POLITECNICO
DI TORINO

Master of science program in Engineering and Management

Master Degree Thesis

Industry 4.0 Impact on Evolution of Product Development: The Bicycle Saddle Case Study

Candidate:

Mohsen Memaran

Student ID: 246432

Supervisor(s):

Prof. Cristiana Delprete, Supervisor

Dr. Abbas Razavykia, Co-supervisor

Dr. Paolo Baldissera, Co-supervisor

Politecnico di Torino

October, 2020

To My Beloved Wife

Acknowledgments

I would like to express my deep gratitude to my thesis supervisor, Professor Cristiana Delprete, which helped me in my way. I extremely appreciate my co-supervisor, Dr. Abbas Razavykia, which I got benefits from his valuable advice during our continuous meetings. I also really thank Dr. Paolo Baldissera, which guided me in the world of bike design.

My sincere thankfulness also goes to Professor Eugenio Brusa, which helped us conclude our try as a paper accepted in IEEE ISSE 2020.

Last but not least, I am grateful to my family for their love.

Abstract

The emerging new technologies, rapid change of market demand, and the influence of society moved the companies to be innovative and improve their product as continuously as effectively. Consequently, the need for smart manufacturing systems and smart products arises to support the manufacturer to deal with mass customization under a highly competitive market. The Industry 4.0 initiative provides a base toward smart manufacturing, aimed at producing the smart and highly connected product. Regarding this necessity, in this thesis, the role of Industry 4.0 technologies in product development processes are examined, supposing the product an Industry 4.0 component in its life cycle. A roadmap can be a good representation to illustrate the impacts of Industry 4.0 in enhancing product development. To do so, the roadmap of developing a customized bike saddle is described as the case study for this investigation. As in reality, the saddle comfort depends on many factors including the rider anatomy. Therefore, it raises the necessity of profound customization to satisfy user needs. Applying artificial intelligence techniques such as data mining for market research, deep learning for customized design, and additive manufacturing technologies such as stereolithography 3D printing in customized manufacturing, are demonstrations of Industry 4.0 technologies in the case study.

Keywords - Industry 4.0, Product life cycle development, Customer needs, Smart product, Artificial intelligence, Data mining, Additive manufacturing, Systems Engineering.

Contents

List of Figures

List of Tables

Chapter 1

Introduction to Industry 4.0

1.1 History

Toward the introduction Industry 4.0, it is essential to look back to the history of the technology revolution. As can be understood from Industry 4.0, technology has experienced three other disruptive changes, Industry 1.0, 2.0, and 3.0. Since their changes had significant impacts on the society and economy, we can introduce them as the revolution [1]. There is no precise date to define the start- and end-point of each revolution period. In the following, brief description of each above-mentioned industries are presented:

1.1.1 Industry 1.0

From 1784 to 1870 [2] is the age of using water, steam, and coal power in mechanical production and agriculture part in place of animal and human labor. These changes happened in Britain firstly and in the textile industry in which the steam engine brought more efficiency and autonomy in manufacturing [3]; compare this with a water wheel that depends on environmental conditions, like dependence of water stream presence. An increase in food and wool productivity was the main conclusion of mechanized tools in rural production [4] and increases in population subsequently [5].

1.1.2 Industry 2.0

The period of 1870 to 1969 [2], by the innovation of electricity in the United States along mass production, is the time of the new revolution of manufacturing [3]. Steel mass production, for instance, led to railways production that consequently helps mass production in other industries [6]. The development of machines has incurred more cost, but it was offset through economies of scale [7]. Due to the crises (e.g., “great depression” in 1893 and the “crash” of 1930) and the two world wars, this period has experienced a negative impact from the economic point of view [1]. However, after world war II, by arising more productive technologies, diffusion of industrialization, and the fast population increase, the number of factories and consequently the competition rose [4, 5]. During the second revolution, companies are created, some of them turned to the large corporation, and income grew significantly [8].

1.1.3 Industry 3.0

This revolution belongs to the period of 1969 till today [2], in which computer, information, and communication technologies had arisen and developed [9], to make effects on society and economy. It started again from the United States, and then Asia continued it as an essential player [3]. Research and Development (R&D), and universities activities, in the fields such as computer and Internet utility, led to advances and complication in manufacturing. Consequently, it created the needs for work manuals, planning, and control procedures [10]. Computer-Aided Design (CAD) and Computer-Aided Manufacturing (CAM) tools are the examples of advances in manufacturing [11]. As Goldhar and Jelinek [12] mentioned, “The aim was to bring greater flexibility, shorter production cycles, more customized products, faster responses to changing market demands, better control and accuracy of processes”. During this era, some companies have been starting to move activities to underdeveloped countries -notably in Asia- in the late 20th century to cope with costs [13, 14].

1.1.4 Industry 4.0

This revolution is started in Germany in 2010 [15] and includes a new set of technologies that Cyber-Physical System (CPS) is the most important of all. The principal goal of Industry 4.0 is to improve the value chain during the product life cycle [16]. It is a combination of physical and cybernetic systems [17]. The result of CPS is the decentralization of decision making through the process steps that lead to more stability and greater flexibility during the operation. It helps the design, development, production, and delivery processes of a product or service that are performed in different sectors at the same time and interactively [1]. In the Industry 4.0 initiative, the autonomous processes are increased, and it can be substituted for the needs of labor in developed countries that incurred a low working-age population [2].

As Klingenberg [1] mentioned, “The innovation rhythm and globalization create a hypercompetition business environment. It means shorter life cycles for products and services, which require flexibility and agility”. Industry 4.0 can satisfy these requirements by presenting modular and self-configuration systems. These systems can cover the niche market in which products are customized at lower costs [1]. Therefore, General-Purpose Technology (GPT), hyper-competition, aging population [1] alongside the appearance of threats like epidemic diseases (e.g., COVID19) for the labor market led to the faster and broader diffusion in Industry 4.0. Industry 4.0 has more impact on five main sectors including Transportation, Energy, Well-Being, Industry, and Infrastructure [18]. It is expected a growth from 15% to 20% by 2030 in the European manufacturing part through implementing the digitalization of their value chains [19].

Upon what is described about industry revolutions, they can be introduced through an appropriate diagram proposed by Simon Roach [20] in Fig. 1.1.

To get insight into Industry 4.0, “Plattform Industrie 4.0” website managed by “Federal Ministry for Economic Affairs and Energy’ and “Federal Ministry of Education and Research” in Germany proposes following definiation [21]:

“Industrie 4.0 refers to the intelligent networking of machines and processes for the industry with the help of information and communication technology.”

Therefore Industry 4.0 makes the flexible production, convertible factory, customer-oriented solution, optimized logistics, use of data, and resource-efficient circular economy possible.

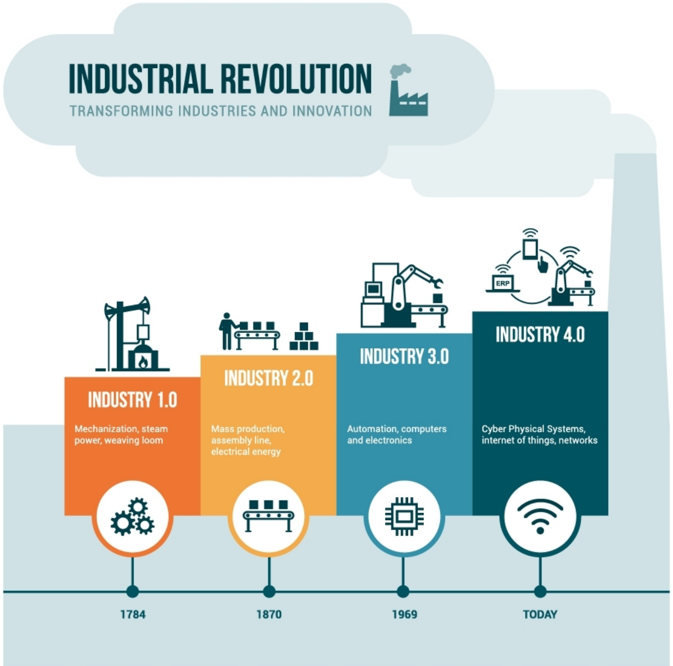

Fig. 1.1 Industrial revolutions [20].

1.2 Design Principles

Based on text analysis and a qualitative literature review, Hermann et al. [22] discovered four main factors for academic researchers and company managers. They might be useful to study more on the Industry 4.0 topic and implement the right scenario for their companies. These four items are considered as the design principles for Industry 4.0 (Fig. 1.2):

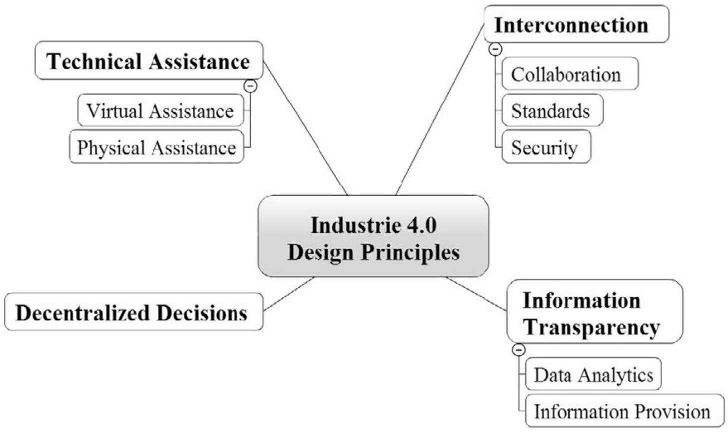

Fig. 1.2 Industry 4.0 design principles [22].

1.2.1 Interconnection

It refers to the connection between machines, devices, sensors, and people through the Internet of Things (IoT) and Internet of People (IoP) [23, 24]. Wireless communication in Industry 4.0 makes a possibility of holistic internet access for collaboration of humans and machines in the companies [23]. As shown in Fig. 1.2, interconnection should be implemented under communication standards to prevent common problems and security issues [25, 26]. Because of these standards, the company can make many combinations of modular machines (from different vendors) to respond to market demand fluctuation and customized requests [25]. Moreover, continuous training, improvement of broadband infrastructures, better work organization models, and regulatory frameworks are the other factors for developing interconnection [22, 27, 2].

1.2.2 Information Transparency

Lasi et al. [28] and Kagermann [29] concluded respectively that the interconnection of objects and people, and merging of the physical and virtual worlds led to a new type of information transparency. Here, the virtual world is a copy of the physical world that is created by linking sensor data with digitalized firm models, and its information can be electronic documents, drawing, and simulation models. On the other hand, physical world information is such as the tool's position or condition.

Both virtual and physical world information is necessary for IoT and IoP members (Internet of Everything -IoE) to make a suitable decision [30], especially real-time information for critical processes [31]. When the data analytics' results are available for all IoE participants through assistant systems, transparency will be created [32].

1.2.3 Decentralized Decisions

In Industry 4.0, CPS makes decentralized decisions through its embedded computers, sensors, and actors. They enable CPS to monitor and control the physical world autonomously [33]. Interconnection of objects and people alongside with information transparency (in and out of the production equipment) are the basis for decentralized decisions. They lead to better decision-making and then higher productivity in the factory, utilizing local as well as global information at the same time [34].

1.2.4 Technical Assistance

Since CPS make the complicated networks and decentralized decisions, humans in dealing with this complexity (in Smart Factories), have to be the strategic decision-maker and flexible problem solver. To obtain that, humans need assistance systems which able to collect and visualize the information clearly. They can support humans to make informed decisions and cope with urgent problems [32]. Smartphones and tablets are assistants through which people are connected with the IoT [35]; or the robots when they come to physical supporting human and making human-machine collaboration [36].

1.3 Contributing Digital Industrial Technologies

Industry 4.0 is also known for the emergence of new digital industrial technologies. From Boston Consulting Group (BCG) point of view, they are introduced in Fig. 1.3 and explained in Table 1.1 [37]:

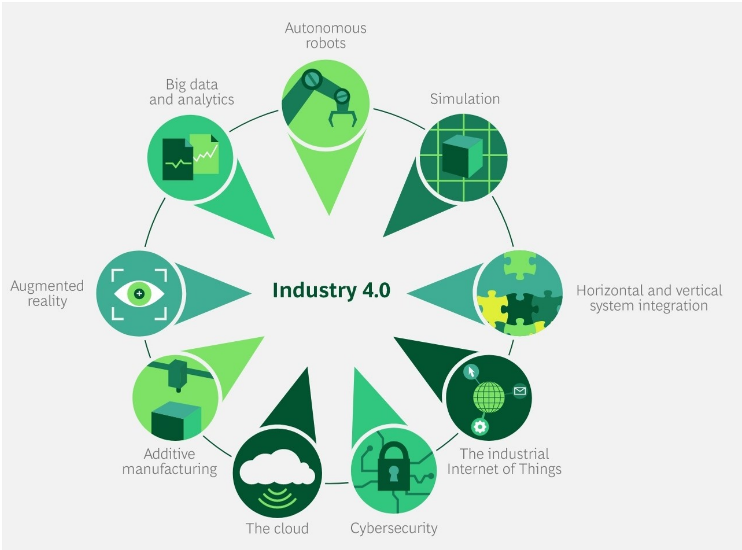

Fig. 1.3 Main digital industrial technologies in Industry 4.0 [37].

Table 1.1 Contributing digital industrial technologies in Industry 4.0 [37]

Big Data and Analytics	Through the massive information (passive or real-time) in an Industry 4.0 context, this technology can be applied to give enough analytic view for predictive manufacturing and development processes.
Autonomous Robots	These robots interact with each other and collaborate with the human under the company network. They are cheaper and more capable than current robots.
Simulation	It reflects the virtual world of the physical world through real-time data. The physical world includes machines, products, and humans. It helps operators to decide better during production.
Horizontal and Vertical System Integration	Improvement of the value chain in product development can happen by possible horizontal and vertical integration.
Industrial Internet of Things	They are the main part of preparing connectivity between physical world members in manufacturing.
Cybersecurity	It is coming up due to the enormous communication and information in the network. When communication would be secure and reliable, the operation will be done safely.
Cloud Computing	By considering the amount of data produced and analyzed in Industry 4.0, the traditional method does not work to cope with them. Cloud makes enough space for storage and calculations.
Additive Manufacturing	Additive manufacturing, like 3D printing, will be used widely in Industrial 4.0 to produce individual components, especially when it is needed for producing a small batch of customized products.
Augmented Reality	In the future, this technology will be applied more, particularly in warehouses and maintenance parts.

1.3.1 Artificial Intelligence in Smart Manufacturing and Digital Transformation

Artificial Intelligence (AI) is another and the main technology among the Industry 4.0 contributors. The application of AI is endless, and it appears more and more everywhere in the industry and society. Even in industry, the role of AI in each step of manufacturing can be perceived. As shown in Fig. 1.4, AI will be ubiquitous in future factories. This figure is a complete example. It says AI can make the processes better, whether inside or outside the factory (including engineering, supply chain management, production, quality, maintenance, and logistic). It impacts all the stages from predicting customer demand and warehouse management to the operation in the shop floor and logistics [38].

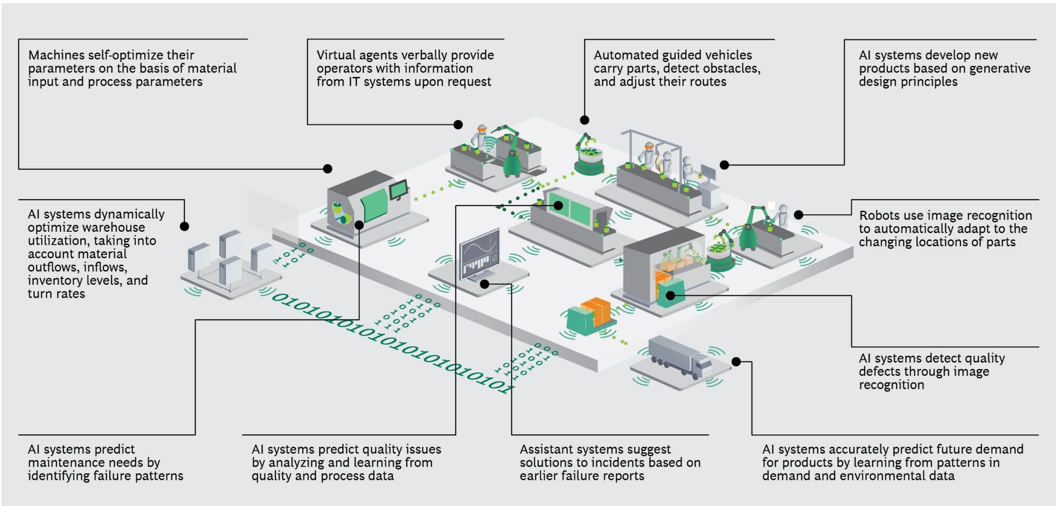

Fig. 1.4 AI will be ubiquitous in the future factory [38].

An important outcome of this AI-integrated structure is providing specific customers with personalized (tailored) products in a shorter lead-time. It also shows the flexibility of the company in dealing with varied demands. Then, AI, on the one hand, reduces cost and downtime, and the other hand, improves the quality and quantity of the products for the manufacturer [39].

The emerge of AI in society and manufacturing made a potential income for providers of software, hardware, and services in AI technologies, including Machine Learning (ML), Deep Learning (DL), Natural Language Processing (NLP), computer vision, machine reasoning, and strong AI. Tractica's report predicted that these providers' global revenue would reach more than $13 billion by 2025 [40]. This market revenue motivated leading technology companies like Google, Amazon, Microsoft, and IBM to find a place to fill in the market [41]. And because of the holistic role of AI, some artificial intelligent startups can arise in the market in the future. Among these startups can refer to Tempus, DataRobot, Freenome, and CloudMinds [42].

1.4 Plattform Industrie 4.0

After the emergence of Industry 4.0 in Germany, three German industrial associations BITKOM[1], VDMA[2], and ZVEI[3], built an appropriate platform to implement Industry 4.0 in 2013, that is called "Plattform Industrie 4.0". In 2015 this platform covered broader organizations under the supervision of the German Federal Ministry of Education and Research (BMBF), and the German Federal Ministry of Economic Affairs and Energy (BMWi). This platform has six working groups with the following topics [43]:

- **Working group 1:** Reference Architectures, Standards and Norms;
- **Working group 2:** Technology and Application Scenarios;
- **Working group 3:** Security of Networked Systems;
- **Working group 4:** Legal Framework;
- **Working group 5:** Work, Education and Training;
- **Working group 6:** Digital Business Models in Industrie 4.0.

To show a more holistic view of Industry 4.0 fundamentals and make a guide for implementing them, Plattform Industrie 4.0 presented the Reference Architecture Model for Industry 4.0 (RAMI 4.0) [44] as a reference framework in 2015. They introduce this model as below:

"RAMI 4.0 is a three-dimensional map showing the most important aspects of Industry 4.0. It ensures that all participants those are involved, share a common perspective and develop a common understanding."

[1] Bundesverband Informationswirtschaft, Telekommunikation und neue Medien.
[2] Verband Deutscher Maschinen und Anlagenbau.
[3] Zentralverband Elektrotechnik und Elektronikindustrie.

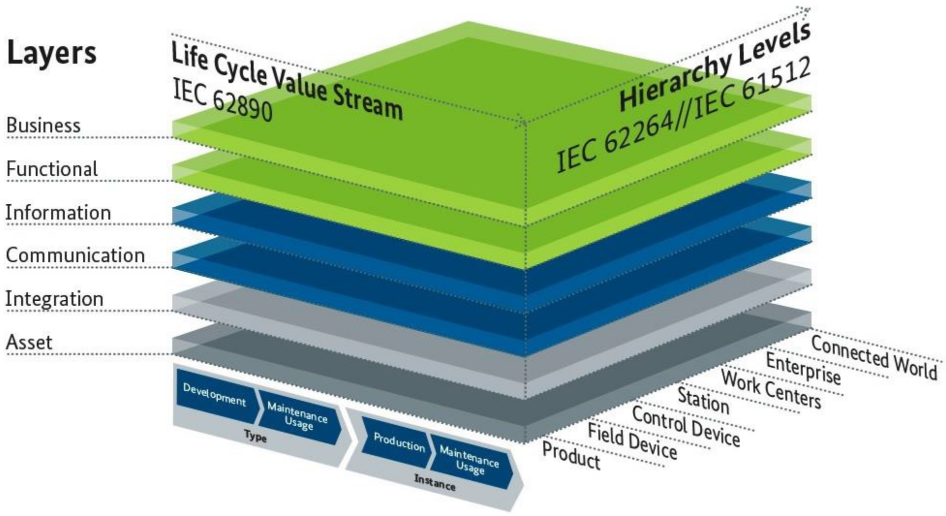

Fig. 1.5 The Reference Architecture Model for Industry 4.0 (RAMI 4.0) [44].

RAMI 4.0 defines a three-dimensional structure of the Life and Value Stream, the Hierarchy Levels, and the Layers. The Life and Value Stream dimension is aimed to demonstrate the digitalization in product life cycle steps and vertical integration process. The Hierarchy Levels dimension shows Industry 4.0 components in a hierarchical manner. And the Layers dimension provides integration of Industry 4.0 goals into a target environment like the production environment [16].

This chapter was an introduction to Industry 4.0. Industry 4.0 is an initiative toward digital transformation for the enterprises (even small and medium-sized ones). This thesis focuses on discovering the transformation of product life cycle development under the Industry 4.0 platform. To achieve that, the next chapter is dedicated to describing the product life cycle process, before and after the introduction of Industry 4.0. Chapter three explains further about the components in Industry 4.0, which make a connected world. This thesis is followed by a case study to give more insight to the reader. It is a bike saddle, which is a known product for everyone. At the end of the thesis, the conclusion and the possible future works are presented.

Chapter 2

Product Life Cycle Development

2.1 Introduction

Industry 4.0 revolution is changing the way of manufacturing toward more productivity and cost-saving. It also gives value to the customers by the possibility of mass customization in small lot sizes. Thanks to the new emerging technologies, the impacts of the fourth revolution are coming up from a higher level of the connectivity between objects and autonomy in decisions making. The objects include humans, machines, and products. There are many contexts to introduce Industry 4.0 and its components. Nonetheless, this research investigates more on the life cycle of a product (product development) in the common process and how it transforms through the smart process in Industry 4.0 reference.

2.2 Conventional Product Development

Product development starts from the customer needs to the constructed workpiece, and it is considered as a part of the whole manufacturing process. In the conventional approach, it includes the collection of views from the market which can describe the features and properties of the product [45], often termed "product brief" or "design brief" [46]. It also can be the individual attribute in Industry 4.0 product development.

In this research, to illustrate the process of product development, the product life cycle models are considered as suitable sequence tools. The principal models that are introduced by literature [45] are the Waterfall diagram, V-diagram, and Spiral diagram. Those are the application of Model-Based System Engineering (MBSE). International Council on Systems Engineering (INCOSE) defines MBSE as “The formalized application of modeling to support system requirements, design, analysis, verification and validation activities beginning in the conceptual design phase and continuing throughout development and later life cycle phases [47].” MBSE facilitates understanding the system and consequently helps in control, event prediction, and decision making. It consists of many applicable models in which System Markup Language (SysML) based models have a higher share in System Engineering (SE) usage. However, the three mentioned models are the common models to describe a life cycle development process. Brusa et al. [45] described each model as below:

- **The Waterfall Diagram:** “It is simply a sequence of blocks or items, listed by reproducing a water drop from the top to the bottom, to represent the time at which actions are performed.” Fig. 2.1 shows the Waterfall diagram which is the simplest ones among the product life cycle models. Its elements comprise Customer needs, Requirement elicitation and product specification, System design, Product building, Testing and Debugging, Disposal and installation, and Operation Service.
- **The V-Diagram:** “It is often proposed to show some typical key steps of the SE process, as it looks in Fig. 2.2. The path to be followed starts from the upper left corner, goes down to the bottom through the left side, and then continues by going up through the right upper corner, across the actions described on the right side.”
- **The Spiral Diagram:** “a spiral frame, to point out that the SE process is a recursive approach and each step needs an assessment, being performed by refining the previous one, step by step, circle by circle, particularly when requirements are concerned (Fig. 2.3).”

V-diagram is utilized in System Engineering and System development, while Waterfall and Spiral models are used in software development because they can support structured, iterative, and incremental development [48].

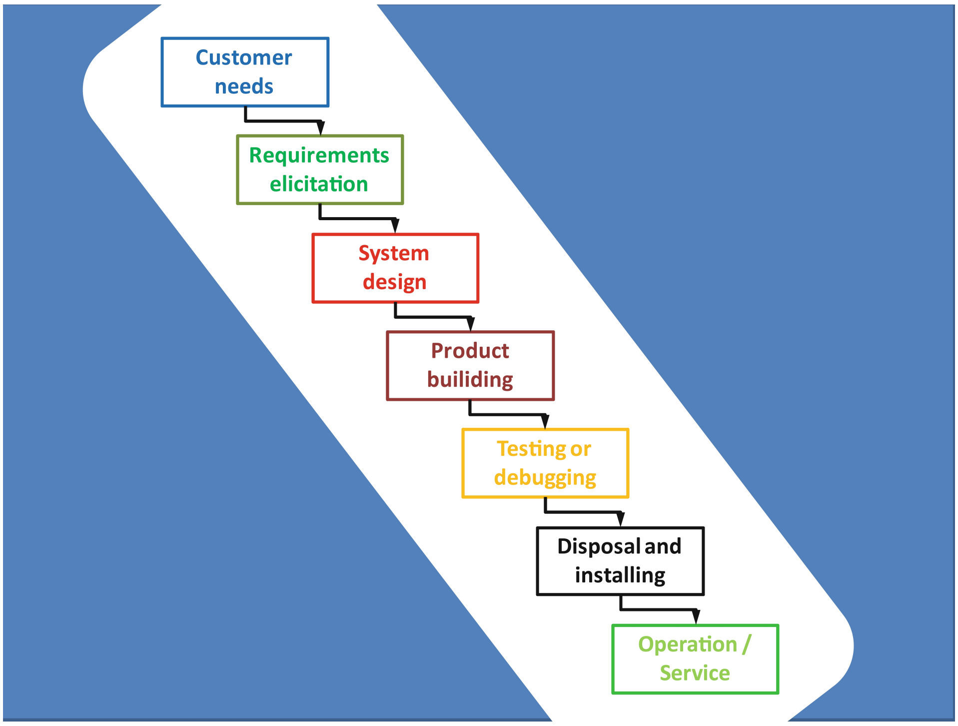

Fig. 2.1 Waterfall diagram: a model of product life cycle development [45].

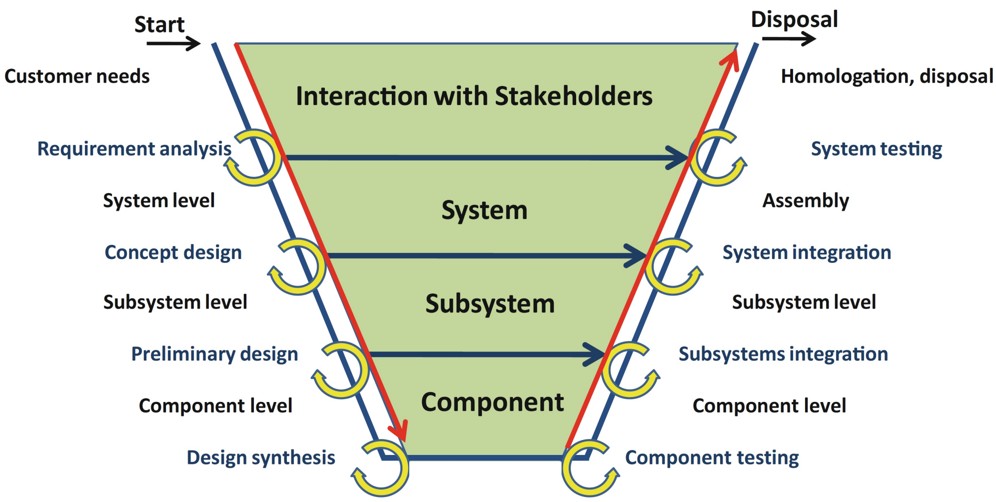

Fig. 2.2 V-diagram: a model of product development in systems engineering [45].

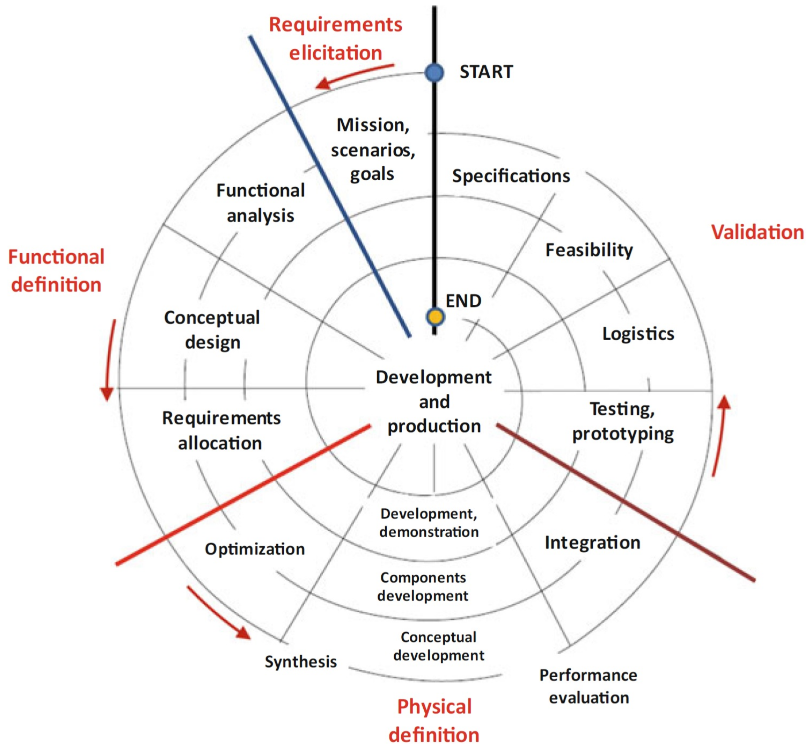

Fig. 2.3 Spiral diagram: a model of product development in systems engineering [45].

To be more transparent, the needs are collected directly from the customers, and it shows the holistic image of the product and what is validated by the customer at the end. While requirements are determined at different levels of design and are the basis of functions, operations, and architectures under standards and existence constraints. In other words, requirements are the technical interpretation of needs. They should be as enough as Specific, Measurable, Achievable, Relevant and Traceable (SMART), and written in proper language to be understandable for other parts of design systems [45].

2.2.1 The Role of Information and Communication Technology (ICT) Tools in Conventional Approach

Briefly, they support the product development process by the virtual representation of the product, and management and transfer of information. Computer-aided tools are the current things that are used in the industry for product development. They are termed to CA-X in which CA refers to computer-aided, and X stands for any functions that they do. For instance, CAD stands for computer-aided design and makes a three-dimensional visualization for ideas or products, or computer-aided engineering (CAE) that helps to simulate the cinematic and dynamic behavior of the product under pressure, thermal, and fluid flow.

Product life cycle management (PLM) systems are another outcome of ICT emersion, which is applied for the product's data management throughout its life cycle. It includes the framework of different modules in the product development process in which the most important modules are:

- Bill of Materials management.
- Configuration management.
- Engineering change management.
- Components and supplier management.
- Workflow management.
- Vaulting systems.
- Project and project portfolio management.

Recently, in some enterprises, they use Enterprise Resource Planning (ERP) systems alongside the PLM to support administrative and production processes [46].

2.2.2 Customer Needs

There is not an official guideline for taking customer needs even though some experts have their own ability to achieve appropriate needs from preliminary data by following a main driveline and systematic approach. Five primary sources for driving customer needs, based on priority, are [45, 46]:

- The customer expectation that is achieved through direct interview or survey, or reports and feedbacks from independent entities and warranty claims, etc.;
- Key features that make the product innovative (innovation targets);
- Constraints, typical of the technical domain or the manufacturer's practice, which are imposed by the manufacturer's facilities;
- Industrial sources such as trade journals and websites or suppliers' and competitors' catalogues;
- Technical standards that seem like the law in driving need or patent database.

2.2.3 Market Research

Market research is the way of collecting customer needs. Owning abilities like flexible manufacturing or rapid manufacturing, firms can implement real-time market research through which varied products are launched based on the actual market.

Usually, real-time market research is accompanied by another concept called Lean Production (LP). In LP, firms adjust their produce by defining, developing, and launching a Minimum Value Product (MVP). MVP is the basis of a product that considers the marketing and financial metrics, and within continuous interaction with different customer segments can be revised and tested.

One significant step in market research is driving the customer's perceptual space, which is a complicated and implicit process. It is not achieved only by asking the customers. Modeling of a hierarchy, regarding the customer needs, is introduced as a common approach to implementing the process.

In this perceptual process, identification of three levels of needs, including Tertiary needs, Secondary needs, and Primary needs are determined as the steps of the process. It starts from the Tertiary level as the elementary needs (with a higher number) and by direct interaction to the customers, to the Primary one as the essential needs (with a lower number). Then, finally, for better illustration of the primary needs, the product developer uses the perceptual maps [46].

2.2.4 Product Specification

Another phase during the development of a product is defining the specifications which are related to the interface of the product with the user. Obtaining enough comprehension about the interaction between user and product is complicated. Typical usage patterns like personas, scenarios, and use cases are proposed to cope with this complication [46].

2.2.5 Quality Function Deployment

Quality Function Deployment (QFD) is one of the most common techniques applied in the product development process within which the voice of the customer could be heard and transform into the requirements and product specifications. This tool is introduced in Japan in the '70s to support the design process. It specifies customer requirements and their importance, and considering competitor product's features, translate them to the consistent product specifications. It can be used throughout the whole process of development from the beginning of product requirements definition to the design of manufacturing processes and quality assurance systems. The structure of QFD reflected in the linked matrixes called Houses of Quality, as shown in Fig. 2.4. Inside each house, the inputs listed in rows of the matrix are translated to the outputs listed in columns. As can be seen in the figure, one house of quality is required for each translation step. The translation from customer requirement to system-level specification, component-level specification, process-level specification, and product assurance specification, and the principals of using are the same in each house.

The level of success in the application of QFD depends on the goodwill with which its user engages.

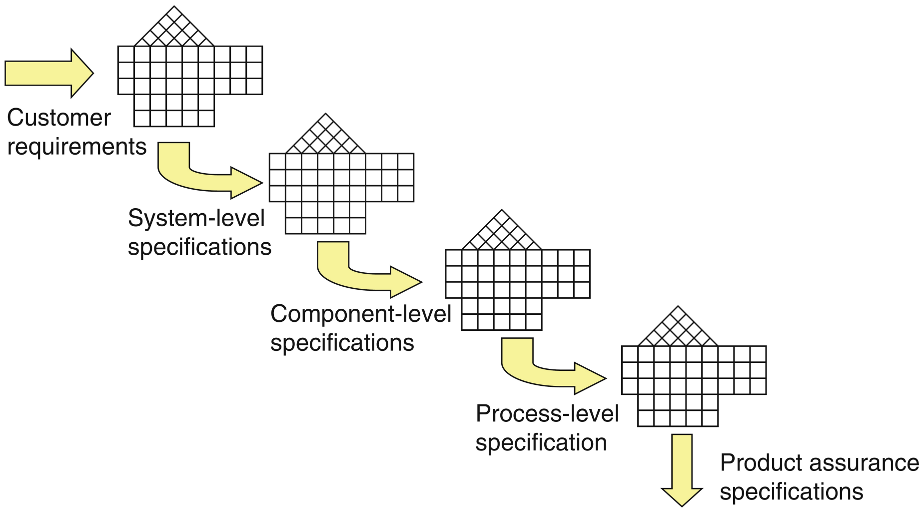

Fig. 2.4 The quality function deployment process [46].

Because of the weak methodologies in the QFD process for prioritization of requirements and technical features, QFD may not lead to the right product for the customer [46].

2.2.6 Conceptual Design

After identifying product needs and specifications, the design team outlines the design problems and related functions. Then alternative solutions are explored and generated. Here the term "concept" arises, which refers to each possible combination of technical solutions (Fig. 2.5a).

Concepts formed by the above procedure are investigated, and the most suited ones are picked. These selected concepts are improved and subjected to a more accurate comparison. Ultimately by taking into account all matters, the single concept is separated and used for the next step of the development process (Fig. 2.5b).

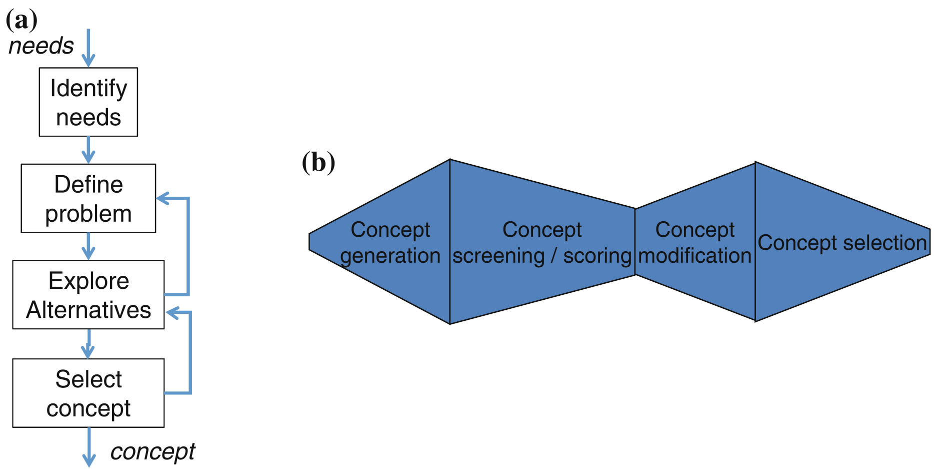

Fig. 2.5 The conceptual design process [46].

2.3 Smart Product Development (Product Development in Industry 4.0)

The fourth industrial revolution introduces the idea of smart factories and smart products as the world in which machines and products can determine their states and communicate them to each other and the humans. It is the world of connected objects in which everything is a part of a network [49].

Smart factory, smart product alongside the new technologies made the distinctions within the product development process in Industry 4.0 and conventional industry. In comparison with the common industry, Industry 4.0 has three main aspects [49]:

- All information about the product is shared with all sections of its value chain.
- The whole of the value chain in the product, from design to life cycle, is organized and controlled.
- By communication between human, product, and technology, value chains are able to be changeable and self-optimizing.

2.3.1 Smart Product

A smart product (or Gentelligent Component in [49]) is a product with the capability of collection, storage, and communication of information during the entire life cycle. Therefore, it is needed for the product to fulfill some criteria to be accounted for as a smart product. Its information may include two types of genetic and intelligence as is illustrated in Fig. 2.6, that shows smart product follows the principles of biology. The genetic information consists of identification data such as geometry, material, and production stored in component, and it is constant and unchangeable. The intelligence information consists of data such as the effects of mechanical and thermal loads during production and life cycle. It is an important feature that is achieved by the integration of the appropriate material and sensors technologies that have the technical ability to autonomously and inherently store, and process information.

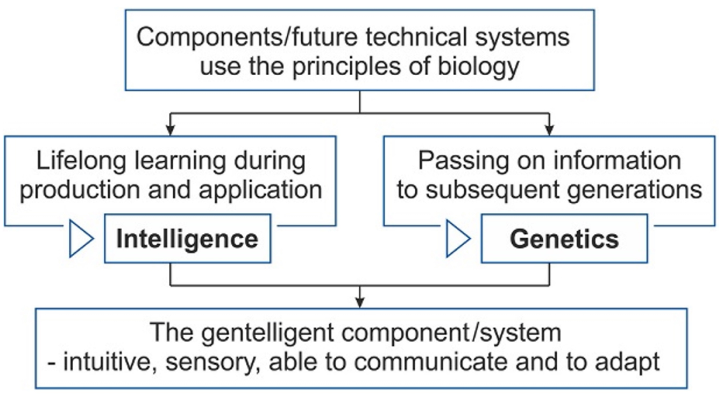

Fig. 2.6 Two types of information in smart product [49].

The combination of these two types of information makes new possibilities to enhance the production process, maintenance plan, and future components design. For instance, the real data of the product during its usage can be a good alternative for models and simulations [49].

In the context of Industry 4.0, this notion goes beyond the smart product, and each asset, including not only the products but also machines, production modules, systems, software installations, intellectual property, or human resources, should represent itself as an entity in the information realm. Here is where the idea of Asset Administration Shell (AAS) has been proposed; a logical representation of the asset in a standardized manner (Fig. 2.7) [50]. In some literature, Industry 4.0 component are defined as an asset with its Administration Shell (AS).

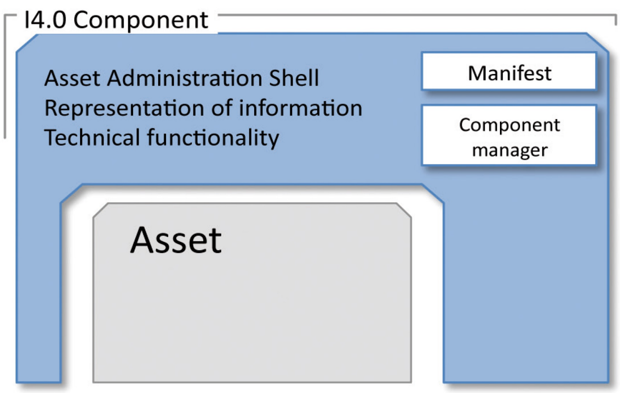

Fig. 2.7 General structure of an Administration Shell [51].

Following some pictures of smart products with their integrated sensors, and data communication and storage instruments are shown.

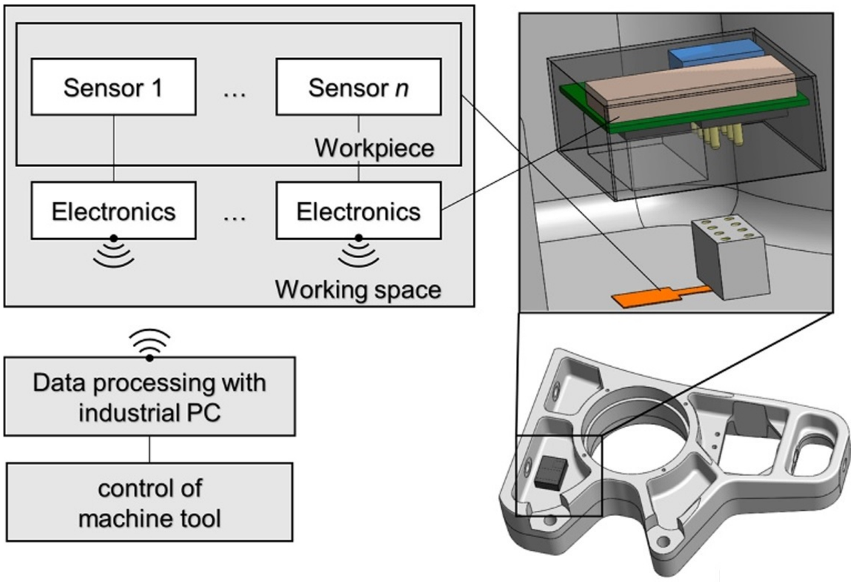

Fig. 2.8 Concept for sensor integration in a wheel carrier as a casted workpiece [49].

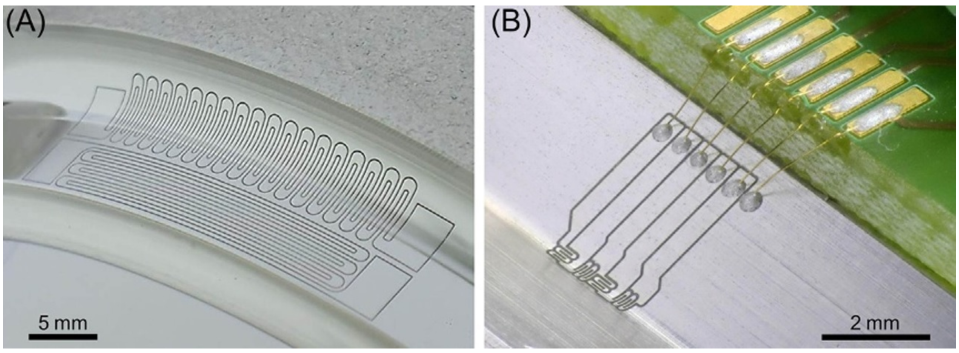

Fig. 2.9 Laser-patterned thin film sensors placed on the bearing ring (A) and into a v-groove of a component of the tool machine (B) [49].

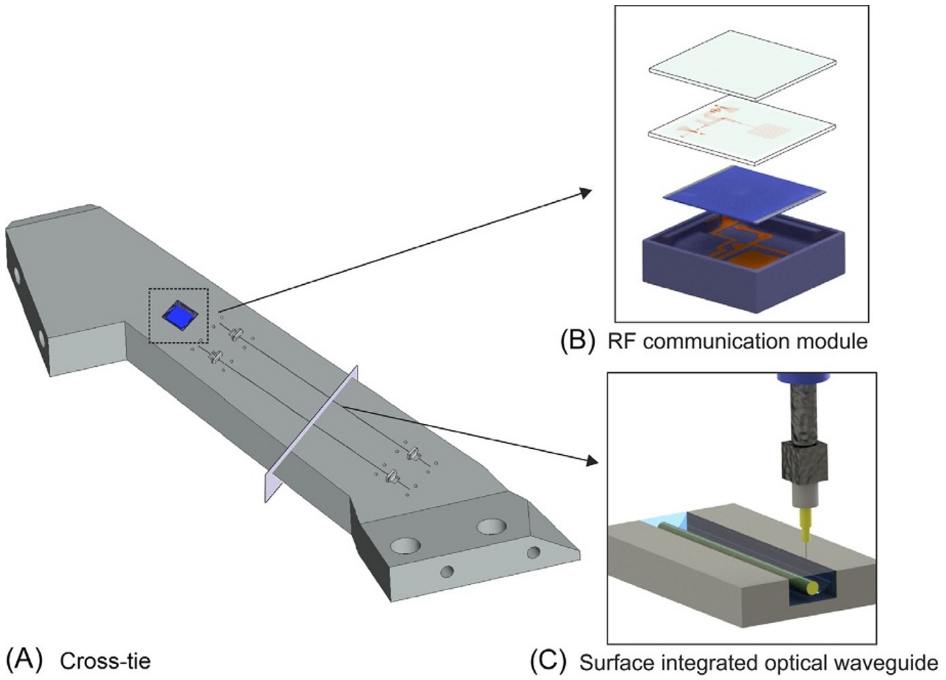

Fig. 2.10 Illustration of a cross-tie (A) with surface integrated communication facilities. Subfigure (B) represents a radio frequency communication module. Subfigure (C) represents a surface integrated waveguide for optical communication [49].

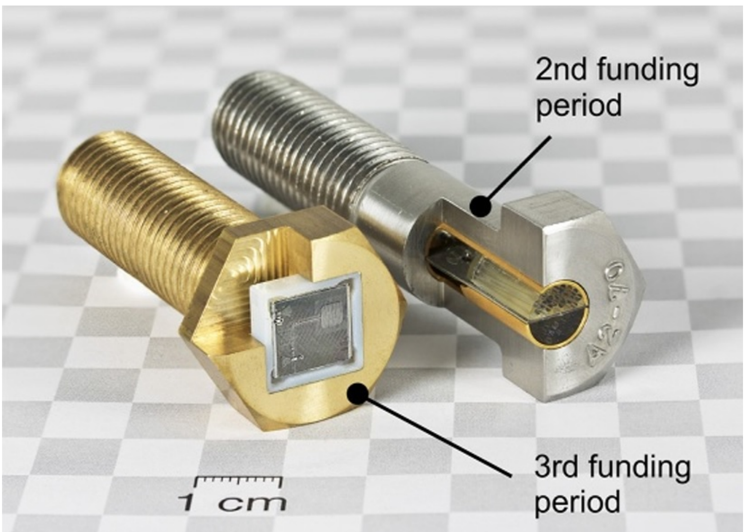

Fig. 2.11 Intelligent screws with integrated communication module [49].

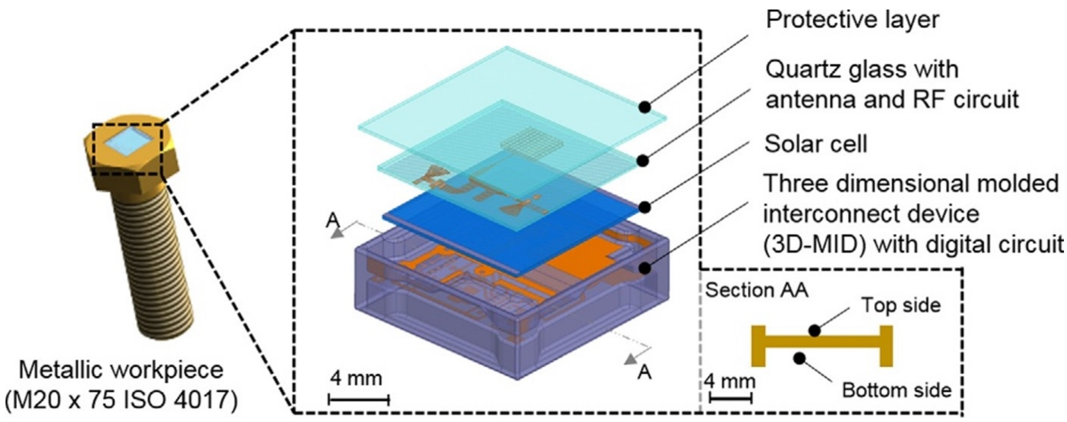

Fig. 2.12 24 GHz communication module integrated in a metallic workpiece, exploded view of the module and cross section view of the 3D device [49].

2.3.2 Life Cycle of the Smart Product

Considering the product capacity in storing its identity and production information through AAS, the new possibility has come up for the product to plan its manufacturing process. It improves the manufacturing process when the product receives detailed process information and the condition of machine tools [49]. It helps to small-lot production.

As an illustration for smart product and smart manufacturing, suppose the wheel carrier of a race car, which represents a small-lot production component. During usage, it is under high mechanical and thermal loads and makes the necessity of many manufacturing processes to be produced. The scenario illustrated in Fig. 2.13 covers the design, production, usage, and maintenance. In each step (example), there is an application of data storage and communication for improving the manufacturing process [49]:

- **In step 1,** there is the usage of the company database for design.
- **In step 2,** the machine tool process has been optimized by using its state data.
- **In step 3,** better work and process planning is carrying out.
- **In step 4,** real-time data during production usage is communicated.
- **In step 5,** there are applications of real-time for maintenance prognosis and optimizing the future design by using a genetic algorithm.

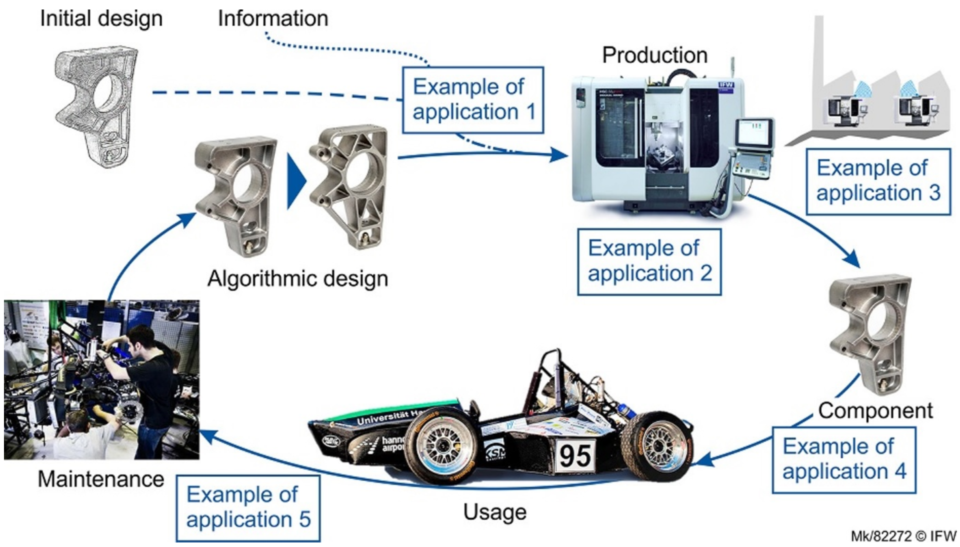

Fig. 2.13 The smart wheel carrier through its life cycle [49].

Those steps can be included in RAMI 4.0. As described before, it is a three-dimension reference framework for implementing Industry 4.0 (Fig. 1.5). It is noticeable that product life cycle is one dimension of this framework.

RAMI 4.0 defines a three-dimensional structure of the life and value stream, the hierarchy levels, and the layers. It can be combined with those of the MBSE [52]. The life and value stream dimension is aimed to demonstrate the digitalization in product life cycle steps and vertical integration process [16, 53]. According to Bitkom [53], the life cycle of a product in Industry 4.0 is divided into two stages: type and instance, as shown in Fig. 2.14.

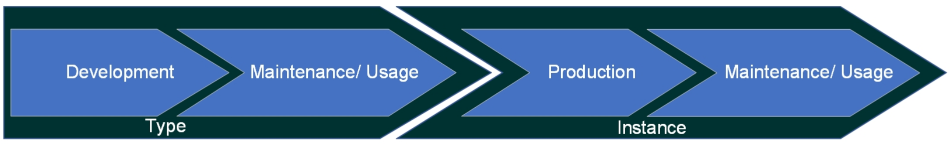

Fig. 2.14 Product life cycle as is modelled in the RAMI 4.0 framework [53].

The type stage refers to the product development process from the idea generation to building and testing the prototype model. As the production of each type of product starts and is prepared for sale, the next stage will begin. The instance stage refers to the production and then the usage of the product by the customer [1]. Any feedback about instance will reach directly to the manufacturer to improve specifications and modify technical constraints for the design of the new type or product version [53]. This can be possible throughout the connected world of Industry 4.0 in which the information from service are collected and driven back to the manufacturer. Cross-linking between different functional areas and steps of value stream brings many opportunities of improvement for industries.

High productivity, product quality, and respond to increasing demand for individualized and flexible manufacturing (or mass customization) make the challenges for international competitions. Notably, in the single item or small-lot production, design and product decisions are based on unstructured practical knowledge. Besides that, in order to find the optimal solution for it, real-time data analysis and process monitoring are necessary to be done [49].

2.4 Smart and Conventional Product Development

Regarding the life cycle description of a product in Industry 4.0 and three common life cycle models of the MBSE, RAMI 4.0 can reduce the barriers of the conventional development methods in dealing with new challenges for the manufacturers. Those challenges are mass customization, continuous demand changes, the complexity of the new product, cost, and time to market [54]. In the context of Industry 4.0, the product development process can implement continuously rather than periodic product development in conventional manufacturing enterprises [55]. Herein, the essence of network and smartness in Industry 4.0 alongside the technology enablers have significant impacts.

To have a perceptible look at the role of digital technologies in product development progress, there are many demonstrations that happened during digital transformation. The following subsections refer to some of them.

[1]From reference [50]: "Type is hardware or software element which specifies the common attributes shared by all instances of the type. Instance is concrete, clearly identifiable component of a certain type. In an object-oriented view, an instance denotes an object of a class (of a type)."

2.4.1 AI Demonstration

In product development, AI helps the designers to reach customer preferences and needs more accurately. At the begging of product development, the product life cycle manager gathers feedback from current product consumers. It can be done in different ways, from doing surveys to new ways of investigating customer reviews in online purchasing websites in which the role of AI is boldened. Evaluating customer reviews has some benefits:

- Collecting the feedbacks with lower cost.
- Better identification of the product's pros and cons.

Timoshenko [56] illustrated that identifying customer needs from user-generated content is more valuable than conventional methods. Doing so needs intelligent algorithms applicable in lexical analysis. AI methods such as data mining are the right choice for this goal. Thanks to the programming languages and their libraries, these methods can be used more practically. They can do sentiment analysis for each review, categorize them in terms of subjective or objective, and, more importantly, feature-based analysis. Through these methods, each word and sentence is analyzed. The sentence can illustrate the user's opinion about the product or service depending on the type of each word (noun, adjective, adverb, verb, article, etc.).

Review analysis helps users to know about a product (service) more than producer description. To help more, online shopping websites like Amazon provide some facilities, including product comparison and rating on their website. These companies can take advantage of their AI technology capability to help companies, too, and give them more knowledge about their products by using customer feedback.

There are many methods to investigate customer reviews that are reflected in literature. Topics that talk about sentiment analysis, feature-based analysis, opinion mining, and so on, are all about exploring the text reviews and driving concrete results. For example, in sentiment analysis, a user's general sentiment about a product is extracted, or in feature-based analysis, it digs more on user's viewpoints about product features. The outcome of the feature-based analysis is common product features with the level of customer satisfaction. It shows the strength and weak points of the product. It should be noted that the rate of customers on the product cannot be informative for either consumer or producer.

2.4.2 Augmented Reality and Virtual Reality Demonstration

Augmented Reality (AR), Virtual Reality (VR), and mixed of them (i.e., mixed reality) provide the design tools through which products are imposed in the real and virtual worlds. They lead that customers fully capture the product features and functions. AR is a technology in which customers can see computer-generated information such as videos and graphics combined with the real world. It improves the user experience of the product by interacting with the virtual information and the real world. On the other hand, VR is a technology that makes a fully virtual and simulated product for users. All these technologies bring the product's design into the visual to facilitate the development processes of complex products [55].

2.4.3 Big Data, Cloud Computing, and AI Demonstration

Yu and Yang [57] propose a big data analysis model and use it to analyze consumer behavior. The feature of big data can be characterized by 5V, including huge Volume, high Velocity, high Variety, low Veracity, and high Value. The challenge comes from diversified data types (Variety), timely response requirements (Velocity), and uncertainties in the data (Veracity). Cloud computing is one technology that emerged and matured in recent years to support Big Data Analysis (BDA) in collaboration with Information Technology (IT) infrastructure.

In the new product development process, BDA takes advantage of real-time data rather than Traditional Marketing Analysis (TMA). It enhances decision making in dealing with real-time uncertainties. Text mining, sentiment mining, and data mining are some of the important areas of BDA in which data can be extracted from social media. Yu and Yang [57] summarized the general process of big data processing for market analysis in the steps shown in Fig. 2.15.

2.4.4 Cloud Computing and AI Demonstration

Nozaki et al. [58] illustrate the application of Artificial Intelligence in the product design in Monozukuri (Japanese way of manufacturing). To do that, they describe the MONOZUKURI AI framework supported by a framework for the utilization of learning models (Fig. 2.16). Utilization framework is a web service implemented on the engineering cloud to provide an environment for websites and CAD/CAE tools that offer services utilizing Machine Learning technology. ML models are controlled and managed through the MONOZUKURI AI framework for designers.

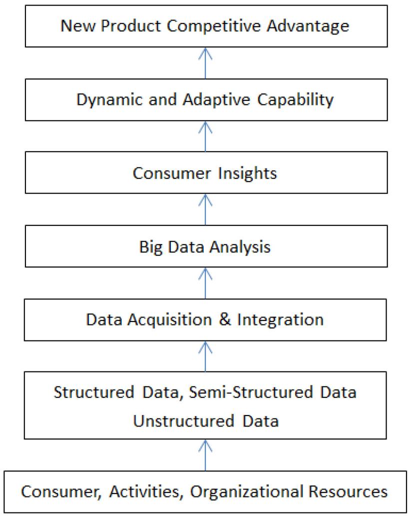

Fig. 2.15 Big data analysis model for market analysis [57].

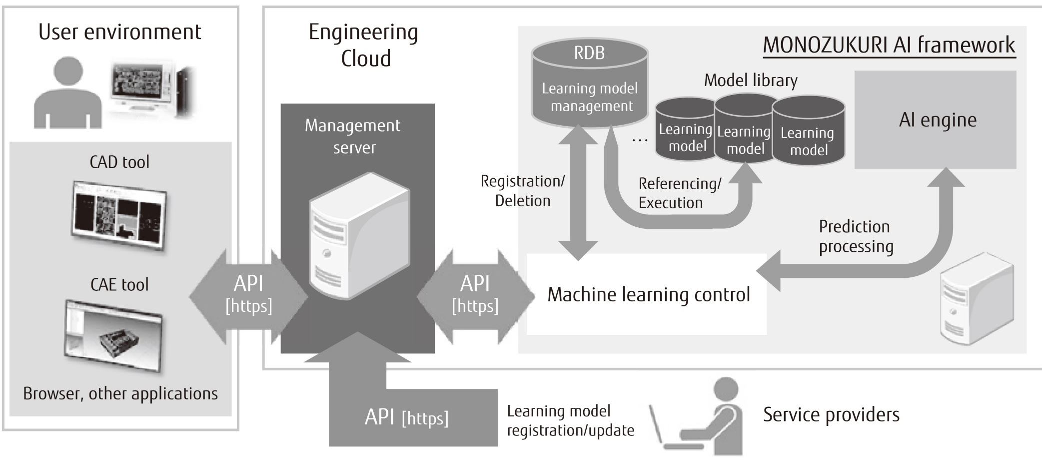

Fig. 2.16 Learning model utilization framework and MONOZUKURI AI framework [58].

Chapter 3

Industry 4.0 Components and Their Relationships

3.1 Asset Administration Shell and Industry 4.0 Component

The Asset Administration Shell is related to the asset. The asset is defined as below [50]:

"physical or logical object owned by or under the custodial duties of an organization, having either a perceived or actual value to the organization."

It includes material and immaterial things at any level of complexity (Fig. 3.1) and can be one of the following [50]:

- Any physical objects such as machine, computer, cables, raw material, screw, wheel, supplies or product.
- Any Software.
- Documents such as data media and life cycle documents.
- Immaterial like license, copyright, and patent.
- Information.
- Humans such as operator and programmer.
- Services.

As Fig. 3.1 shows asset can be even plant and station in the point of the hierarchical view.

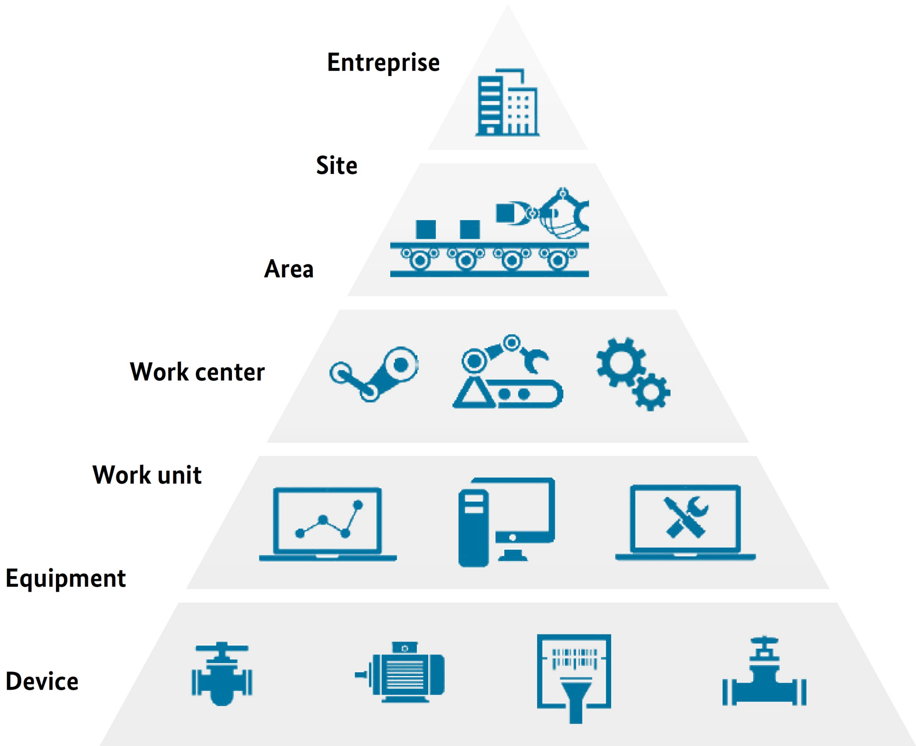

Fig. 3.1 Asset in hierarchy level of complexity [50].

The main feature in Industry 4.0 or smart manufacturing is networking or interoperability, the ability of cooperation, and information exchange among at least two assets. For instance, an enterprise comprises different sectors, which can be divided into two floors: shop floor (for production) and office floor (for organization). Both floors work closely together, and they include all the departments, from design and development to finance and marketing. Fig. 3.2 shows a rough structure of the enterprise with its network of devices. To avoid misinterpretation, it should define a common language between both floors.

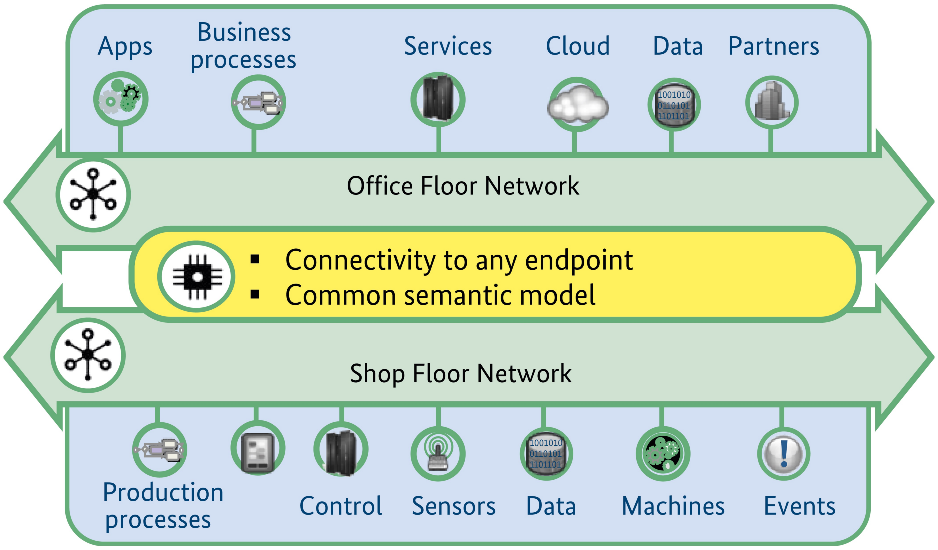

Fig. 3.2 A rough structure of the enterprise with shop and office floor [50].

To make interoperability in assets, it is needed to define each asset in a manner to be meaningful in the network. Here is where the Administration Shell comes up as the standardized digital representation of the asset.

Each asset with its AS creates a component in Industry 4.0 or Smart Manufacturing (Fig. 3.3), and as it is said about the asset's hierarchical level, AS can be the representation of a simple component or a plant industry. In Industry 4.0 or smart manufacturing, AS includes the information of its asset during the life of the asset until its disposal, and it is updated by system designers, asset users, and even by the asset itself. For more clarity, Fig. 3.4 shows the AS in the life cycle of product type and instance that can be integrated into a high-level asset like production system. The product types have a history with different versions, and at the same time, the instances of these types and versions are produced and incorporated into the industrial facilities.

Depending on smart manufacturing requirements and variety of the use cases, AS should have the ability to maintain information and functions in different technical fields, various steps of the life cycle, and different applications [50]. As a crucial point, it is not necessary for all the assets to be defined in the Industry 4.0 component context [59].

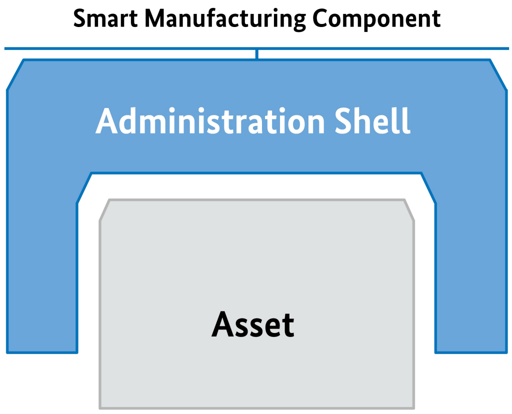

Fig. 3.3 Smart manufacturing component [50].

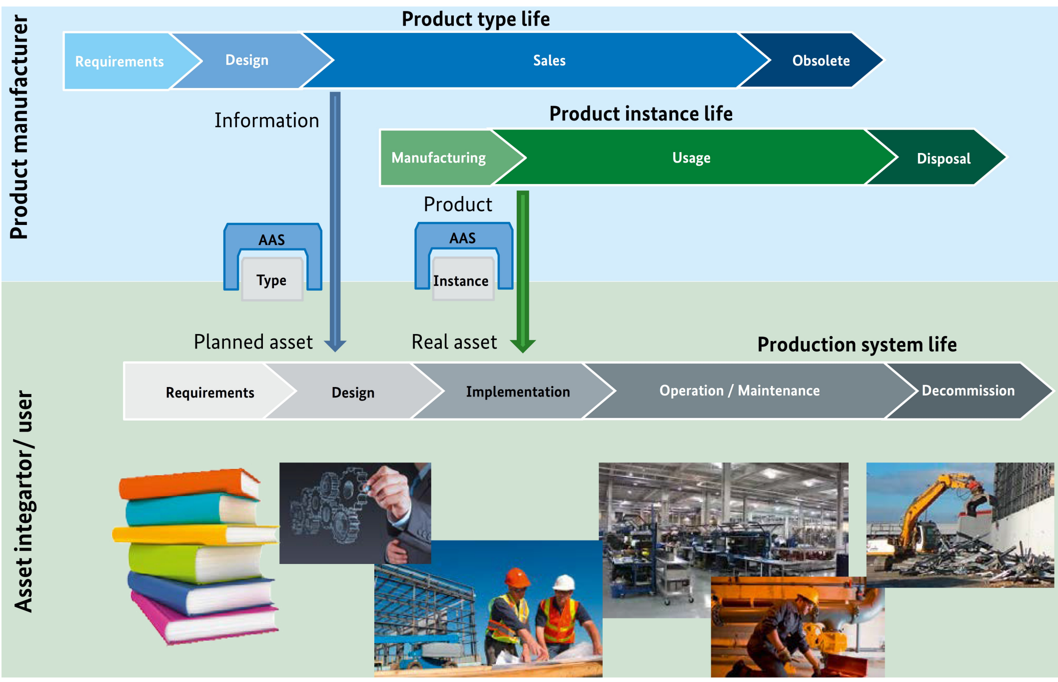

Fig. 3.4 The Administration Shell in product and system life cycles [50].

3.1.1 Naming the Industry 4.0 Component

It is worthy to notice, every asset and its AS should have a unique ID globally for designation and identification, those are always linked together.

To name the products, manufacturers mostly apply an identical name for product type, which identifies the same class or category of products, with specific abbreviation, which is more precisely (e.g., servomotor_MKS140). Then, for product instances, they use a serial number (mix of ASCII letters, numbers, etc.) to distinguish product instances of the same type. In some cases, that products are made of considered material, identification is performed through the material serial number. A naming strategy can be clarified via following examples as:

- Product name: Servomotor_MKS140
- Material number: 1122334455
- Serial number: 6677889900012345

An issue arises as many assets like cables do not have any serial number, and they just determine by product and manufacturer name. There are more details about product name and identification in affiliated standards like ISO [50].

3.1.2 Importance of the Asset Administration Shell

To encourage the data-driven economy and making value creation in industrial production, it is essential that all the aspects be considered. Therefore, to achieve this, in the smart manufacturing area, four aspects are determined to be taken into account (Fig. 3.5) [50]:

1. Horizontal integration by networks of value.
2. Vertical integration from raw material supplies to factories and product shops.
3. Life cycle management and end-to-end engineering in the value chain.
4. The role of human beings in arranging the value stream.

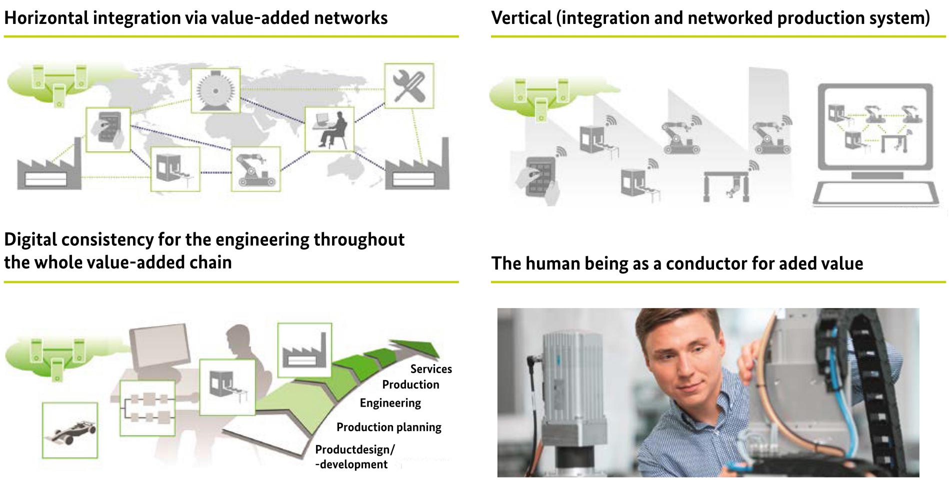

Fig. 3.5 Four important aspects of Smart Manufacturing [50].

The AAS facilitates the value proposition in smart manufacturing through the above aspects and data world applying a flexible framework on the information and functions.

3.1.3 The Structure of the Administration Shell

AS consists of two main parts: **header** and **body** (Fig. 3.6). The header gives an identification of the asset (like information that identifies whether an asset is a type or an instance) and the AS. The body organizes sub models that each of them represents one feature from the asset. Therefore, these sub models have their properties, including data and functions. Through the body's sub models, AS can record and depict the runtime information of the asset like position, actual current for a servo amplifier, machine status, or assembling [50, 59].

Since the AS is a standardized digital representation of the asset, its sub models should be defined using available standards as far as possible. In Fig. 3.7 some related standards that can be applied for different functions have been shown. Even IEC 61360 is provided for description of the sub models properties in a standardized format [59].

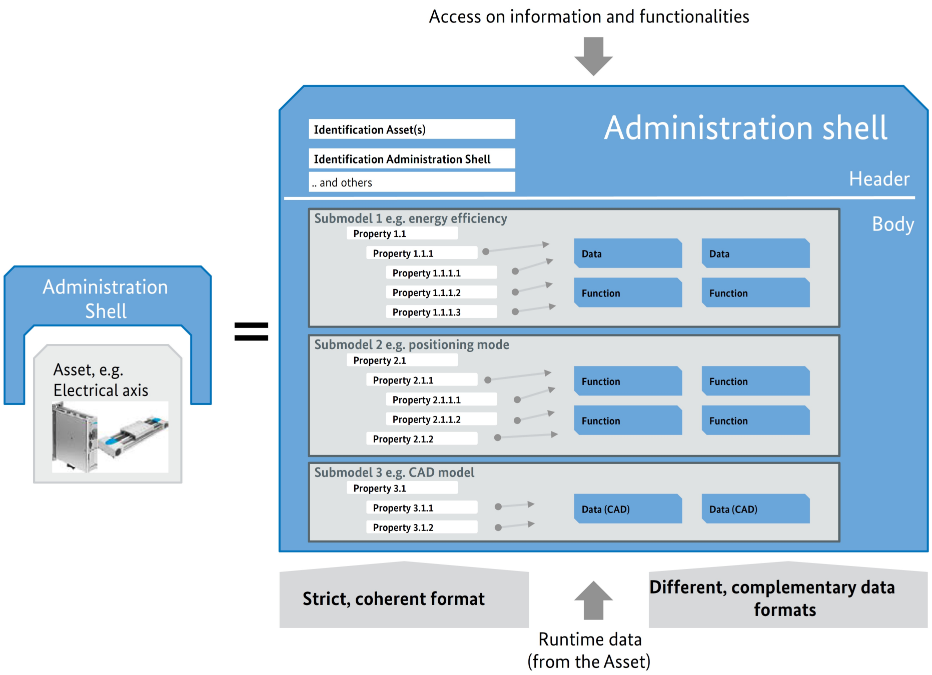

Fig. 3.6 General structure of an Administration Shell [50].

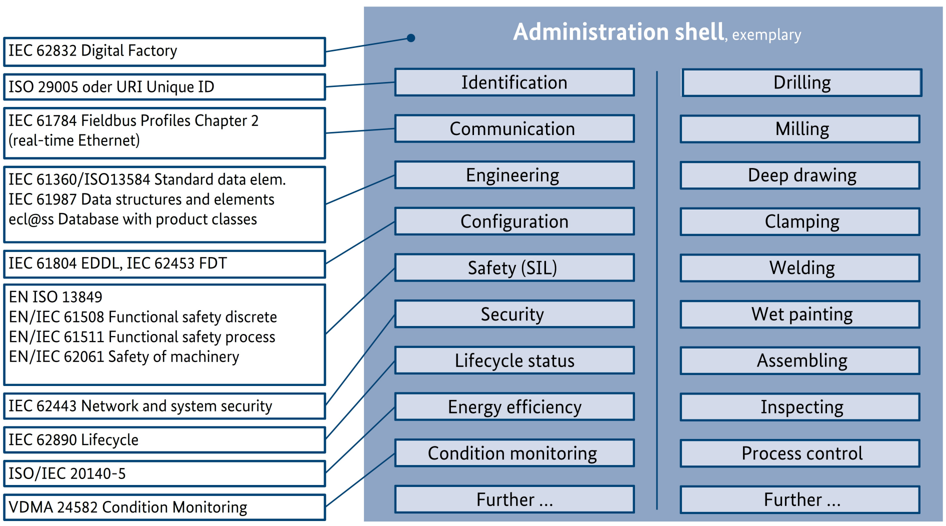

Fig. 3.7 Some potential sub-models in an Administration Shell and their related standards [59].

3.2 Cooperation in Industry 4.0

Typical cooperation and interactions in the engineering area are Human-Human and Human-Machine, but what is making Industry 4.0 distinctive is Machine-Machine systematic cooperation. In Fig. 3.8 one typical cooperation between machines and its equivalent between humans is shown in which they know each other.

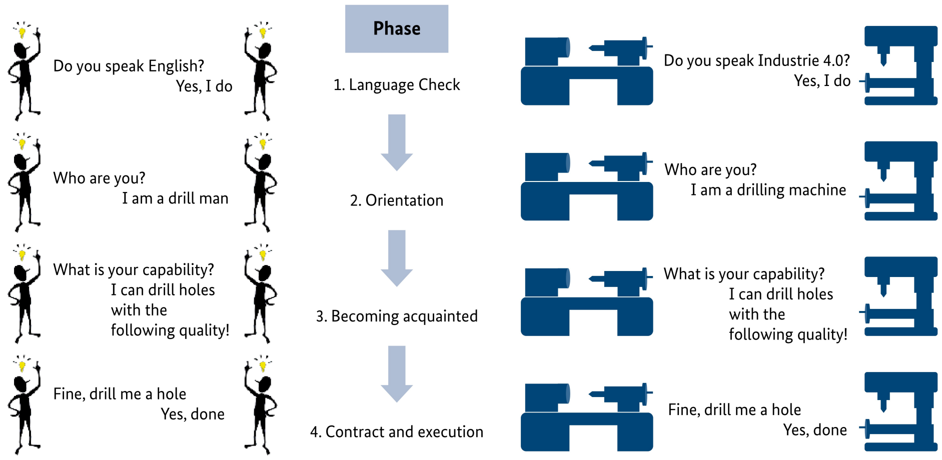

Fig. 3.8 Typical cooperation between machines and its equivalent between humans [59].

Human-Machine-Machine cooperation is one of the factors that make flexibility in the production line. Fig. 3.9 to Fig. 3.12 show Human-Machine-Machine cooperation from production request by the human to delivering the product by machines [59]. The production line consists of Production Manager (PM) and Production Units (PUs), which are Industry 4.0 components (i.e. they include asset and its AS, the information, and functions structured according to RAMI 4.0). PM's function can be a part of the Manufacturing Execution System (MES) and Enterprise Resource Planning system.

The scenario starts with a production request to the PM. Then, PM's algorithm determines the required functions, and as shown in Fig. 3.8, it checks the capabilities of the PUs. Afterward, PM sends requests for suitable and available PUs (Fig. 3.9). As shown in Fig. 3.10, related PUs send back their proposals, including availability and price conditions. It helps PM to determine all the business conditions and, finally, by approving from the responsible person in the relevant department, will send a digital quote to the customer. In this step, may some PUs do not give their proposals.

After business condition clarification, the customer (if agreed on the quote) delivers its order to the PM, and the PM organizes the PUs which correspond to the customer order (Fig. 3.11). Once all the orders have been finished by the PUs, the PM reports completion, and it can receive the next order from the customer. They can even process new orders during the execution of the current order when the setup is fixed appropriately (Fig. 3.12) [59].

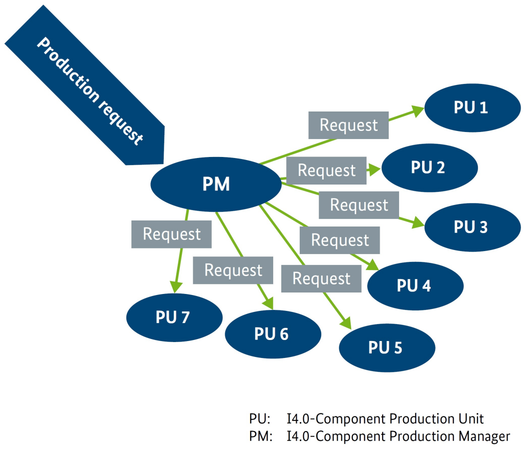

Fig. 3.9 Production request and checking the production resources [59].

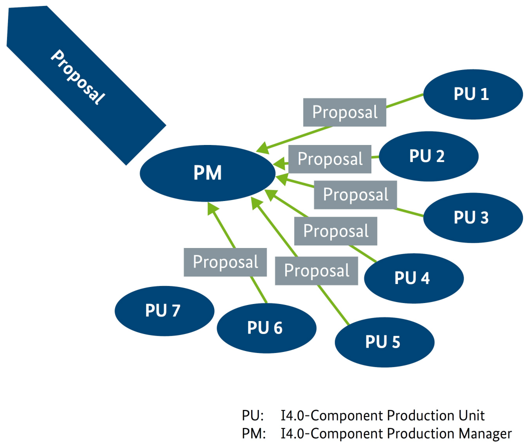

Fig. 3.10 Manufacturing quote of the PUs [59].

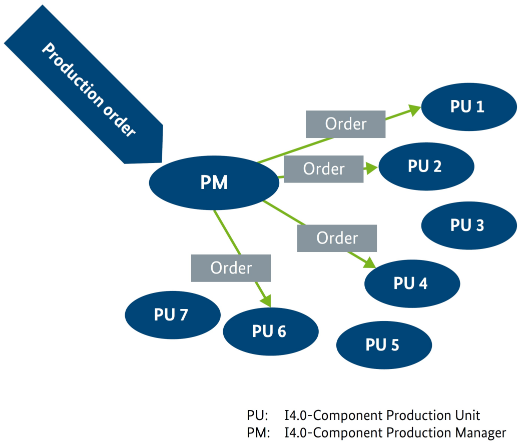

Fig. 3.11 Awarding the production order [59].

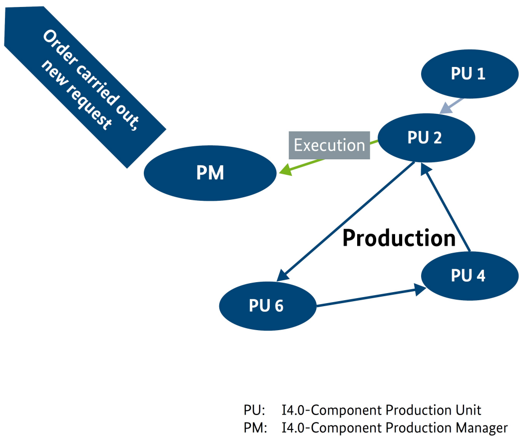

Fig. 3.12 Production process with completion report [59].

As shown in the above typical scenario, Human-Machine-Machine cooperation reduced the barriers in traditional process of ordering and production as it makes more autonomy and decentralization in production decision making.

3.2.1 Connections and Relationships between Assets

Assets can connect through their properties that are defined in their ASs. There are two types of relationships in the information world (Fig. 3.13) [59]:

- “static relationships describe the arrangement (black lines);”

- "dynamic relationships describe the cooperation between Industry 4.0 components during operation (red lines)."

The dynamic relationship can be an energy connection (supposing r1) between energy property (supposing M1) of ASs of Industry 4.0 components.

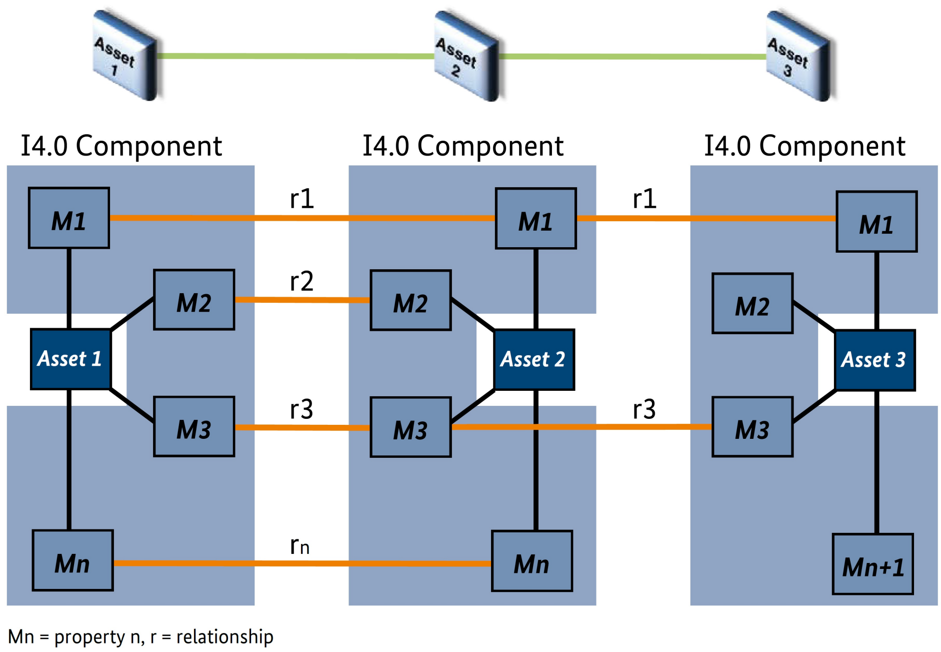

Fig. 3.13 Relationships between Industry 4.0 components [59].

The relationships can also be categorized in different views. These views for asset relationship may be defined as:

- Business relationships such as prices, terms of delivery, order codes;
- Constructive relationships;
- Functional relationships, such as issue order or execute order;
- Data relationships that cover all data and information that is required, generated, or modified at the functional level;
- Communication relationships which are about everything for exchanging the data;
- Integration relationships with below sub relationships which reflecting the physical world:

  - Energy;
  - Mechanics;
  - Material flows;
- Location relationships, which consist of geographical information of connected assets;
- Temporal relationships, which are about temporal information of connected assets such as time in simulation purposes;
- State relationships that describe state-related information of assets in the relationships;
- Asset relationships that represent the connection between two assets in the physical world;
- Human-Asset relationships within which human can intervene in an Industry 4.0 system from outside.

For instance, Fig. 3.14 shows two connected assets (Programmable Logic Controller (PLC) and 3D printer) and the possible basic view relationships between their ASs.

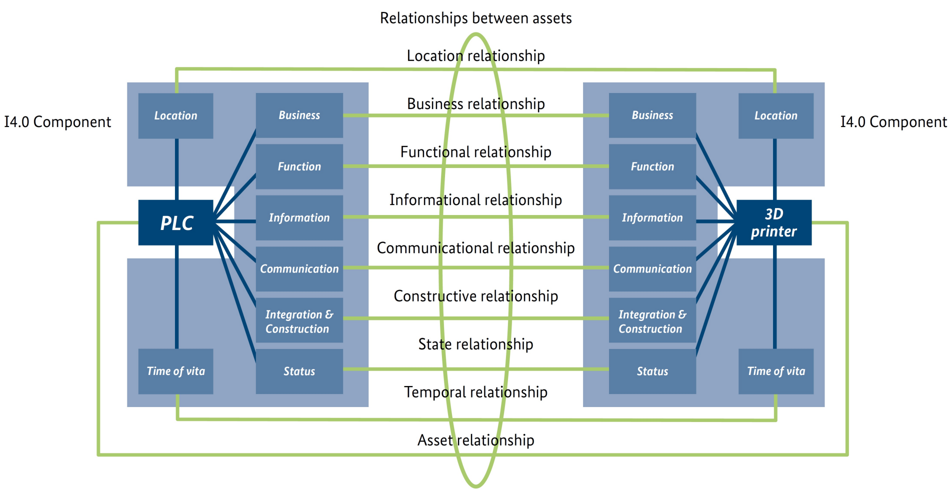

Fig. 3.14 Sample relationships between assets based on a PLC with a 3D printer [59].

One necessity for cooperation between assets through the relationships is the existence of the common interaction language, which is based on associated properties of linked ASs. It is noteworthy that the connection line or any infrastructure asset associated with relationships has its own AS and constitutes an Industry 4.0 component [59].

3.2.2 Interlinking Between Different Administration Shells

Regarding the asset and its AS definition and structure, it can be concluded that there should be many assets and their ASs in the industrial area. Even some assets may have several AS that each of them is a representation of the asset in the information world in different locations. With this in mind, Industry 4.0 components make an extensive repository of the ASs as shown in Fig. 3.15 [50, 59].

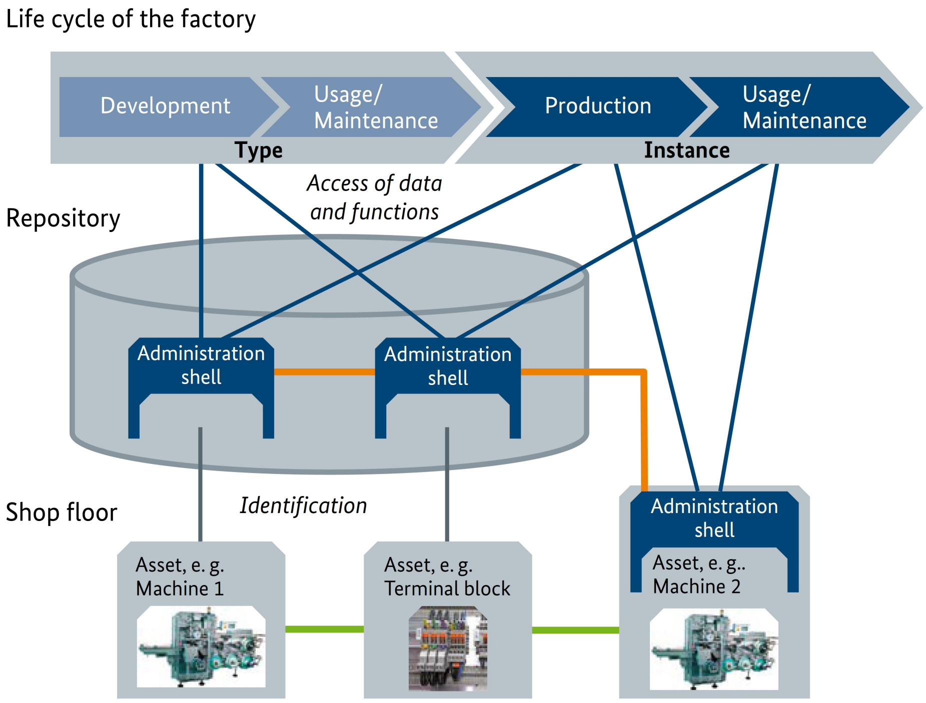

Fig. 3.15 Repository of all Administration Shells of the Industry 4.0 components [59].

Therefore, it is necessary to make a service-oriented Application Programmer's Interface (API) in which there are possibilities such as [50]:

- "Addressing and identification of ASs and assets through the header information."
- "Efficient search mechanism for properties, and referenced information and functions."

Besides the necessity of API, interlinking and referencing are the features that are needed for ASs to be able to copy related information and then updated. Suppose an asset like a servo amplifier as a product of one manufacturing system. It may have three ASs during the life cycle (Fig. 3.16) [50]:

- **Type/Development:** The manufacturer uses it for internal purposes such as updating asset (product) development information.
- **Type/Usage:** For external purposes and its customer.
- **Instance/Usage:** It is the AS for each instance that is delivered to and maintained by the user.

Through the interlinking and referencing each other, Instance/Usage and Type/Usage can update each other for maintenance goals, and Type/Development can use their information for developing the product in the future and reflect it to the Type/Usage one. Assume a component producer and system integrator that uses that component in its design. The component producer creates AS of the Type/Development and creates an AS for Type/Usage, which its instance is delivered to the system integrator. Both the producer and integrator update their ASs for future development and usage.

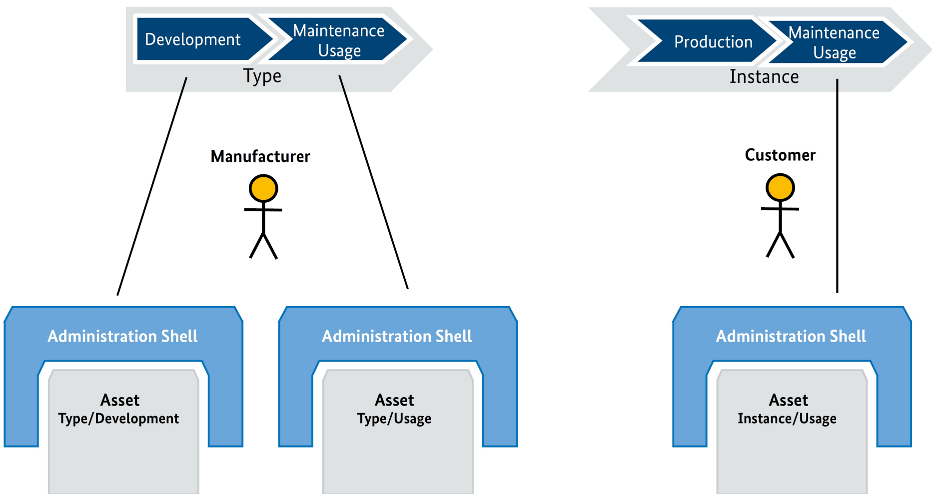

Fig. 3.16 The Administration Shells of a product during its life cycle in smart manufacturing [50].

In a bigger and more complex sample, the production system can be an asset with different ASs. One in possession of the system integrator in the design and implementation phase, another one is held by the customer or user of the system in operation phase, and the last one is used by an external service provider for maintenance. Fig. 3.17 shows all these three ASs during the asset's life cycle. Again, here it makes the requisite for them to update each other for objects like developing and maintenance [50].

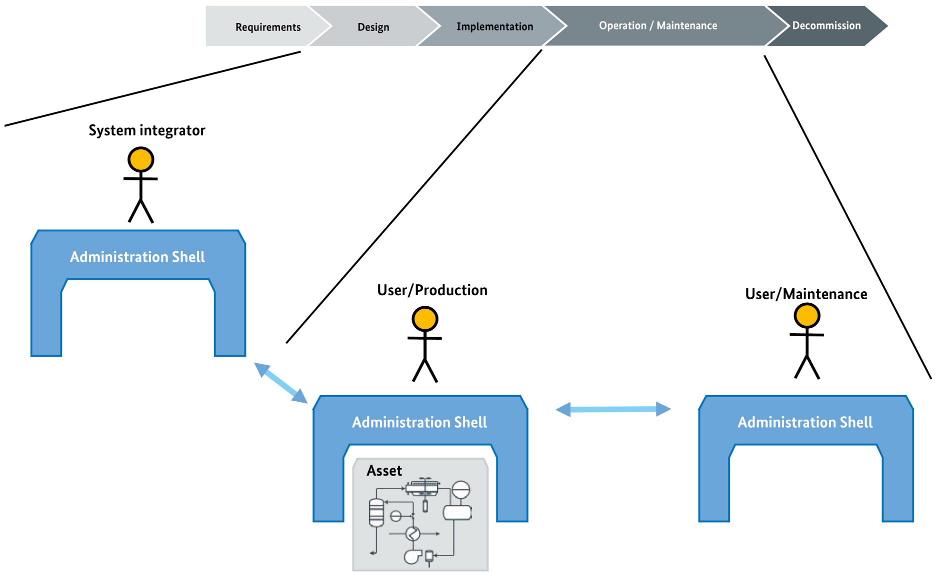

Fig. 3.17 Administration Shells of complex asset [50].

3.2.3 Composite Components

Toward a more complicated step, simple products and a production system are connected through the ASs. Considering the hierarchical level of the assets, the lower level (or individual) ASs are combined and make the higher-level (composite) one (Fig. 3.18). For example, Fig. 3.19 shows the AS of an electrical axis system, which is a combination of the lower-level components, such as the mechanical axis and motor. The functions and features of the new asset are defined as the sub models in its Administration Shell. Regarding Fig. 3.20, there would be an assembly sub model which explains how Assembly 123 is made (assembled) of the other assets [50, 59].

Thereby, composite component is made of at least two Industry 4.0 components when they are connected through at least one property (one relationship). It has its own AS with header and body, which is a combination of the sub models for describing the functions and information of the asset. In each sub model, there are descriptions of the relevant constituting assets, their properties, relationships, and application data, etc. Fig. 3.21 and Fig. 3.22 show a visual representation of an assembled asset as a composite component in Industry 4.0 context [59].

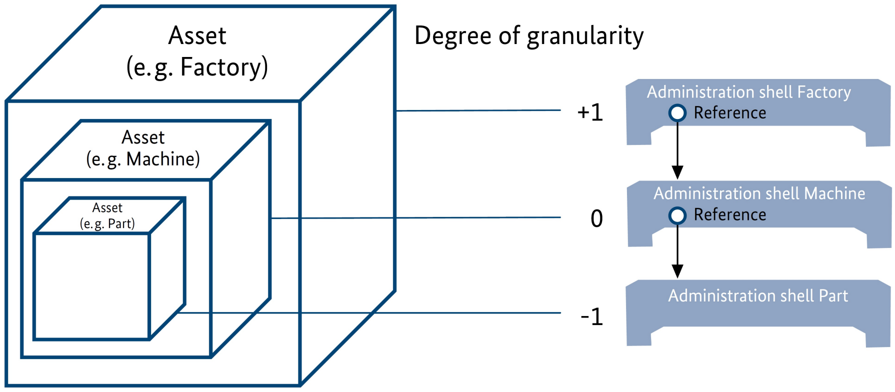

Fig. 3.18 Assets and their Administration Shells in the hierarchical level [59].

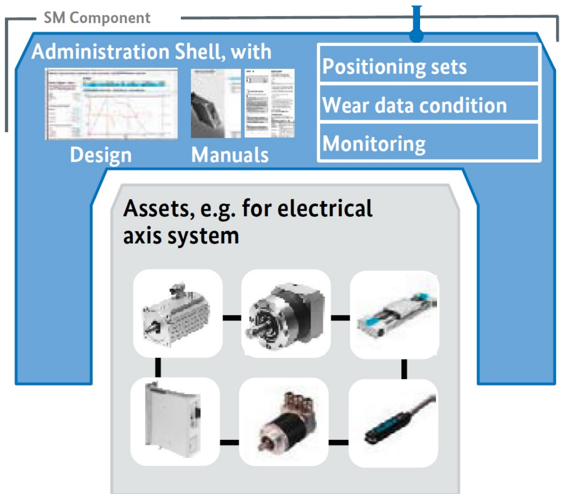

Fig. 3.19 Administration Shells of an electrical axis system [50].

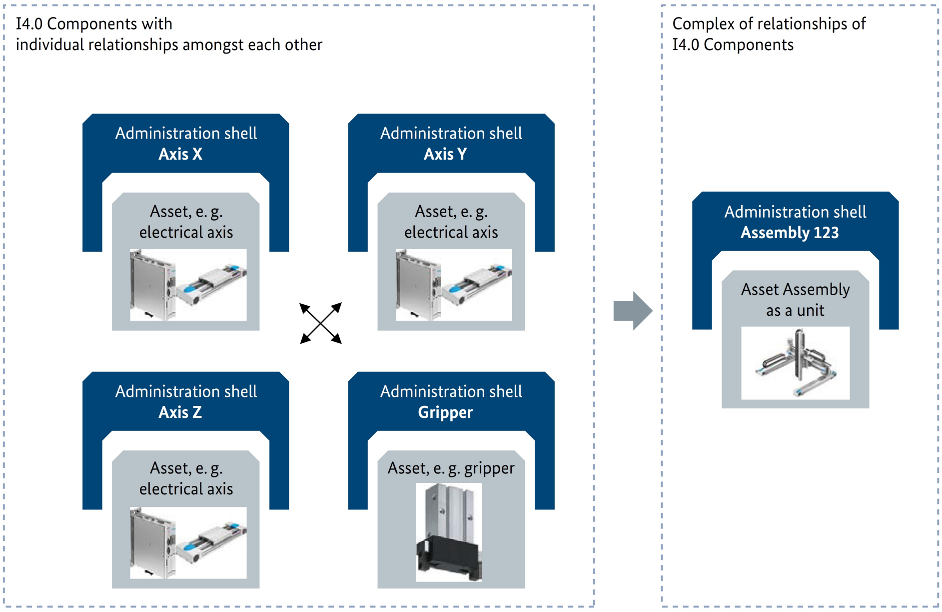

Fig. 3.20 An Industry 4.0 component as an assembled form of the individual Industry 4.0 components [59].

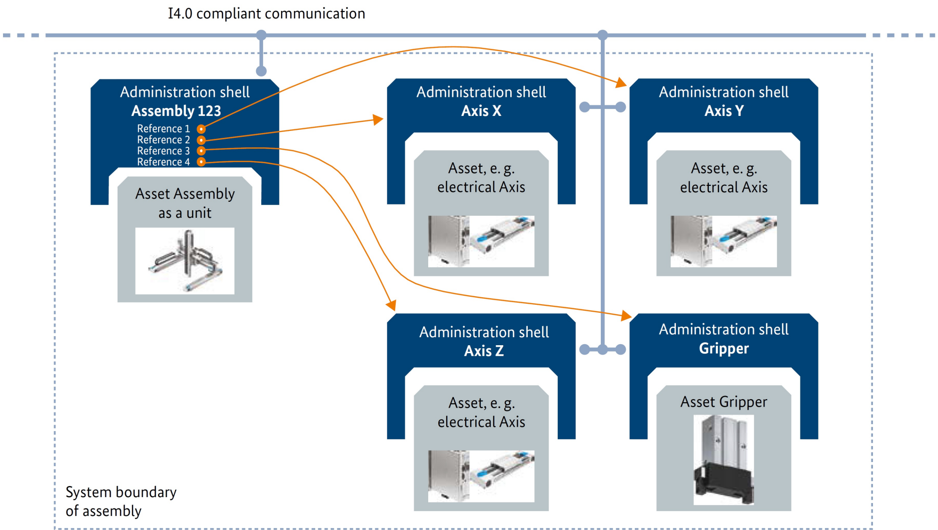

Fig. 3.21 An assembled asset as a composite component in Industry 4.0 [59].

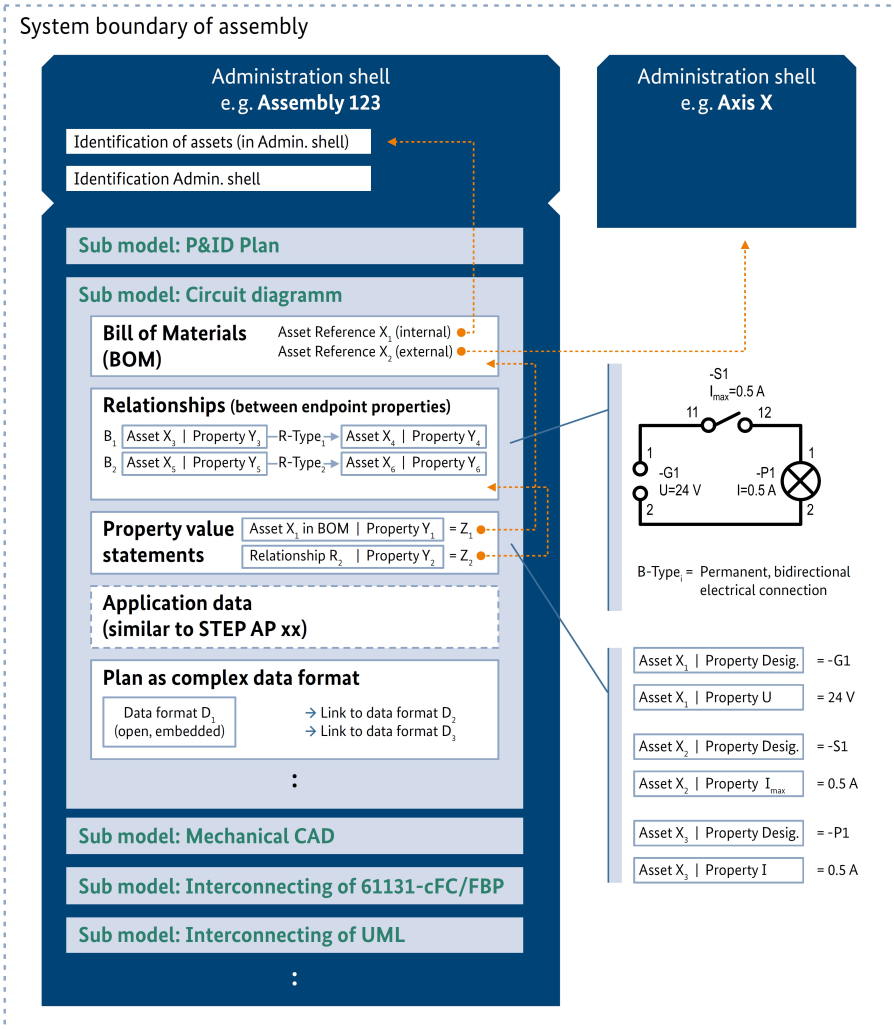

Fig. 3.22 Overview of abstract concepts for sub models of composite components [59].

3.3 Criteria for Industry 4.0 Products and Their Product Characteristics

Upon what is said about Industry 4.0 components and products and their connected world, it is essential to make standards and frameworks for producers to encourage the transformation toward the Industry 4.0 context. The "Reference Architecture Model Industrie 4.0 (RAMI 4.0)" and "Industrie 4.0 Components" are two reference models as part of the standardization, which are provided by German institutes to deal with this transformation. The former represents the total extent of solution for Industry 4.0, and the latter focuses on components and how an Industry 4.0 component is connected to the network.

Further initiative for this purpose is introducing the required criteria for accepting a product as an Industry 4.0 (I4.0) product. These criteria are created by the collaboration of "ZVEI-SG models & standards," and the working group 1 on reference architectures, standards, and norms of "Plattform Industrie 4.0," which are independent of the manufacturers and they improve these criteria continuously.

The mentioned criteria are included in the following area:

1. Identification
2. Industry 4.0 communication
3. Industry 4.0 semantics
4. Virtual description
5. Industry 4.0 services and states
6. Standard functions
7. Security

Fig. 3.23 illustrates the positions in which each of these criteria can cover the architecture layers of the product across its real/digital world. More details of these criteria are incorporated in the section 4 and section 6 in the study done by Federal Ministry for Economic Affairs and Energy (BMWi) [60].

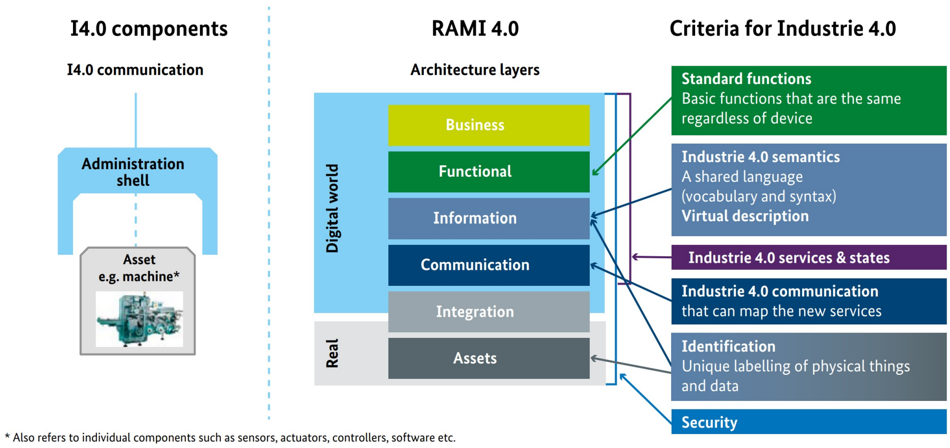

Fig. 3.23 Deriving criteria for Industry 4.0 products [60].

Meeting the Industry 4.0 product criteria leads to labeling that product as an Industry 4.0 product and makes more transparency and security for the market. The impact of labeling would be as below [60]:

- For manufacturer, it is as a guide for product development;
- It helps provider in the market to distinguish the Industry 4.0 product;
- It helps customer by clarity about performance and features of the Industry 4.0 product.

To make more sense, regarding the impact of the presence of smart manufacturing and its features, the next section of the thesis is followed by the investigation of a case study, which is the development of a bike saddle under Industry 4.0 regulation. The bike saddle production under the Industry 4.0 context makes a significant gain for the manufacturers alongside the raising customer satisfaction. It is explained in the form of a roadmap to represent the role of each enabling technology during the product development process.

Chapter 4

Case Study: Bike Saddle

The case study of the current investigation is a bike saddle. A saddle comfortness is an essential parameter for the rider, and it is affected by many factors. Even in the fitted position on the bike, most riders claim the comfortability issues in the saddle. The origin of the pain comes from the touchpoints of the body (especially seat bones) with the saddle's shell (Fig. 4.1). Depending on the body structure and flexibility, and the varied cycling situations, each cyclist may feel different from another utilizing the same saddle [61]. Therefore, it arises the need for customization in the saddle design and small-lot production.

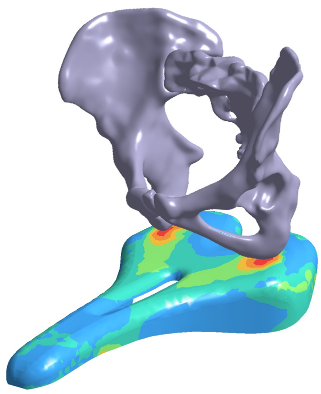

Fig. 4.1 The position of seat bones over the bike saddle and the pressure map on the bike saddle.

It is possible to determine the pressure distribution over the saddle using measurement tools such as saddle pressure sensors [62]. Using these sensors makes more clearance for saddle designers through product development. Moreover, there is safety problem in some road-cycling saddles, which happens when riders use it for a while. It is the break in the rail which mounts the saddle to the bike frame [63]. Therefore critical design issues for a bike saddle are raised from comfort and safety (Fig. 4.2). These problems can be fixed considering the development of a bike saddle as a product in the Industry 4.0 context (smart product or Industry 4.0 component), which makes the customized and flexible design possible.

It means the product has the ability to obtain, maintain, and communicate the information. All the information about the product is shared through its value chain. It makes more transparency and helps the stakeholder through the life cycle to provide a customer-oriented product. New digital industrial technologies are tools that make these possibilities.

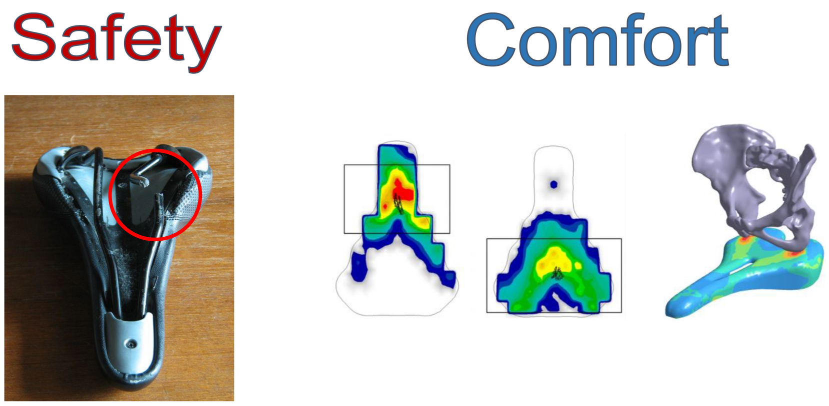

Fig. 4.2 Bike saddle design main challenges

4.1 Product Development

A specific roadmap for an Industry 4.0 product is considered as the proposed framework of product development for a bike saddle in the current study (Fig. 4.3). Basically, product development is composed of three steps which all three steps are included in the presented roadmap. These steps are:

- Market research and capturing customer needs.
- Design.
- Manufacturing.

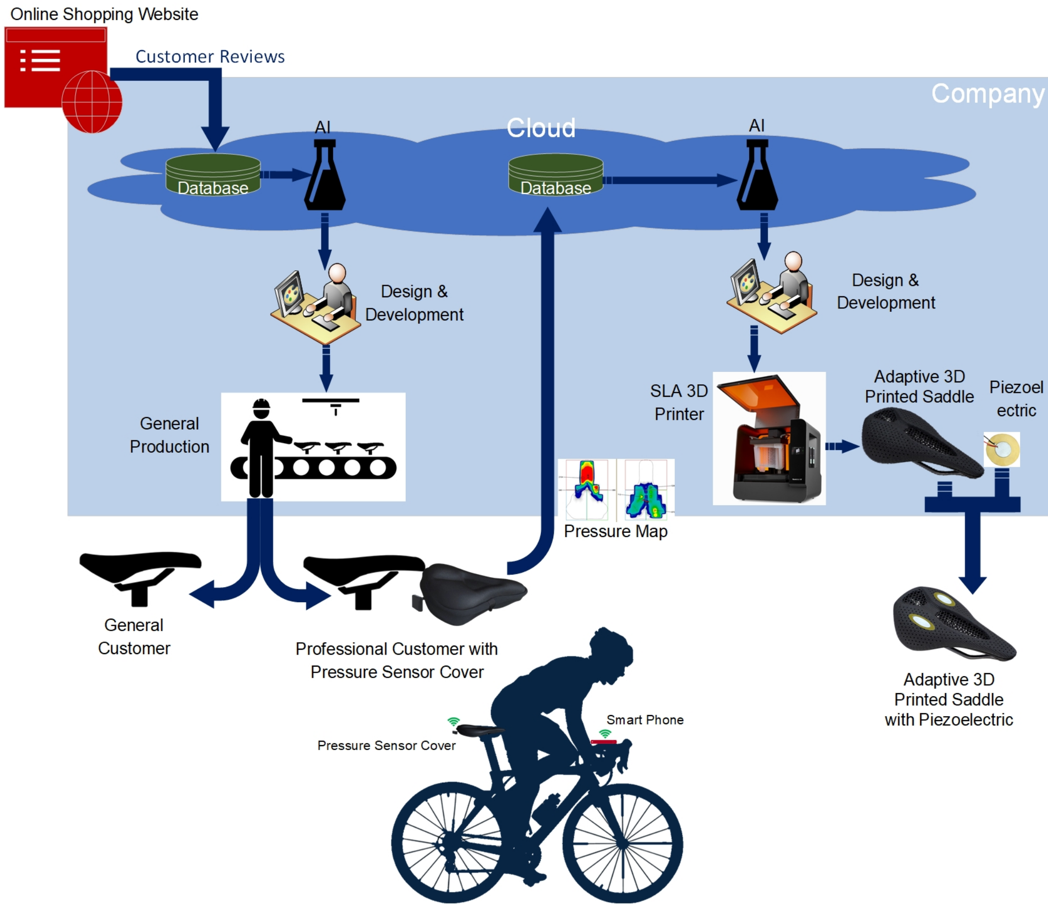

Fig. 4.3 Bike saddle product development roadmap.

4.1.1 Customer Needs

Regarding the Fig. 4.3, the product development process is started by collecting customers' feedback about current products from online shopping websites. It is essential because it reflects the general weaknesses and strengths of the available products on the market. Investigation of the customer reviews has some benefits:

- Collecting the feedbacks with lower cost.
- Better identification of the product's pros and cons.

To do so, the verified customer reviews, which are commented on Amazon website for a bike saddle [1], are collected. The review collection forms a database

[1]The intended bike saddle for this study belongs to Brooks England company with model B17.

for more analysis in the next steps. It is the ability of AI algorithms such as neural networks, Natural Language Processing, and reinforcement-learning to analyze the data generated from business websites and social networks. IBM Watson and Google DeepMind are examples of cognitive AI systems that use these capabilities for data mining purposes [64, 65]. In this study, data mining with NLP is used on the database to do feature-based analysis for the product and elicit general customer preferences as a provided algorithm shown by Fig. 4.4. This is a part of application of AI techniques in smart manufacturing. The outcomes show the opinion of customers about the main features of the product.

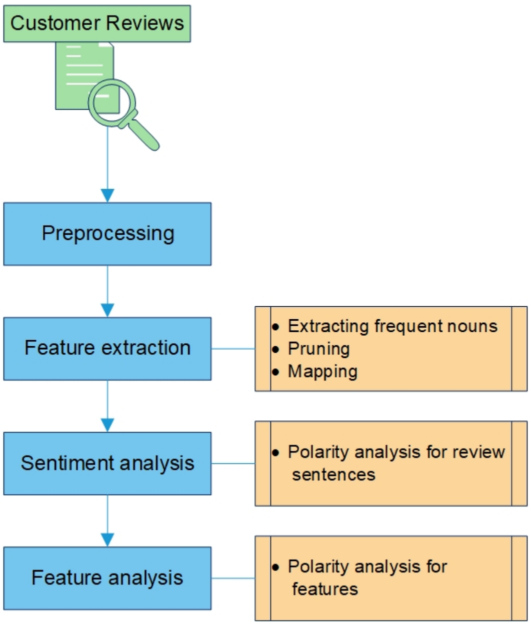

Fig. 4.4 The algorithm of the feature-based analysis.

The main steps are as below [65] which have been implemented in Python (version 3.8) programming language environment [2]:

1. Preprocessing
2. Feature extraction
3. Sentiment analysis
4. Feature analysis

[2]The NLP has been implemented by Python programming language. All the codes are provided in the GitHub, which is accessible through "https://github.com/M-Memaran?tab=repositories".

Preprocessing is the first step to work on the textual dataset (corpus). It is equivalent to data cleaning step in any Machine Learning process in which data is investigated and transformed to be useful input for models. Otherwise, they may lead to errors, mistakes, and low accurate results. Through the preprocessing (normalization) and data cleaning, the data, which is incorrect, corrupted, incorrectly formatted, duplicate, or incomplete, is removed or fixed [66]. Depending on the goal of text analysis, there are multiple paces for the normalization of the dataset [67]. However, the applied steps for this research are as below:

1. Converting characters into lower cases;
2. Removing punctuation;
3. Removing numbers;
4. Tokenization;
5. Stop word filtering;
6. Stemming;
7. Part-of-speech tagging.

Tokenization is the step of breaking the raw text into small chunks like word and sentence, which is called tokens [68]. Stop word filtering leads to removing words such as 'is' and 'do,' which are not meaningful [69]. Since the words like 'rides,' 'riding,' 'rode,' and 'ridden' mean the same thing, they can be transformed to their root 'ride' through the stemming [70]. Finally, for preparing the words to be processed in NLP, Part of Speech (POS) tagging is done. It labels the words based on their type (role) (noun, adjective, adverbs, verbs, etc.) in the sentences and holds them in the bags of words. Since product features are noun-type words, it is necessary to determine the POS tag for each token to be applicable for feature extraction [71].

In this research, the idea for product feature extraction is based on word frequency. Exploring the reviews illustrated that frequent nouns could be the candidates for the most commented product features in those reviews. Implementing the algorithm for identifying frequent words is necessary, and further investigation would complete it to reach features that are most mentioned by the customers [65, 72, 73].

To do so, words with noun-tag are separated from other types. It is because the other types of words do not delegate a feature for a product. Nonetheless, it is needed to work more on noun-type words. There are meaningless and redundant nouns that should be pruned. For instance, ‘bike’ and ‘saddle’ are two useless nouns for feature extraction. Sometimes it is necessary to map frequent nouns to some potential features that describe a more holistic feature of a product [71]. As an example, here ’gel,’ ’leather,’ and ’cover’ are some similar nouns that can be categorized as the ’saddle shell’ among the saddle features.

According to the noted consideration, four features, including saddle shell, weight, price, and color, are extracted as the most commented features for the bike saddle.

Sentiment analysis is a part of the work which indicates how customers feel about related features. Thanks to the proposed algorithms in Python for NLP, it can be possible to do this part. Polarity analysis for review sentences is the facility of Python Tetxblob library in which the attitude and emotion of the writer (negative, neutral, and positive) is displayed in a range between -1 to 1. Consequently, it can be possible to distinguish the level of feeling of the customer. Because the polarity number for a very bad emotion comment (e.g. -0.9) is lower than a bad emotion one (e.g. -0.3).

To determine the satisfaction level of customers about the extracted features, sentiment analysis is applied to each review sentence, which includes that feature. The average polarity of all these review sentences is introduced as the feature polarity in the last step of the analysis. Doing so, the result is shown in Fig. 4.5. The outcomes tell the opinion of customers about the main features of the product.

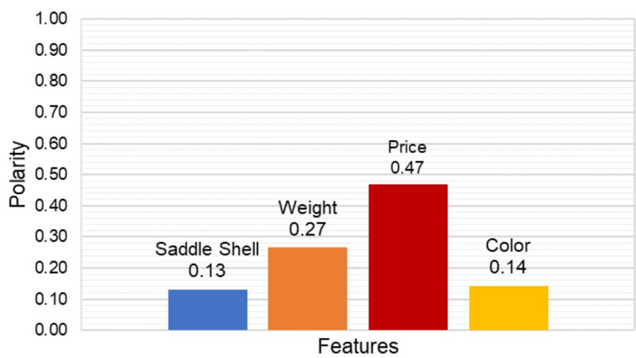

Fig. 4.5 Feature analysis of bike saddle.

The polarity shows the sentiment of customers about the saddle is totally positive. Nevertheless, if the company wants to gain more positive feedback, it should care about the design of the saddle shell and work on the more aesthetic feature (color). Studying some tokenized reviews, it is realized that comfortability is the common opinion of the customers about the saddle shell. The results in Fig. 4.5 shows that the incorporation of the cognitive AI methods can drop the conventional ways' deficiencies in the prioritization of requirements and technical features. What exists in the QFD process [64].

To test the performance of the lexical analysis, the outcome of polarization is compared with the customer rates. The range of polarity and rate in online shopping websites (e.g. Amazon website) is different. The polarity range is between -1 to 1 in which -1, 0, and 1 determine negative, neutral, and positive feel, respectively. In the Amazon website, the rate ranges from 1 to 5 is depicted as the customer feel (supposing 1 mean negative, 3 means neutral, and 5 means positive). Because of the difference, the polarity numbers are mapped to the range of rate. Table 4.1 shows the result of this comparison and the accuracy of the analysis which are in reasonable range for text analysis works [65, 71].

Table 4.1 The accuracy of the feature-based analysis.

	Bike Saddle Features			
	Saddle Shell	Weight	Price	Color
Polarity	0.13	0.27	0.47	0.14
Mapped Polarity	3.26	3.53	3.94	3.29
Amazon Rate	4.91	5.00	4.63	5.00
Polarity Accuracy	66.40	70.69	85.02	65.75

The whole process is shown in Fig. 4.6, and as shown in Fig. 4.3 the outputs of the customer needs procedure will be the inputs for designing and developing products. This process is performed by applying AI techniques (data mining) on online customer reviews.

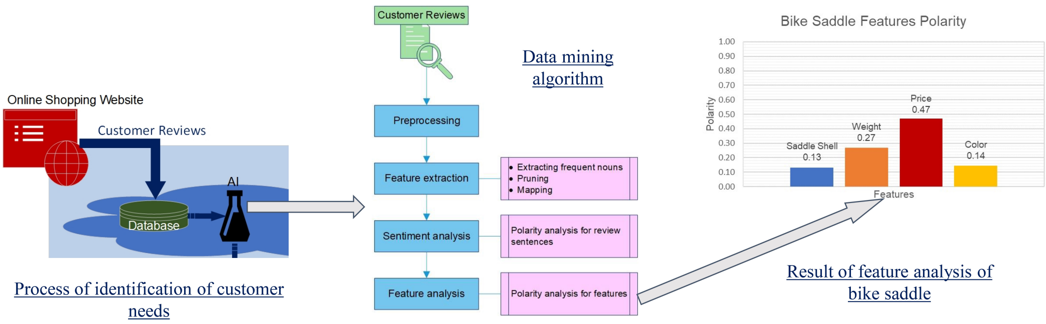

Fig. 4.6 Customer needs procedure.

4.1.2 Design

The design process in this study goes in two ways. One for general customers and another is dedicated for special and professional customers. Regarding the roadmap, the customers' needs analysis outcomes will be utilized in the design and development section to modify the current design of the bike saddle. Then, the new design will be applied in the production line to replace the current saddles with the new ones. This product is coincident with opinion analysis, which is done through data mining on customer reviews. It can satisfy the expectation of the customers with lower sensitivity. Here, they are called general or amateur customers. Nevertheless, professional cyclists (who are looking for more performance) are more sensitive to comfortability (especially in long-distance riding), and they prefer to choose the most personalized and fitted saddle to their needs.

The proposed solution would be using a pressure sensor cover over the new bike saddle in which both together make an Industry 4.0 component. Pressure sensor cover can measure pressure on the saddle, which is affected by the cyclist body (Fig. 4.1) in the different cycling situations. The pressure map (shown in the roadmap as a sample) will change during the cycling depending on the many factors like the condition of the body, the road of the race, and the cycling (first or end of the race).

The professional rider can use this smart product for a while and, in different exercise circumstances. Thanks to the capabilities of the pressure sensor cover, the pressure data can be transmitted to a smartphone in real-time and through wireless transmission [74]. The smartphone (or any other smart devices on the bike) using the appropriate application can transmit the data to the cloud in the company to store them as a database associated with that cyclist. Data transmission through the roadmap, proves the capability of the Internet of Things in making a network of devices. At the design section of the company, AI techniques such as deep learning are the other tools to help stress analysts to make good knowledge for saddle designers from pressure distributions [75]. It means product developers can get the most out of the AI techniques results and provide the closest fitted saddle design for the professional cyclist. Fig. 4.7 shows the product design process. The final design will be used as an input for the manufacturing system.

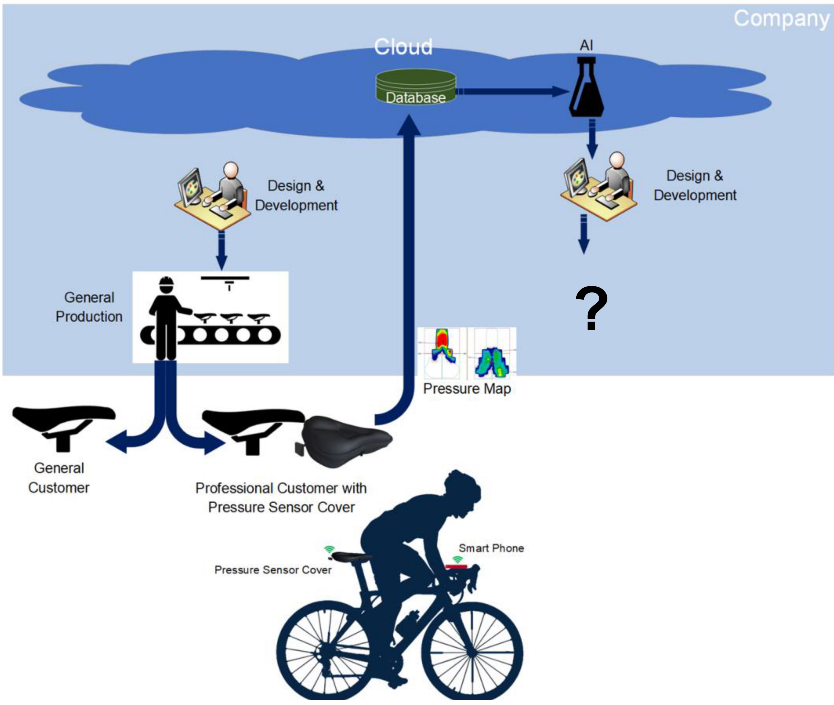

Fig. 4.7 Product design procedure.

Instead of applying some conventional processes, already assessed for general products, for the customized product, the innovation target are achieved in applying:

- The IoT services.
- The AI techniques.
- Storing and exchanging data through the Cloud.

4.1.3 Manufacturing

When it comes to produce a customized saddle in a small lot size, a significant challenges for the engineers will arise, those demand the specific manufacturing processes instead of conventional processes. Additive Manufacturing (AM) processes enable the transition from conventional manufacturing to digital manufacturing using Computer Aided Design tools to encourage fast prototyping through building the part layer by layer [76, 77].

Among the AM technologies, and with respect to the common materials (polymers) to produce a saddle, Photopolymerization becomes a potential candidate. Photopolymerization which is generally known as stereolithography (SLA) encompasses the curing of a photosensitive monomer resin using a scanning laser or Ultra Violet (UV) radiation and transferring photo-resin fluid into a crosslinked solid as illustrated in Fig. 4.8 [78].

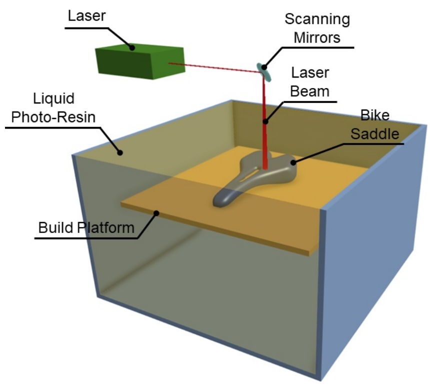

Fig. 4.8 Schematic of stereolithography (SLA) process.

SLA promotes the fabrication of highly detailed parts with dimensions ranging from the micrometer- to meter-scales with broad applications such as dental models, hearing aids, fast prototyping, and tooling. Consequently, an SLA 3D printer can build the intended customized saddle in a small-lot size [79, 80].

As an additional option, it is possible to place some piezoelectric plates in the saddle shell to get the most out of mechanical stresses and generate an electric charge (shown in the last stage of the roadmap). The piezoelectric plates can provide the electric source for varied consumption inside the bike saddle (as a smart product), or even charge any embedded battery. Some examples for electric consumers could be the Light-Emitting Diodes (LEDs), sensors, and data storage and communication devices.

To have the saddle's highest damping property and obtain the larger the stress acting on the piezoelectric plates, the saddle comes with the lattice structure. As the stress field over the saddle is defined using pressure sensor cover (Fig. 4.1), the number and size of piezoelectric plates and adequate lattice structures are engineered to obtain the highest possible efficiency to supply the electrical energy. Recently, AM technologies have encouraged the production of many lattice structures, regardless of the complexity. For instance, Fig. 4.9 illustrates a Face Centered Cubic (FCC) structure. The finalized design is sent as an STL file to the SLA machine to be printed. Using the SLA 3D printers illustrates the importance of Additive Manufacturing in dealing with increasing demand for customization.

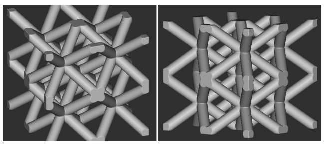

Fig. 4.9 Face Centered Cubic (FCC) lattice structure.

To assist the professional cyclists facing difficulties like rail breaking in the saddle, it is suggested to embed some strain gauges inside the rails. They enable the saddle to measure, store, and transmit the mechanical load's data to a computing center (like a cloud) to predict fatigue failures and avoid cyclists' accidents.

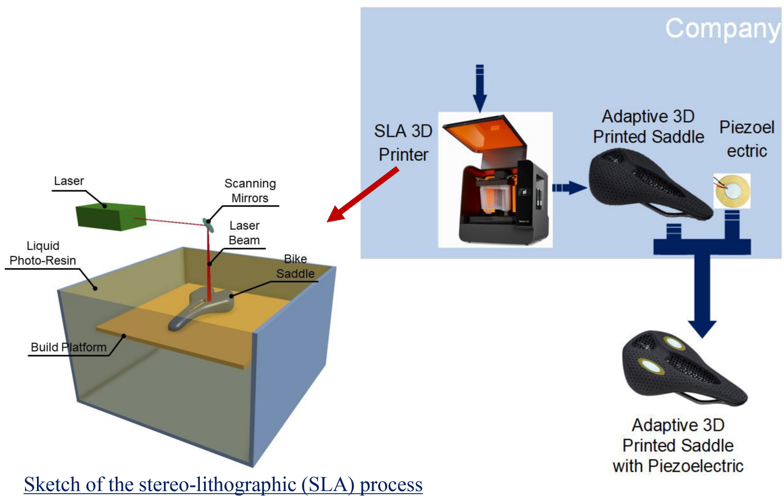

Fig. 4.10 Product manufacturing procedure.

The whole product development roadmap, used to reach the desired saddle, applies:

- IoT services.
- AI techniques.
- Cloud computing.
- Additive Manufacturing technologies.

4.2 Cyber System (Asset Administration Shells)

As each Industry 4.0 product consists of two main parts, this saddle is a combination of asset and its administration shell, which is shown in Fig. 4.11.

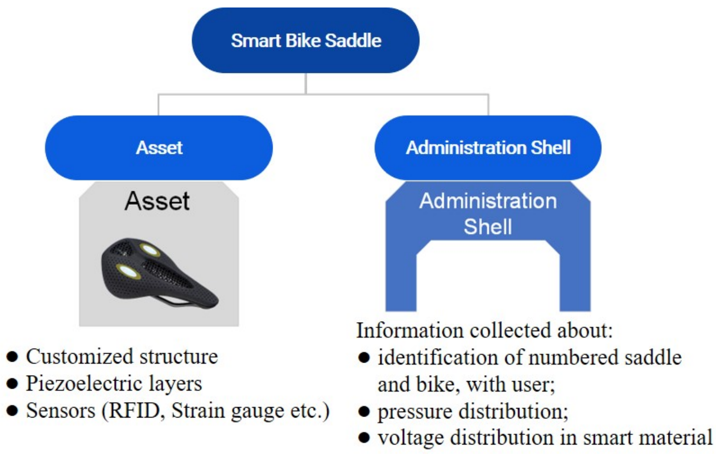

Fig. 4.11 Asset and administration shell of the smart bike saddle.

As mentioned before, an Industry 4.0 product passes two stages during the life cycle (Fig. 2.14). For the smart bike saddle, when the company uses the combination of the normal bike saddle and the pressure sensor cover, it makes the development version of the product in the type stage. It has internal applications for the company. The goal is that the designer adapts the saddle to each user, and retrieving data of pressure to identify the comfort of the cyclist helps this activity. The second stage of the product life cycle begins when the company manufactures the saddle for given user. This step corresponds to the production phase in the instance stage. When the cyclist receives the smart bike saddle and uses it, the last stage of the life cycle is started until the disposal of the product (which is correspond to the usage phase in the instance stage). However, the rider's smart bike saddle can directly and continuously sends to the company some feedback. They help in planning the maintenance actions, and allow introducing some suitable modifications, through the embedded devices, as the pressure sensor and the strain gauge. For this reason, one phase of the type stage is dedicated to the maintenance actions of the delivered bike saddle.

There is a repository for the ASs of all the above-mentioned versions of the Industry 4.0 products. It can exist inside the manufacturer or any related organization. Fig. 4.12 shows the repository with the assets and their ASs. Regarding Fig. 4.12, there are three ASs for the smart bike saddle during the life cycle. Throughout the connected world in Industry 4.0, all the bike saddle's ASs are connected and updated. It is worthy to notice that the Instance/Production phase is the moment that product is produced and prepared for sale. Consequently, it is not essential for Instance/Production to have AS and be connected to the information world until it is delivered to the customer.

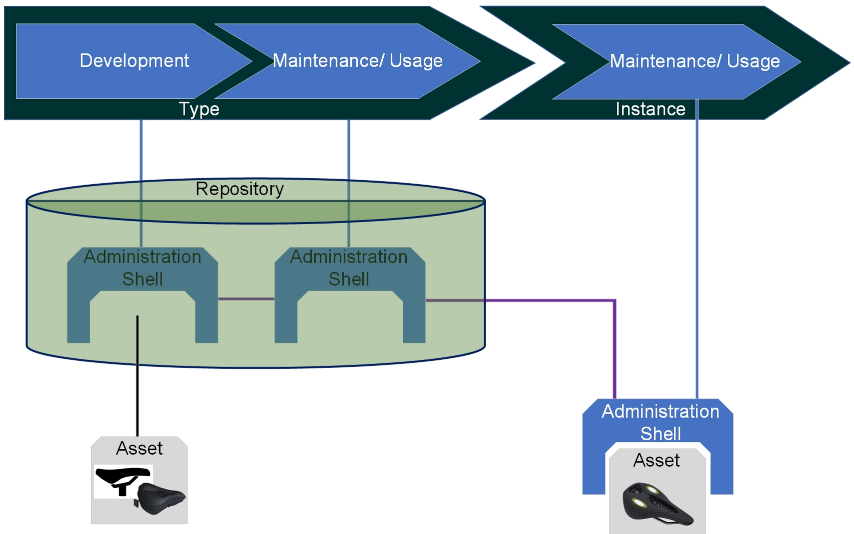

Fig. 4.12 Connected administration shells of bike saddle in the life cycle.

Interlinking and referencing each other, the Instance/Usage and Type/Usage allow updating both for maintenance goals. The information stored and updated is then used for developing the new versions of the product. This information is the exigencies of customers identified in operation, elaborated, and through the traceability of requirements and functions, they are reflected in the Type/Usage step, even by exploiting the tools of the MBSE.

Chapter 5

Conclusion and Future Works

Smart manufacturing and smart product are two new notions in recent years. The fourth industrial revolution introduces Industry 4.0 as a system involving smart manufacturing and smart products. Cyber-Physical Systems and wireless communication under a holistic network are the main pillars of Industry 4.0. They lead to interconnection, information transparency, decentralized decision-making, and technical assistance through development and production. Incorporating the new digital industrial technologies such as IoT and AI in Industry 4.0 made such the capabilities for manufacturers in dealing with mass customization, continuous demand changes, the complexity of the new product, cost, and time to market, which are the challenges for producers nowadays.

In this study, the impact of Industry 4.0 on the product life cycle processes (including capturing customer needs, design, and manufacturing) was investigated. An example of the product customization process supported by the enabling technologies of Industry 4.0 is proposed. The test case consists of a customized bike saddle. To customize this product for a specific user, the saddle's comfort and performance must be assured. Those issues are related to a well-distributed contact of the user's body with the saddle shell, a limited pressure, a controlled friction, and a good damping. In terms of safety, the risk of failure of the saddle rail is still significant. Considering the bike saddle as a smart product, a strain gauge can be embedded into the rail to monitor the mechanical load. Moreover, some smart material layers as piezoelectric sheets embedded into the saddle package can detect the pressure distribution and amplitude and convert the stress into electric charge for energy harvesting. The information collected can be transmitted to a smartphone for remote monitoring and data mining. By converse, the new bike saddle package can be designed and produced by resorting to the AM technologies to shape the shell properly and embed sensors. The lattice structures help in tuning the weight and the damping effect of the saddle, as well as enhancing the coupling effect of piezoelectric layers.

Through the test case, it is realized that data generated from business websites and social networks could be a good alternative for conventional methods in market research and capturing customer preferences. This may be done more accurately and affordable, using appropriate data mining algorithms. The cognitive AI methods can reduce the deficiencies of conventional design methods (such as QFD) in prioritizing requirements and technical features.

It is shown, in the connected world of Industry 4.0, cross-linking between different functional areas and steps of the value chain brings many opportunities for improvement in industries. Smart bike saddle can connect to the cyber world and express its state; it will improve designer efficiencies in designing a more customized and fitted saddle. The manufacturer demonstrated that retrieving information from system operation is possible and helps refine the product when the unfitted saddle is just monitored. Then the product is suitably customized in a new version fit-to-purpose as data obtained in operation by the user are exploited together with the traceability of requirements and functions assured by tools of MBSE. 3D printing of the studied bike saddle with SLA demonstrates how AM techniques, with their extensive capacities in manufacturing, can facilitate to reach the goal of mass customization.

This study is a brief investigation of the role of Industry 4.0 in product development enhancement. Having look at Industry 4.0 features and technologies, there are more opportunities in the product development process to take advantage of Industry 4.0 and deliver more value during the life cycle. Digital twin, virtual reality, and augmented reality are the samples of the emerged technologies in Industry 4.0 context that facilitate the simulation processes for analysts and designers in the industry.

References

[1] Cristina Orsolin Klingenberg and José Antônio do Vale Antunes Jr. Industry 4.0: what makes it a revolution? In *EurOMA*, 2017.

[2] Henning Kagermann, Wolfgang Wahlster, and Johannes Helbig. *Recommendations for Implementing the Strategic Initiative INDUSTRIE 4.0: Securing the Future of German Manufacturing Industry ; Final Report of the Industrie 4.0 Working Group*. Forschungsunion, 2013.

[3] Chris Freeman and Luc Soete. *The Economics of Industrial Innovation*. Routledge, 1997.

[4] Eric J. Hobsbawm. *Da Revolução Industrial Inglesa ao Imperialismo*. Forense Universitária, 2016.

[5] Max Roser, Hannah Ritchie, and Esteban Ortiz-Ospina. World population growth. *Our World in Data*, 2013. https://ourworldindata.org/world-population-growth.

[6] Shu Tay, Lee Te Chuan, A. Aziati, and Ahmad Nur Aizat Ahmad. An overview of industry 4.0: Definition, components, and government initiatives. *Journal of Advanced Research in Dynamical and Control Systems*, 10:14, 12 2018.

[7] Michael C. Jensen. The modern industrial revolution, exit, and the failure of internal control systems. *The Journal of Finance*, 48(3):831–880, 7 1993. http://dx.doi.org/10.1111/j.1540-6261.1993.tb04022.x.

[8] Jeffry A. Frieden. *Capitalismo global: História econômica e política do século XX*. Zahar, 2008.

[9] Yongxin Liao, Fernando Deschamps, Eduardo de Freitas Rocha Loures, and Luiz Felipe Pierin Ramos. Past, present and future of industry 4.0 - a systematic literature review and research agenda proposal. *International Journal of Production Research*, 55(12):3609–3629, 2017. https://doi.org/10.1080/00207543.2017.1308576.

[10] Chris Freeman and Luc Soete. *A Economia da Inovação Industrial*. Psychology Press, 2008.

[11] David Lei, Michael A. Hitt, and Joel D. Goldhar. Advanced manufacturing technology: Organizational design and strategic flexibility. *Organization Studies*, 17(3):501–523, 1996. https://doi.org/10.1177/017084069601700307.

[12] Joel D. Goldhar and Mariann Jelinek. Plan for economies of scope. Harvard Business Review, 11 1983.

[13] Michael E. Porter. The role of location in competition. *International Journal of the Economics of Business*, 1(1):35–40, 1994. https://doi.org/10.1080/758540496.

[14] Jan Stentoft, Jan Olhager, Jussi Heikkilä, and Lisa Thoms. Manufacturing backshoring: A systematic literature review. *Operations Management Research*, 10, 05 2016. https://doi.org/10.1007/s12063-016-0111-2.

[15] H. Kagermann, W. Wahlster, J. Helbig, and Forschungsunion Wirtschaft Wissenschaft. *Im Fokus: das Zukunftsprojekt Industrie 4.0 ; Handlungsempfehlungen zur Umsetzung ; Bericht der Promotorengruppe Kommunikation*. Forschungsunion, 2012.

[16] Reiner Anderl. Industrie 4.0 - advanced engineering of smart products and smart production. 10 2014.

[17] Jay Lee, Behrad Bagheri, and Hung-An Kao. A cyber-physical systems architecture for industry 4.0-based manufacturing systems. *Manufacturing Letters*, 3:18–23, 2015. https://doi.org/10.1016/j.mfglet.2014.12.001.

[18] Bernhard Schätz, Martin Törngren, Roberto Passerone, Saddek Bensalem, Alberto Sangiovanni-Vincentelli, John McDermid, Holger Pfeifer, and María Cengarle. Cyber-physical european roadmap and strategy – research agenda and recommendations for action, 04 2015.

[19] Digital transformation of european industry and enterprises: a report of the strategic policy forum on digital entrepreunership. the Strategic Policy Forum on Digital Entrepreneurship, 2015.

[20] Simon Roach. The 4th industrial revolution. https://kemptechnologies.com/blog/the-4th-industrial-revolution/, (accessed: Nov. 26, 2018).

[21] Screws. What is industrie 4.0? https://www.plattform-i40.de/PI40/Navigation/EN/Industrie40/WhatIsIndustrie40/what-is-industrie40.html, (accessed: Sep. 15, 2020).

[22] Mario Hermann, Tobias Pentek, and Boris Otto. Design principles for industrie 4.0 scenarios. pages 3928–3937. 2016 49th Hawaii International Conference on System Sciences (HICSS), 2016. https://doi.org/10.1109/HICSS.2016.488.

[23] Daniel Giusto, Antonio Iera, Giacomo Morabito, and Luigi Atzori. *The Internet of Things*. Springer New York, 1 2010.

[24] Thomas Vilarinho, Babak A. Farshchian, Jacqueline Floch, and Bjørn Magnus Mathisen. A communication framework for the internet of people and things based on the concept of activity feeds in social computing. pages 1–8. 2013 9th International Conference on Intelligent Environments, 2013. https://doi.org/10.1109/IE.2013.24.

[25] Detlef Zühlke. Smartfactory-towards a factory-of-things. *Annual Reviews in Control*, 34:129–138, 04 2010. https://doi.org/10.1016/j.arcontrol.2010.02.008.

[26] Xiaofeng Lu, Zhaowei Qu, Qi Li, and Pan Hui. Privacy information security classification for internet of things based on internet data. *International Journal of Distributed Sensor Networks*, 11(8):932–941, 2015. https://doi.org/10.1155/2015/932941.

[27] Fabiana Scapolo, Peter Churchill, Vincent Viaud, Monika Antal, Hugo Cordova, and Peter De Smedt. *How will standards facilitate new production systems in the context of EU innovation and competitiveness in 2025?* Joint Research Centre (European Commission), 2014.

[28] Heiner Lasi, Peter Fettke, Hans-Georg Kemper, Thomas Feld, and Michael Hoffmann. Industry 4.0. *Business and Information Systems Engineering*, 6(4):239–242, 2014. https://doi.org/10.1007/s12599-014-0334-4.

[29] Henning Kagermann. *Change Through Digitization—Value Creation in the Age of Industry 4.0*, pages 23–45. 12 2015. https://doi.org/10.1007/978-3-658-05014-6_2.

[30] Dominik Lucke, Carmen Constantinescu, and Engelbert Westkämper. Smart factory - a step towards the next generation of manufacturing. In Mamoru Mitsuishi, Kanji Ueda, and Fumihiko Kimura, editors, *Manufacturing Systems and Technologies for the New Frontier*, pages 115–118, London, 2008. Springer London. https://doi.org/10.1007/978-1-84800-267-8_23.

[31] Thomas Bauernhansl. *Die Vierte Industrielle Revolution – Der Weg in ein wertschaffendes Produktionsparadigma*, page 5. Springer Fachmedien Wiesbaden, 2014.

[32] Dominic Gorecky, Mathias Schmitt, Matthias Loskyll, and Detlef Zühlke. Human-machine-interaction in the industry 4.0 era. In *2014 12th IEEE International Conference on Industrial Informatics (INDIN)*, pages 289–294, 2014. https://doi.org/10.1109/INDIN.2014.6945523.

[33] Edward A. Lee. Cyber physical systems: Design challenges. In *2008 11th IEEE International Symposium on Object and Component-Oriented Real-Time Distributed Computing (ISORC)*, pages 363–369, 2008. https://doi.org/10.1109/ISORC.2008.25.

[34] T W Malone. Is 'empowerment' just a fad? control, decision-making, and information technology. *BT Technology Journal*, 17(4):141–144, 1999. https://doi.org/10.1023/A:1009663512936.

[35] Javier Miranda, Niko Mäkitalo, Jose Garcia-Alonso, Javier Berrocal, Tommi Mikkonen, Carlos Canal, and Juan M. Murillo. From the internet of things to the internet of people. *IEEE Internet Computing*, 19(2):40–47, 3 2015. https://doi.org/10.1109/MIC.2015.24.

[36] Muhammad Awais and Dominik Henrich. Human-robot interaction in an unknown human intention scenario. In *2013 11th International Conference on Frontiers of Information Technology (FIT)*, pages 89–94, Los Alamitos, CA, USA, dec 2013. IEEE Computer Society.

[37] Embracing industry 4.0 and rediscovering growth. https://www.bcg.com/capabilities/operations/embracing-industry-4.0-rediscovering-growth.

[38] Daniel Küpper, Markus Lorenz, Kristian Kuhlmann, Olivier Bouffault, Jonathan Van Wyck, Sebastian Köcher, Jan Schlageter, and Yew Heng Lim. Ai in the factory of the future. https://www.bcg.com/publications/2018/artificial-intelligence-factory-future, (accessed: Apr. 18, 2018).

[39] Louis Columbus. 10 ways ai can improve digital transformation's success rate. https://www.forbes.com/sites/louiscolumbus/2020/04/15/10-ways-ai-can-improve-digital-transformations-success-rate/#40e508315c43, (accessed: Apr. 15, 2020).

[40] Tractica. Artificial intelligence for smart manufacturing applications. https://tractica.omdia.com/research/artificial-intelligence-for-smart-manufacturing-applications/, (accessed: Apr. 15, 2019).

[41] John Divine. Artificial intelligence stocks: The 10 best ai companies. https://money.usnews.com/investing/stock-market-news/slideshows/artificial-intelligence-stocks-the-10-best-ai-companies, (accessed: Jun. 11, 2020).

[42] Alyssa Schroer. 34 artificial intelligence companies building a smarter tomorrow. https://builtin.com/artificial-intelligence/ai-companies-roundup, (accessed: Sept. 09, 2020).

[43] Plattform Industrie 4.0. Working groups of the plattform industrie 4.0. https://www.plattform-i40.de/PI40/Navigation/EN/ThePlatform/Structure-Organization/PlatformWorkingGroups/platform-working-groups.html, (accessed: Sep. 18, 2020).

[44] Plattform Industrie 4.0. RAMI4.0 – a reference framework for digitalisation. https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/rami40-an-introduction.pdf?__blob=publicationFile&v=7. [Online; accessed September 18th, 2020].

[45] Eugenio Brusa, Ambra Calà, and Davide Ferretto. *Systems Engineering and Its Application to Industrial Product Development*. Springer International Publishing, 1 edition, 2018. https://doi.org/10.1007/978-3-319-71837-8.

[46] Marco Cantamessa and Francesca Montagna. *Management of Innovation and Product Development*. Springer-Verlag London, 1 edition, 2016. https://doi.org/10.1007/978-1-4471-6723-5.

[47] Albert Solberg. Model based systems engineering (mbse). https://www.nasa.gov/consortium/ModelBasedSystems, (accessed: Feb. 26, 2020).

[48] Jeff A. Estefan. *Survey of Model-Based Systems Engineering (MBSE) Methodologies*. INCOSE MBSE Initiative, 5 2008. http://www.omgsysml.org/MBSE_Methodology_Survey_RevB.pdf.

[49] Berend Denkena and Tobias Morke. *Cyber-Physical and Gentelligent Systems in Manufacturing and Life Cycle: Genetics and Intelligence - Keys to Industry 4.0*. Elsevier Science, 2017. https://www.elsevier.com/books/cyber-physical-and-gentelligent-systems-in-manufacturing-and-life-cycle/denkena/978-0-12-811939-6.

[50] Plattform Industrie 4.0. *The Structure of the Administration Shell: TRILATERAL PERSPECTIVES from France, Italy and Germany*. Federal Ministry for Economic Affairs and Energy (BMWi), 1 edition, 3 2018. https://www.de.digital/DIGITAL/Redaktion/DE/Publikation/the-structure-of-the-administration-shell.pdf?__blob=publicationFile&v=6.

[51] ZVEI Zentralverband Elektrotechnik und Elektronikindustrie e.V. *Examples for the Asset Administration Shell for Industrie 4.0 Components – Basic Part*. German Electrical and Electronic Manufacturers' Association, 1 edition, 4 2017. https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2017/April/Asset_Administration_Shell/ZVEI_WP_Verwaltungschale_Englisch_Download_03.04.17.pdf.

[52] E. Brusa. Synopsis of the mbse, lean and smart manufacturing in the product and process design for an assessment of the strategy "industry 4.0". In *Conf. on Sys. Eng. CIISE*, 2018. http://ceur-ws.org/Vol-2248/paper3.pdf.

[53] Bitkom. *Implementation Strategy Industrie 4.0*. Bitkom e.V. and VDMA e.V. and ZVEI e.V, 1 2016. https://www.zvei.org/fileadmin/user_upload/Presse_und_Medien/Publikationen/2016/januar/Implementation_Strategy_Industrie_4.0_-_Report_on_the_results_of_Industrie_4.0_Platform/Implementation-Strategy-Industrie-40-ENG.pdf.

[54] Klaus Schwab. The fourth industrial revolution, 2016. Cologny, Switzerland.

[55] M. Lopes Nunes, A.C. Pereira, and A.C. Alves. Smart products development approaches for industry 4.0. *Procedia Manufacturing*, 13:1215 – 1222, 06 2017. https://doi.org/10.1016/j.promfg.2017.09.035.

[56] Artem Timoshenko. *Machine Learning Methods for Targeting and New Product Development*. PhD thesis, Massachusetts Institute of Technology, Sloan School of Management, Sloan School of Management., 2019. https://dspace.mit.edu/handle/1721.1/123572.

[57] Shidong Yu and Dongsheng Yang. The role of big data analysis in new product development. pages 279–283. 2016 International Conference on Network and Information Systems for Computers (ICNISC), 2016. https://doi.org/10.1109/ICNISC.2016.068.

[58] N. Nozaki, Eiichi Konno, M. Sato, M. Sakairi, Toshiyuki Shibuya, Yuuji Kanazawa, and S. Georgescu. Application of artificial intelligence technology in product design. *FUJITSU Sci. Tec.*, 53:43–51, 07 2017. https://www.fujitsu.com/global/documents/about/resources/publications/fstj/archives/vol53-4/paper10.pdf.

[59] Plattform Industrie 4.0. *Relationships between I4.0 Components – Composite Components and Smart Production*. Federal Ministry for Economic Affairs and Energy (BMWi), 1 edition, 6 2017. https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/relationships-i40-components.pdf?__blob=publicationFile&v=5.

[60] Plattform Industrie 4.0. *Which criteria do Industrie 4.0 products need to fulfil?* Federal Ministry for Economic Affairs and Energy (BMWi), 1 edition, 4 2019. https://www.plattform-i40.de/PI40/Redaktion/EN/Downloads/Publikation/criteria-industrie-40-products.pdf?__blob=publicationFile&v=5.

[61] Phil Burt. The bike fit window. In *Bike Fit: Optimise Your Bike Position for High Performance and Injury Avoidance*, chapter 1. Bloomsbury Sport, 2014.

[62] SQlab. Pressure measurement saddle. https://www.sq-lab.com/en/ergonomics/studies-and-research-projects/pressure-measurement-saddle/, (accessed: Jun. 05, 2020).

[63] Federico Giubilato and Nicola Petrone. Stress analysis of bicycle saddles structural components during different cycling conditions. *Procedia Engineering*, 72:636 – 641, 2014. https://doi.org/10.1016/j.proeng.2014.06.103.

[64] Kim E Stansfield and Freeha Azmat. Developing high value iot solutions using ai enhanced iso 16355 for qfd integrating market drivers into the design of iot offerings. In *2017 International Conference on Communication, Computing and Digital Systems (C-CODE)*, pages 412–416, 2017. https://doi.org/10.1109/C-CODE.2017.7918967.

[65] Neena Devasia and Reshma Sheik. Feature extracted sentiment analysis of customer product reviews. In *2016 International Conference on Emerging Technological Trends (ICETT)*, pages 1–6, 2016. https://doi.org/10.1109/ICETT.2016.7873646.

[66] Tableau Website. Data cleaning: The benefits and steps to creating and using clean data. https://www.tableau.com/learn/articles/what-is-data-cleaning, (accessed: Jul. 11, 2020).

[67] Raymond Cheng. Text preprocessing with nltk. https://towardsdatascience.com/nlp-preprocessing-with-nltk-3c04ee00edc0, (accessed: Jun. 29, 2020).

[68] Srinivas Chakravarthy. Tokenization for natural language processing. https://towardsdatascience.com/tokenization-for-natural-language-processing-a179a891bad4, (accessed: Jun. 19, 2020).

[69] Sai Teja. Stop words in nlp. https://medium.com/@saitejaponugoti/stop-words-in-nlp-5b248dadad47, (accessed: Jun. 10, 2020).

[70] Hafsa Jabeen. Stemming and lemmatization in python. https://www.datacamp.com/community/tutorials/stemming-lemmatization-python, (accessed: Oct. 23, 2018).

[71] Jawad Khan and Byeong Soo Jeong. Summarizing customer review based on product feature and opinion. In *2016 International Conference on Machine Learning and Cybernetics (ICMLC)*, volume 1, pages 158–165, 2016. https://doi.org/10.1109/ICMLC.2016.7860894.

[72] Kushal Bafna and Durga Toshniwal. Feature based summarization of customers' reviews of online products. *Procedia Computer Science*, 22:142 – 151, 2013. https://doi.org/10.1016/j.procs.2013.09.090.

[73] Zehra Kavasoğlu and Şule Gündüz Öğüdücü. Personalized summarization of customer reviews based on user's browsing history. *IADIS International Journal on Computer Science and Information Systems*, 8:147–158, 2014. http://www.iadisportal.org/ijcsis/papers/2013160211.pdf.

[74] Medilogic. Bicycle seat measurement. https://medilogic.com/en/bycicle-seat-measurement/, (accessed: Jul. 10, 2020).

[75] Liang Liang, Minliang Liu, Caitlin Martin, and Wei Sun. A deep learning approach to estimate stress distribution: a fast and accurate surrogate of finite-element analysis. *Journal of the Royal Society Interface*, 15(138), 1 2018. https://doi.org/10.1098/rsif.2017.0844.

[76] William E. Frazier. Metal additive manufacturing: A review. *Journal of Materials Engineering and Performance*, 23(6):1917–1928, 6 2014. https://doi.org/10.1007/s11665-014-0958-z.

[77] Kai Zeng, D. Pal, and Brent Stucker. A review of thermal analysis methods in laser sintering and selective laser melting. In *23rd Annual International Solid Freeform Fabrication Symposium - An Additive Manufacturing Conference, SFF 2012*, pages 796–814, 2012.

[78] Hyub Lee, Chin Huat Joel Lim, Mun Ji Low, Nicholas Tham, Vadakke Matham Murukeshan, and Young-Jin Kim. Lasers in additive manufacturing: A review. *International Journal of Precision Engineering and Manufacturing-Green Technology*, 4(3):307–322, 7 2017. https://doi.org/10.1007/s40684-017-0037-7.

[79] Kaufui V. Wong and Aldo Hernandez. A review of additive manufacturing. *International Scholarly Research Notices*, 2012, 8 2012. https://doi.org/10.5402/2012/208760.

[80] Ho-Chan Kim, Jae-Won Choi, and Ryan Wicker. Scheduling and process planning for multiple material stereolithography. *Rapid Prototyping Journal*, 16:232–240, 06 2010. https://doi.org/10.1108/13552541011049243.