefits of this technology. One of the major obstacles is the lack of data on the capabilities of robots to perform generic tasks in certain industrial fields.

Industry 4.0 is expanding with new technology enhancements. Numerous Industry 4.0 concept frameworks exist in the literature such as presented in [1]. The digital and technological transformation of the company is based on dimensions such as a horizontal integration, used to transform the physical production system (robot, internet of things, cyber-physical systems) and processes, or a vertical integration for structuring, and managing data and decisions that would be taken for increasing the company performance. Despite the positive impact of these concepts on the company performance, the integration of robotics, IoT, or artificial intelligence in SMEs transformation is confidential in France. However, technologies such as autonomous guided vehicles (AIV) could be used to transport loads in their production systems or within their warehouses, and cobots to perform daily tasks on fixed stations. Indeed, these frameworks do not obtain the membership of SMEs and it is necessary to find solutions to transform them technologically, digitally, and to optimize them. This chapter presents a framework that exploits sustainability as the kernel of the transformation in order to take into account social, societal, and environmental aspects, combined with new technologies for defining levers of transformation and increasing the company performance. The main objective of the new framework is to transform digitally and sustainably the SMEs for increasing their performance by using new technologies for aiding operators in their daily tasks and facilitating operational information management (between operators, machines, robots, and the information system).

This chapter focuses on solutions of human/machine collaboration for optimizing the company production system. It describes new Industry 4.0 concepts for improving the production processes through the implementation of new technologies such as AIV, cobots, IoT, information systems, and decision-aided tool. These solutions will contribute to the company's digital transformation. The objective of this chapter is to show different solutions, allowing the improvement of logistics within the framework of Industry 4.0.

After a literature review of organizational methodologies, Industry 4.0, robotic collaboration, and big data analytics, the sustainable Industry 4.0 framework will be presented, and the associated human/machine collaboration concepts will be shown. Use cases based on an electronics card company will be exposed.

## **2. Literature review**

The digital transformation for increasing the company performance requires the focus on theories and concepts that could be exploited for improving the enterprise. Indeed, organizational and management methodologies are essential, but Industry 4.0 concepts, robotic collaboration concepts, and big data analytics could also be used in this transformation. Some of these theories and concepts are presented in the following part in order to choose those that are adapted to the sustainable Industry 4.0 framework and the intelligent tool for supporting the company transformation.

### **2.1 Organizational methodologies**

The improvement of the company production system requires to exploit the adequate methodology. Numerous methodologies are used in companies for increasing their performance such as GRAI Methodology [2], CIMOSA [3], or PERA [4] for structuring the global company, lean manufacturing, DMAIC (Define, Measure,

Analyze, Improve, Control) method, design of experiments for focusing on the production system, and solving specific problems. The performance criteria mostly used are quality, cost, and delivery time (QCD).

Based on the theory of systems, GRAI Methodology, contrary to CIMOSA (technological aspects) and PERA (human aspects), focuses on all the company aspects: decisional, informational, and physical systems. Five models (physical, functional, process, informational, and decisional) have to be used for transforming a company and improving its performance. This methodology is adapted to the objective to integrate Industry 4.0 concepts in SMEs but a zoom on the physical system is necessary to increase the efficiency of the company transformation. Indeed, lean manufacturing methodology is the most exploited because of its objective to structure the supply chain organization around customer demand satisfaction in terms of quality, cost, and delivery time.

The concept of lean manufacturing has been firstly described in [5] and applied in Toyota Company. Lean manufacturing is a methodology used for reducing seven wastes such as transportation, overproduction, motion, waiting, defects, inventory, over-processing. Lean principles allow optimizing the company efficiency. As exposed in [6], “sustainable manufacturing and lean practices focus on creating an intelligent network system that improves productivity, quality, and customer orientation, while eliminating waste.” Many tools could be used in the frame of lean manufacturing methodology implementation such as Value Stream Mapping (VSM), Single Minute Exchange of Die (SMED), Failure Mode Effects Analysis (FMEA), 5s, Total Productive Maintenance (TPM), Kaizen, Kanban.

As explained in [7] lean manufacturing not only contributes to optimize added value for satisfying customer expectations but also increases environmental benefits. Indeed, SMEs could not improve their performance by ignoring the actual environmental context. In addition, in the use of lean manufacturing, the cadence of the production line that is called takt time could be considered by mistake (bad application of lean concepts) as nonsocial and nonsocietal. For instance, if the takt time is not well defined, it could create stress for operators because of their desire to succeed. Indeed, the positive impact is defined in the company through the elimination of waste time and non-added value, giving operators more value time for well finishing their tasks. The use of lean tools such as SMED, for reducing the external operations, allows to implement tools near machines optimizing by this organization the ergonomics and the useless moving.

This continuous improvement method integrates physical and informational flows in an industry with aiming at the identification and elimination of wastages that affect lead time, material cost, and quality of products [8, 9]. But for a SME the digital transformation of its processes needs to solve specific problems (use cases) for ensuring the feasibility and efficiency of solutions that will be implemented. Both DMAIC and DOE are able to manage these specific cases (use cases).

Six sigma is a method based on DMAIC (Define, Measure, Analyze, Improve, Control) principles. Six sigma allows to improve the quality of the production system and not only the product quality. DMAIC is used as a problem-solving method for increasing the quality level in the company.

Then, a combination of GRAI methodology, lean manufacturing DMAIC, and DOE methods will allow to define an efficient and well-adapted framework for Industry 4.0 concepts implementation in SMEs. The following part details the concepts of Industry 4.0 and the necessity to integrate sustainability in the digital transformation approach.



## **2.2 Industry 4.0**

Industry 4.0 concepts use a multitude of technologies to improve company performance. They are involved in logistics, production, data management, and communication between systems. These technologies meet the modernization needs of businesses. Several technologies and tools must be taken into account to integrate the concepts of the industry of the future such as the verticality of production systems, the horizontality of the integration of production chains, the optimization of the value chain, and the use of disruptive technologies. These technologies are cyber-physical systems (CPS), internet of things (IoTs), human/machine interface (HMI), cloud computing, big data, artificial intelligence, advanced robotics, immersive (augmented or virtual) reality, simulation, and cybersecurity [1]. All of these technologies have enabled great advances in the company's digital transformation. For instance, a usual application of these technologies could consist in the exploitation of sensors for collecting information on production lines, big data system for capitalizing these data in a server for analyzing them, and for taking good decisions. Then, according to the production processes and by using these data, operators could interact in the production environment with collaborative or mobile robots. Cyber-physical system stations could be deployed to control all the production systems by integrating programmable logic controllers with different inputs and outputs and various communication modules such as IO-Link modules or Ethernet interfaces.

As presented in [10, 11], based on lean manufacturing, Industry 4.0 could make the company "processes smart by enabling digitalization, modern information-sharing technologies, smart machines, which, in amalgamation, help in fast, effective, and efficient decision-making".

### *2.2.1 Robotics in Industry 4.0 concepts*

Autonomous intelligent vehicles (AIV) are used in warehouses for transporting products. In addition to problems of flow management and optimization, specific problems could be presented such as the management of the robot autonomy or prioritization. They could be exploited for transporting raw materials or final products from production lines to storage and vice versa. Indeed, these mobile robots are equipped with internal tracking and embedded system. They are able to move in warehouses to carry stocks of products. The robots transport their material to the exact location at a specific time [12]. They are able to move in a fleet and to recognize each other [13]. Moreover, they are not separated from traditional operators and move in a common environment. They have a camera and/or laser system to prevent possible collisions. Then, the problem of safety could be pointed out and different safety systems could be integrated into the robot for insuring the production system efficiency. If the robots detect a force, they could stop and activate their safety. They are also able to open doors that are connected to cyber-physical systems. Thanks to this, logistics are smoother, and productivity is increased. All these transport times, which are no longer provided by man, allow him to work on other issues. Development robots allow workers to concentrate on creativity, productivity, and other dynamic processes, which lay the basis for growth and prosperity [12].

Cobots are collaborative robots able to interact with humans. Cobots are used to support operators on repetitive or specific tasks. In [14], the top-3 reasons to choose to implement cobots (operational efficiency, innovation, and ergonomics) have been repeated and the automation of production lines with cobots has been promoted with

the use of lean manufacturing methods. The cobots are affiliated with the methods of Lean Manufacturing as they promote the automation of production lines [14].

Cobots have cameras to effectively visualize their environment and adapt accordingly. They are able to recognize and identify shapes, bar codes, QR codes or even colors. Some of them are used for quality control thanks to their high precision. Vision has become the key to Industry 4.0. Cobots are lightweight and easy to configure, unlike conventional robots [12]. Cobots are less costly than their counterparts and can yield more stable effects [12]. On top of that, they have a safety system that physically blocks them when they detect a collision. They are able to switch from a collaborative mode to a cooperative mode. In addition, cobots can work with each other. They are able to communicate *via* the network dedicated to them.

### *2.2.2 Internet of things*

Industry 4.0 is a concept-driven by IoT, allowing interconnection between objects, equipment, and computers. Robots can be controlled remotely by a central computer using logical programming. Human intervention is then no longer necessary. It is only used for maintenance or recalibration. The classic IoT also includes the internet of robotic things (IoRT). The robots are also equipped with inputs and outputs to control external systems. The data and values used by the robots *via* their sensors are stored in databases in real-time. They can then be operated by external systems. The combination of local computational power and IoT has turned ordinary sensors into intelligent sensors such that the measured data are calculated locally in a sensor module in a complex manner [15]. Robotics and the internet of things have been motivated by several ambitions that are all interconnected. IoT focuses on ubiquitous sensing, control, and recording services, while robotic societies concentrate on development, engagement, and autonomous behavior [12]. The combination of the two technologies makes it possible to limit errors on production lines and increase their efficiency.

All the sensors (cameras, force sensors, etc.) present on the robots allow the inspection to be carried out and participate in quality controls. The IoT is revolutionizing not only production methods but also maintenance strategies [16]. They must be able to exploit robot data in order to prevent possible problems [16]. New skills are expected for operators in the industry of the future. This concept of Operator 4.0 aims to present the transition of the Human-CPS interaction toward a Human-Automate symbiosis for a balance within the production chain [16]. IoT focuses on services promoting pervasive sensing, surveillance, and recording and the emphasis on processing, engagement, and independent activity in robotic societies [17].

As presented in [18–20], IoT “refers to intelligent physical and virtual objects which are integrated in a global (or local company) network, which have identities, and which communicate between themselves or with other internet-enabled devices.”

In [21], IoT is defined as a technological concept that utilizes sensors, microcontrollers, and other embedded terminal devices through which real-time data can be collected from manufacturing machinery and facilities.

### *2.2.3 3D printing*

3D printing is an important technology in the concept of Industry 4.0. It is used for rapid prototyping of mechanical parts. The accuracy and quality of the prints are high enough to make tools for robotics. It is possible to produce different parts whether they are rigid (support) or flexible to adapt to needs [17]. In particular,

companies are developing grippers for their robot arms using this technology. Robotic-enabled 3D printing represents a more sustainable manufacturing method [12]. Thanks to 3D printing, companies are making reliable mechanical implementations to deploy new use cases. The flexibility of this technology encourages them to constantly develop their robotic solutions.

#### *2.2.4 Cyber-physical systems*

Robotics allows better optimization of variable productions and therefore better economic performance. Automotons and computers allow robots to evolve and be smarter. Application flexibility allows computers to optimize production according to schedule demand or markets [12]. CPS is defined in [22] as a “system that integrates computation, communication, and control.” It uses sensors for obtaining data, which will be capitalized and analyzed with computing devices and a decision-aided system for taking good decisions concerning the physical system. CPS contributes to improve productivity by remotely controlling physical machines inputs and outputs. This concept is used to qualify sensors in production lines.

CPS is described in [23, 24] as physical and engineered systems whose operations are monitored, controlled, coordinated, and integrated by a computing and communicating core. The concept of a cyber-physical system is presented in [25] as based on emerging technologies such as additive manufacturing, advanced robotics, augmented and virtual reality, big data, cloud computing, and the internet of things.

As explained in [26], lean manufacturing and Industry 4.0 could be combined for transforming a manufacturing system into a Cyber-Physical Production system (CPPS) with advanced productivity capabilities.

As noted in [27, 28], the “successful integration of SMEs into Industry 4.0 is a relevant social challenge and thus, specific policies and programs should be designed accordingly.

#### *2.2.5 Big data analytics*

With the implementation of the CPS, big data are obtained from the physical and informational systems and need to be analyzed for taking good decisions in the company. The objective is to increase the company’s performance.

Big data correspond to the collection of massive data from various sources. These data are structured, non-structured, or semi-structured but must be analyzed and exploited to taking decisions. A typology of data sources has been proposed in [29]:

- Manufacturing resource data including real-time performance data of smart devices, collected through the industrial Internet of Things and production data
- Manufacturing systems and computer data aid data (product design, order configuration, material allocation, production planning, business management, etc.)
- Internet data issued from open Web sites (social services sites, e-commerce platforms, social networking platforms).

Seven features have been defined in [30] for characterizing big data: volume, variety, velocity, veracity, value, variability, and volatility. As explained in [31] the level of production standardization, operation network, and service precision could

be substantially revamped by using big data analytics. In industrial and manufacturing systems, big data promote enterprises to accurately perceive changes in the system and facilitate scientific analysis and decision making for optimizing the production process, reducing cost, and improving operational efficiency [32]. Two main paradigms could be used for big data analytics:

- Model-driven approaches focus on how the physical system works, rely on a deep understanding of the system or process, and can benefit from scientifically established relationships [33]
- Data-driven approaches are based on the correlation between system status parameters and the target estimated by various artificial intelligent models [34].

These data contribute to the elaboration and the efficiency of an intelligent manufacturing system in a company. The intelligence of the production systems is based on their ability to accumulate and analyze big data [34]. This analysis can improve customer service, enhance product quality, and create more value in the enterprise as expected by SMEs. Indeed, technological problems have to be solved in this case such as data quality management, data security and privacy protection, the generality of the conceptual framework in actual production, data integration processing in industrial manufacturing systems, and accessing primary manufacturing data. Then, the intelligent system (including the big data analytics) that will be proposed needs to integrate these aspects.

All the concepts of Industry 4.0 that have been presented above are required for digitally transforming the company but their efficient utilization in SMEs needs to focus on the brakes on Industry 4.0 implementation in SMEs and to find levers for accelerating their use in the SME performance improvement. Indeed, sustainability, including social and societal dimensions such as the place of the human in the future production process (human/robot collaboration), but also environmental demands (people expectations, the earth preservation, and official rules), appears as the parameter to integrate for obtaining the membership to Industry 4.0 philosophy.

### **2.3 The context of the robotic collaboration**

Robots have revolutionized the manufacturing process of companies. They have enhanced the automation of systems and the execution of repetitive tasks at low prices [12]. The potential of robots is great, and the resulting applications are numerous. In addition, some robots use AI to improve their performance. They are able to learn from their environment and from their experience. Several working methods have been established so that human and machine can collaborate.

Human-robot collaborative systems are presented in [35] as a solution with a shared workspace, which mixes the dexterity and cognitive faculties of human operators and the accuracy, in addition to the repeatability skills of robots.

The coexisting mode results in the distinct separation of workspaces between human and machine, no interaction is possible in this configuration. The advantage is that the robots can operate in difficult conditions for humans (e.g., high temperature, risk of intoxication.) The cooperation mode is manifested by the work of human and machine in the same space of work on different objects or tasks. Finally, the collaborative mode results in the simultaneous work of human and machine on common objects or tasks.



Unlike operators, robots are not distracted, and they work without interruption and have a low error rate thanks to their precision and repeatability. Robots are able to predict their maintenance. To do this, they collect data throughout the production lines.

If robots are destined to perform fast and dangerous gestures, safety zones are set up to limit access. Operators are not left out of this technology, because they are able to control them *via* portable systems such as computers, tablets, or even phones. They thus ensure the supervision of the robots. These increasingly intelligent robots, in cases where human intervention is difficult, may be able to make decisions based on their visions, productions, or knowledge of the state of the production line.

A detailed risks analysis has to be done by exploiting the safety guidelines and standard documents such as:

- The type-A standard ISO 12100 focused on the machinery risk assessment [36]
- The type-C standards ISO 10218 parts 1 and 2 for the general safety requirements for industrial robots and integrated robots systems [37]
- The technical specification ISO TS 15066 for the safety requirements destined to collaborative operations [38]
- The technical report ISO TR 20218-1 for the main safety measures for the design and integration of end-effectors used robot systems and collaborative operations [39].

Contrary to the classical robot, collaborative robots (cobots) are contained with intuitive interfaces that support human operators in the physical workload of manufacturing tasks [40]. In addition to the safety required for ensuring the good production and the optimization of the manufacturing system, the human-cobot collaboration needs the elaboration of an interface

- For making robots, cobots, and IoTs managed by the operators without additional knowledge in robots programming or IoT utilization,
- and for facilitating the operator decision-making.

They are no barriers between cobots and human operators, but safety mechanisms to prevent harming humans are endowed [41]. They also provide solutions to ergonomics problems, by being alternative solutions to awkward postures and repetitive movements [42].

Robot programming also needs the user to be familiar, but operators in SMEs have no knowledge about the programming language. However, they have to be informed about the physical and computational action the robot can carry out [43]. Then, a new programming environment called CAPIRCI has been developed. It allows non-technical users to create typical programs executable by COBOTTA, the collaborative robot by DENSO WAVE Ltd.

This chapter proposes to exploit the idea of this programming interface, for developing an interface that aims for operators to manage with button the new technology tools integrated in the production manufacturing such as robots, cobots, mobile robots, IoTs, and also to take good decisions.

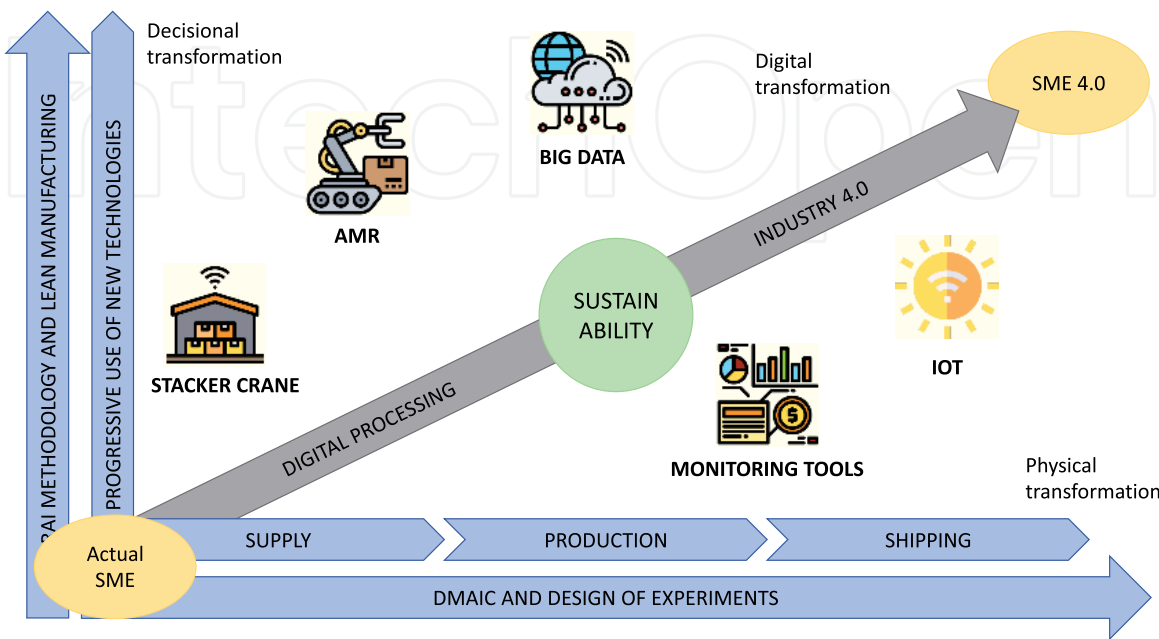
Social, societal and environmental aspects have been integrated in the Industry 4.0 concepts implementation and allow to obtain a human-centered manufacturing, more resilient and sustainable, that has been defined by the European commission as the Industry 5.0.

The concepts and methodology developed in this chapter are based on this objective. The idea in this c contrary to the proposition presented in [44] as the “automation of complex business and production processes with the help of artificial intelligence (AI), while employees undertake monitoring activities instead of being actively involved in those processes” is to let the operators in processes at the center of the digital transformation.

### 3. Concepts and methodology

The Industry 4.0 concept implementation in SMEs requires the use of sustainability as the kernel of the company’s digital transformation. This c proposes the use of GRAI methodology in combination with lean manufacturing, DMAIC, and Design of Experiments for elaborating a sustainable framework for this transformation in order to improve the company performance [45]. The framework allows to improve the company supply chain through three axes (**Figure 1**).

- The physical transformation is destined to transform the SME by implementing lean manufacturing concepts but also by using DMAIC and Design of Experiments methods for solving use cases (problems) in the internal and external logistics process of the company. The integration of robots, cobots, mobile robots, IoTs, and other tools is realized at this level.
- The decisional transformation is used for structuring the company decisions in short, middle, and long terms by exploiting GRAI methodology.



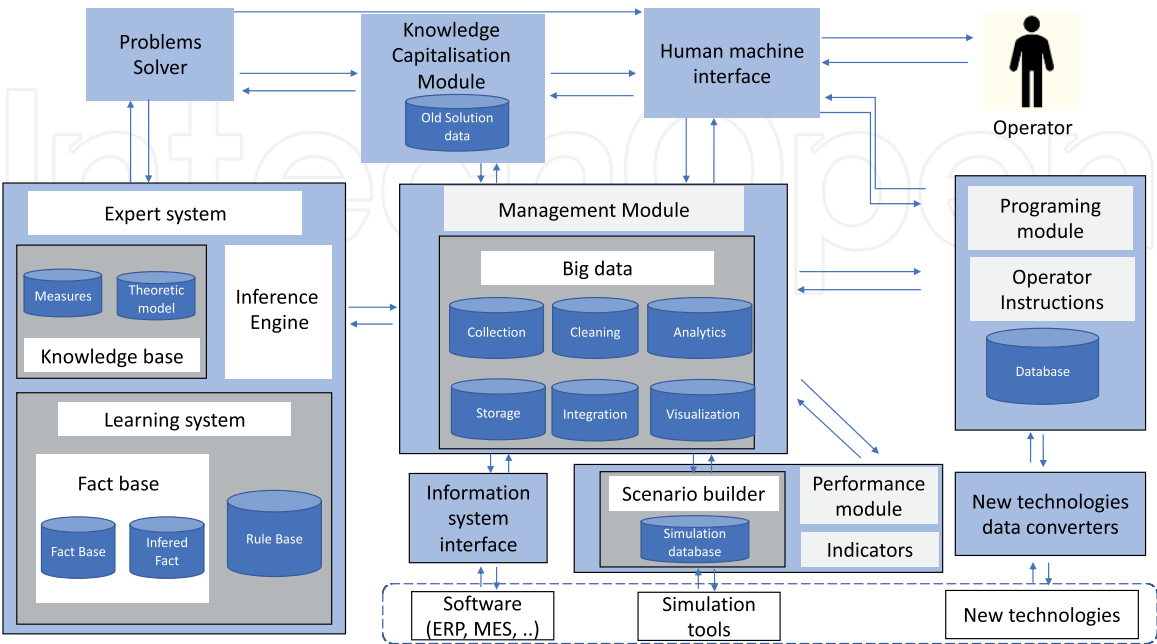
**Figure 1.**  
Framework for sustainable Industry 4.0 concept implementation.

- And the informational transformation involving the integration of an information system such as ERP, MES, WMS in the company for improving its performance, but also the exploitation of an intelligent manufacturing system including the decision aided module, the human-machine interface, and the cyber-physical system adapted to the company being transformed.

The sustainable digital transformation is supported by intelligent manufacturing and logistics human-machine collaboration (HMC) system (**Figure 2**). The objective is to facilitate the collaboration between the physical new technologies (robots, cobots, mobile robots, IoTs), the information system, and the operators but also contribute to the production processes optimization. It will allow the operators to be at the center of the production process in terms of ergonomics, production management, and flexibility.

The software tool is composed of the following:

- An information system interface that manages data between the company information system, the production managers, the production system, and the operators. Information will come from the production system through the cyber-physical system containing the IoTs and will be integrated into the information system. And in the other direction, information and production orders and constraints will come from the information system for the manufacturing system (operators, machines, IoTs).
- A management module that contains big data (reference data, input and output data, and results of a problem or task) and an analytics module.
- A human-machine interface (HMI) allows the operator to manage machines, robots, production tasks, and decisions that he will have to take.



**Figure 2.**  
*Architecture of the intelligent manufacturing and logistics HMC system.*

- A performance module is a decision-aided module that contains a dashboard for showing the operator, information on the system performance (robot machine, process, and operator), and support him for taking a good decision. This module also contains a digital twin (simulator) for showing the operator the impact of his decision before validation.
- A programming module that allows the acquisition of instructions coming from machines or robot tools (or going to them) that will be exploited by operators.
- An instruction transcriber treats the program or instructions from operators to machines or from machines to operators.
- An expert system that contains a knowledge base, an inference engine, and a learning system that allows to manage the problem to solve (use cases).
- A problem-solving module that is used for transcribing the operator difficulties into an adequate format for being analyzed and solved.
- A capitalization module that is used for recording operator instructions or problem results in order to reuse them for a new use case.

In addition to the framework and the intelligent manufacturing HMC system, a sustainable flexibility 4.0 approach has been defined for optimizing the use of the manufacturing resources (technical and human). The following part is destined to this flexibility.

## **4. Sustainable flexibility 4.0**

### **4.1 Sustainable flexibility 4.0 tool**

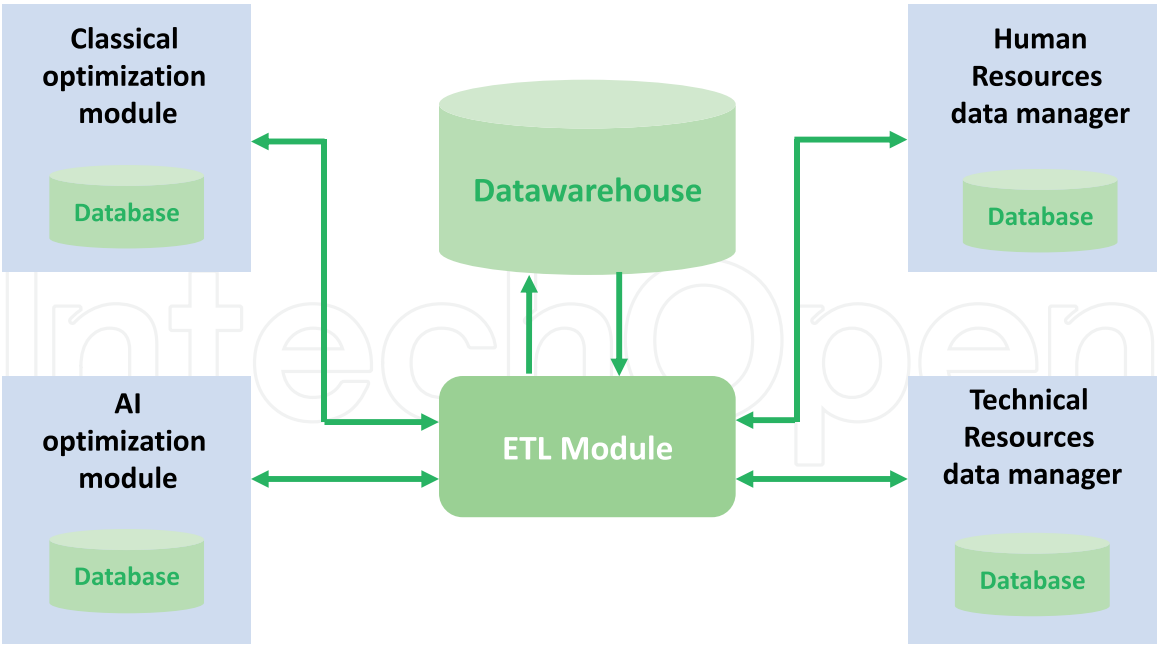
The sustainable flexibility 4.0 is based on the use of production management techniques such as scheduling, theory of constraints, operational research algorithms, and artificial intelligence for defining for optimizing the exploitation of cobots, robots, machines, mobile robots, and IoTs, of the logistics and manufacturing system (**Figure 3**). It involves the optimal use of technical resources, the good management of operational tasks by operators, and the optimization of human resources. As in the previous software tool, sustainability is the kernel of flexibility optimization. It implies the flexibility of organization around the operators.

### **4.2 Sustainable flexibility 4.0 approach**

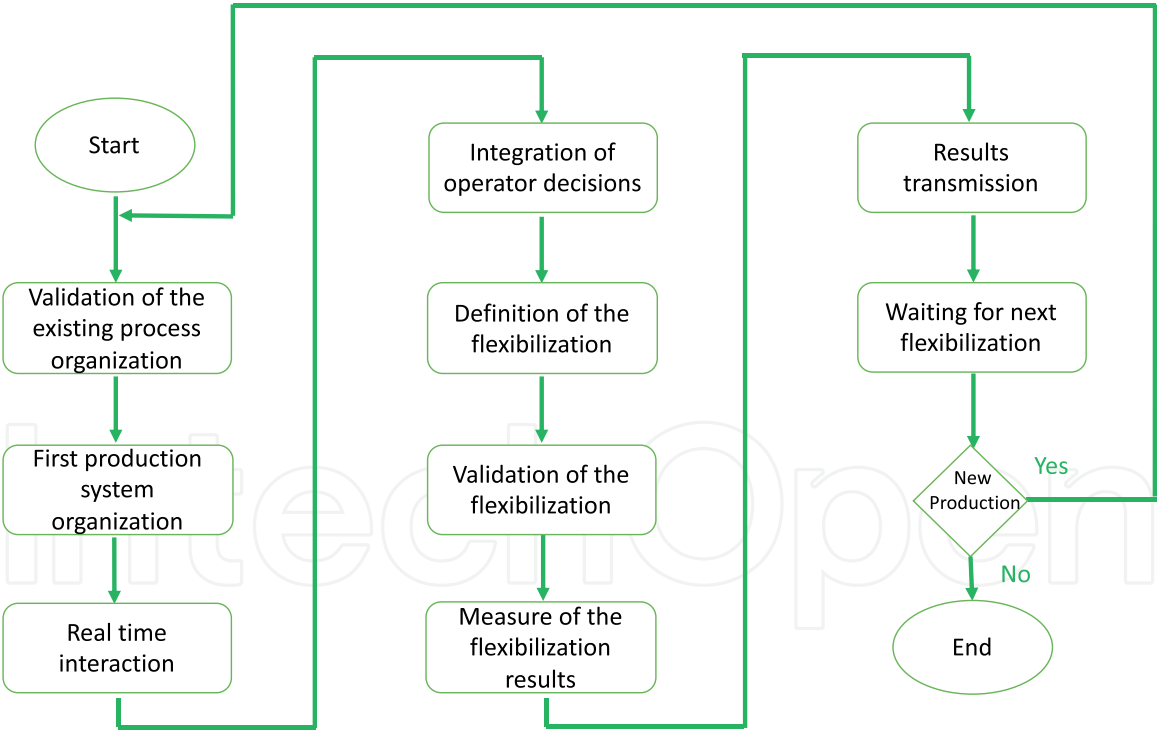
The general approach for using the sustainable flexibility 4.0 in a company is described as follow (**Figure 4**).

- Validation of the company processes optimization with lean manufacturing principles
- Elaboration of the first organization of the production system
- Integration of the first production orders for the resources (human and technical)





**Figure 3.**  
*Architecture of the sustainable flexibility 4.0 tool.*



**Figure 4.**  
*Sustainable flexibility approach.*

- Real-time interaction with the information system for managing the flexibility according to the production manager orders and the customer demand
- Integration of the operator decisions for technical and human flexibilization in collaboration with the intelligent tool

- Definition of the flexibilization to apply
- Validation of the flexibility in real time
- Measure of the flexibilization results
- Transmission through the intelligent module of the results to the operator and the information system (for production managers)
- Waiting for the next flexibilization.

## 5. Use case

Indeed, the framework has been used with success on SME for defining the steps the company of the digital transformation as presented in [42]. This part presents use cases that have been solved in this company. The company is an electronic card production enterprise and would like to transform digitally itself for being more competitive. The objective of the company was to be able to transfer the cobot from one production line to the other in less than 6mn for increasing the company's global performance. Indeed, the same cobot will produce an electronic card near the operator and at the end of this production will be integrated into the packaging process.

### 5.1 Cobots utilization optimization

Industry 4.0 concepts allow to review the operating methods of traditional industry. Operators are giving way to robots and cobots which today are mainly developed to perform specific tasks on fixed workstations. **The challenge of Industry 4.0 is to make production more flexible.** It is, therefore, necessary to improve fixed robots by making them mobile and adaptive then, production lines will be more flexible and smarter. The solution was to allow mobile robots to be able to take cobots from a station to another without human intervention to optimize production time. But the validation of the moving has to be done by operators. The development of a fully autonomous production line leads in particular to new problems of stability and precision for cobots. A mobile robotic system including mobile support and a fixed cobot has been elaborated. In the development of this solution, it was necessary to take into account the precision of the robot and thus adapt its movements. It was also important to solve the problem of cobot calibration when it arrives at the new production line. Subsequently, it was essential to ensure stability for the proper functioning of the robot, especially during high-speed actions or moving. It was also important to solve the problem of power (electric and pneumatic). Indeed, a cobot on a fixed station can be easily powered *via* a wired mains socket. For a robot moving, it is not simple. It was necessary to find alternatives that overcome these power supply problems.

For solving the use case, a cobot has been used. All the interconnected sensors allow the cobots to learn about their environment and decide on the tasks to be carried out based on the information received. Parts of the transporting system and connections have been elaborated by exploiting 3D printing as suggested in Industry 4.0 context. An AIV has been used to transport the robotic system from

one station to the other. The problem of connection between the robotic system and the mobile robot had to be solved. Indeed, this solution has been implemented in the company and has shown its effectiveness in allowing the transport of cobots to their workstations, eliminating a task that would be repetitive and tiring for operators.

The challenge of the robotic solutions described in this chapter is to be able to use a cobot at the fixed origin on several workstations. The movement of the cobot needs to be deepened. One possibility of movement is the attachment of a cobot on an inter-station trolley. This system allows it to move between different fixed positions. In this chapter, the choice was made on the solution of the inter-station trolley due to its adaptability to the company industrial environment and its easiness to be transported by an AIV.

## **5.2 Technical solutions for moving the cobot**

### *5.2.1 Proposition 1*

The movement of the inter-station trolley is ensured by the AIV. The important aspects to consider are the fixation and the stability of the cobot on its workstation. Jacks represent a possibility of fixing the inter-station trolley to the ground when the latter is placed in front of a workstation. Four jacks are positioned on either side of the carriage. They each have a force of 90 kg. A mechanical part makes up the fixing mechanism. It allows a large contact surface with the ground. In addition, the jacks are actuated by the automaton controlling the entire production chain. The digital outputs control the analog outputs of the system. When the jack system is actuated, the trolley wheels are raised and the trolley is then secured to the ground. The advantage of this solution is that the fixed stations are not mechanically modified. The inter-station trolley is able to ensure its own stability. However, due to the low weight of the trolley, mostly made of aluminum profiles, the stability is not sufficient. The forces applied to the carriage when it is fixed to the ground cause a partial tilting of the structure. In addition, this solution is dependent on the flatness of the ground.

### *5.2.2 Proposition 2*

Another alternative is the implementation of an electromagnets system to ensure the stability of the inter-station trolley. Electromagnets are used to lock access in many establishments. They guarantee high safety due to their holding force of 272 kg in the case studied. The electromagnets are positioned on the inter-station carriage and the metal plates on the fixed station. To ensure the mechanical insertion of the system, 3D printing supports have been created. These are installed on the aluminum profiles making up the workstation and the trolley. To complete the device, an obstacle sensor is installed on the inter-station trolley so that the electromagnets are activated at a short distance from the fixed station. When the electromagnets are activated, they are then brought into contact with the metal plates. The two parts are then locked together and ensure the attachment between the inter-station carriage and the fixed station. The advantages of this solution are the ease of installation and the low cost. The stability is higher than that with the jacks system. However, this device is sensitive to shear forces. This weakness can cause the inter-station cart to stall when the cobot is performing its tasks at the workstation.

### 5.2.3 Proposition 3

The fastening solution chosen for the company is the Vero-S system from Shunk enterprise. This device is made up of tightening modules and positioning pullers. Each clamping module has a tensile force of 8000 N. The operating principle is as follows: the clamping modules are normally closed by slides. An air pressure of  $5.10^5$  to  $6.10^5$  Pa is sent to the clamping modules to release the slides. The positioning zippers then fit into the clamping modules; then the slides close with the air purge. The air supply is controlled by solenoid valves, directly linked to the cyber-physical systems of the production line. To use this system, two clamping modules are positioned on the fixed station and two pull tabs on the inter-station carriage. When the AIV approaches the truck in front of the workstation, the Vero-S system is activated and allows a strong fixation and stability between the two structures. This solution responds to all types of exerted forces. In addition, the Vero-S system allows locking in three dimensions which makes it possible to prevent shifts in flatness between the base of the robot and the fixed station, in particular in the Z direction not allowing it to be checked mechanically. On the other hand, the calibration of the cobot will be able to correct it.

## 5.3 Power transmission

Once the cobot is locked to the fixed and stable position, it must be powered. For the SME study, the cobot used is a techman TM5 700 developed by Omron, and it can carry maximum payloads of 6 kg for a reach of 0.700 m. The power supply required by the techman is 240 V AC and has a maximum charge current of 14 amps. The cobot is placed on a trolley, the choice of a power supply battery allowing a cobot function is possible but greatly weighs down the trolley and could hinder its movement. In this study, the choice fell on the use of electrical modules (initially a mains socket) arranged on the trolley and on the fixed station using 3D printed support. The brackets have been adjusted so that the electrical modules are connected only when the fastening system is in place and no operator can receive a discharge. The modules located on the fixed station are supplied by the mains. The system works well and allows power to the cobot. To go further the main plugs have been replaced by more advanced electrical modules composed of 19 power supply passages, which allowed to power the cobot but also to supply the cobot. Other components of the truck (example: solenoid valve), have been implemented, in order to transmit information via the inputs and outputs of the cobot.

The cobot is able to use pneumatic grippers, so it is necessary to think of a system similar to the electrical modules that allow air transmission. By using pneumatic modules fixed on the trolley and the stationary station using 3D printed support, they connect when the fastening system is in place.

## 6. Conclusions

In this chapter, a new framework sustainable Industry 4.0 concepts implementation has been presented. Then, an intelligent logistics and manufacturing human-machine collaboration system has been exposed. An approach for implementing sustainable flexibility 4.0 in SMEs has been explained and the supporting tool shown. A focus has been made in the flexibility technical problems that have been



presented through a use case of an electronic card production company. This chapter exposes the interests for SMEs of robotic mobility and human-machine collaboration in a sustainable Industry 4.0 context and the new technological challenges that are issued from flexibility deployment. The adaptability of systems is a major issue in the context of the industry of the future. The concepts and solutions provided in this chapter illustrate new possibilities for logistics and manufacturing optimization. These improvements make the workstations of the production lines autonomous by putting the operator as the operational manager of the workstations (including IoTs, cobot, and mobile robot management). Operators are then less exposed to repetitive and stressful tasks. In addition, this flexibility helps to reduce development costs by increasing the versatility of cobots. Finally, the solutions presented in this chapter contribute to the digitalization of companies and strengthen the field of use of new technologies and humans at the heart of the industry.

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