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Master Thesis No. —

# Context-based Manufacturing Processes

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## Abstract

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# 1. Introduction

Since manufacturing processes involve the processes to transform raw materials into finished goods on a large scale, economists around the globe assert manufacturing to be a wealth-producing sector of an economy. Manufacturing world thrives upon many complex variables. In the recent years, due to innovations in Information and Communication Technology (ICT) the focus of supply and demand are shifting, thus manufacturing industry is experiencing more complex supply chains. Customers demanding high levels of individualized products are driving fierce competition in pricing and forcing manufacturers to strive for highest levels of efficiencies. The kind of turbulences a manufacturer can expect now-a-days can be found in Figure 1.1. Still manufacturers can develop effective survival strategies amidst all these turbulences, if they are able to continuously adapt their organizational structures [Wes06].

The challenge lies in making the manufacturing adaptive by accessing all available information when it is needed, where it is needed, and in the form it is most useful to drive optimal actions and responses. Adaptive manufacturing also enables manufacturers to generate and apply data-driven manufacturing intelligence throughout the life-cycle of design, engineering, planning, and production.

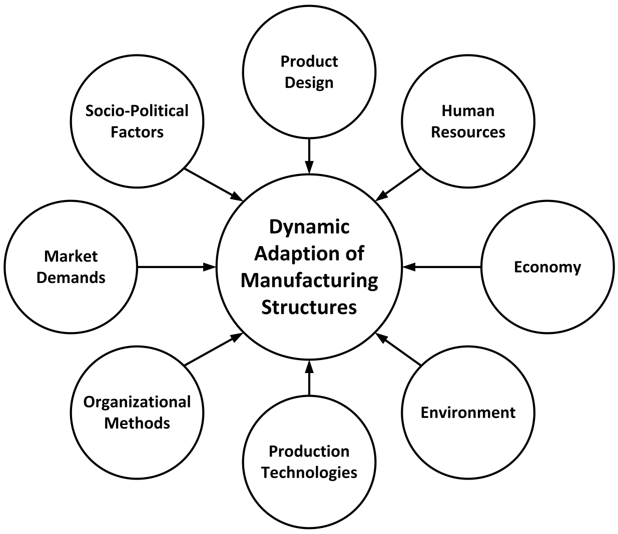


**Figure 1.1.:** Sources of Turbulences in Manufacturing - Adapted from [Wes06]

With the advent of a new wave of technological changes there is already driving a paradigm shift in manufacturing. Manufacturing sector is at the verge of a new industrial revolution which promises all range of opportunities for innovation in terms of smarter industrial processes, new business models and customized products. The new technological wave builds on the concept of interaction between the real and virtual worlds which becomes the core of the manufacturing processes. Both production equipment and manufactured products are now able to gather, process and analyze data of the physical world and interact with each other autonomously.

The primary objectives of production are known as the *"Holy Trinity"* of cost, quality, and time. Some authors do refer this trio as *"Iron Triangle"* [Bas14]. Most important is to point out the right direction of goal achievement – low production costs, high quality of products, as well as short lead times in production and order processing. Recently the product variety on demand is added to these production goals. Products produced in series and not positioned within the lowest price segment can only be distinguished from competition by the 'long tail' of innumerable possible variants or individualized (customized) products - as we refer them [Erl12].

Erlach [Erl12] explains the relationships between the four goal dimensions and the relevant goal conflicts by the logical square of goals shown in Figure 1.2. In sum, the possible relationships between the four goal dimensions can be distinguished into following four types:

1. The contradictory antagonism of goals describes the strongest type of conflict where goal achievement for the one goal deteriorates that of the other goal.

2. The contrary antagonism of goals describes that the attainment of the two goals cannot be improved at the same time, though the fulfillment of the one goal can be improved without negatively affecting the fulfillment of the other goal.

3. The subordination of goals is possible when attainment of some goals are basically easier to accomplish than others thanks to their lower implementable requirements.

4. The compatibility of goals exists if the two goals can be better accomplished independently.

Improving individual goals does not necessarily mean that another goal is affected to the same degree; some goals can actually be improved simultaneously. The objective of production optimization is to counterbalance operation of production and the product range at a specific production site with the four goal dimensions in order to achieve the best level of goal achievement [Erl12].

To increase the efficiency of production process, automation, optimization, and dynamic adaption became the most important requirements in manufacturing sector [Hen14]. Since the dawn of sensors and networking technologies, vital information can be gathered beforehand to decide the most suitable and optimized process. The selection of each execution step may depend on different factors as new technological advancements provide more solution options to the same kind of problems. Manually conducted assembly tasks may provide alternatives to the existing automation methods depending on the current demand, status of the machinery, and occupation of the machinery [SBLW15]. Situations can be observed using modern world smart-systems that enable the application of well-adopted business process modeling and execution solutions in the context of manufacturing companies and tracking of activity flows in the real world [WKNL07].

To strengthen the case, a recent sector research work by Deutsche Bank [Hen14] can be looked upon. This predicts that Germany with its favorable fundamental features will find the next industrial revolution a major long-term opportunity to consolidate its leading position in

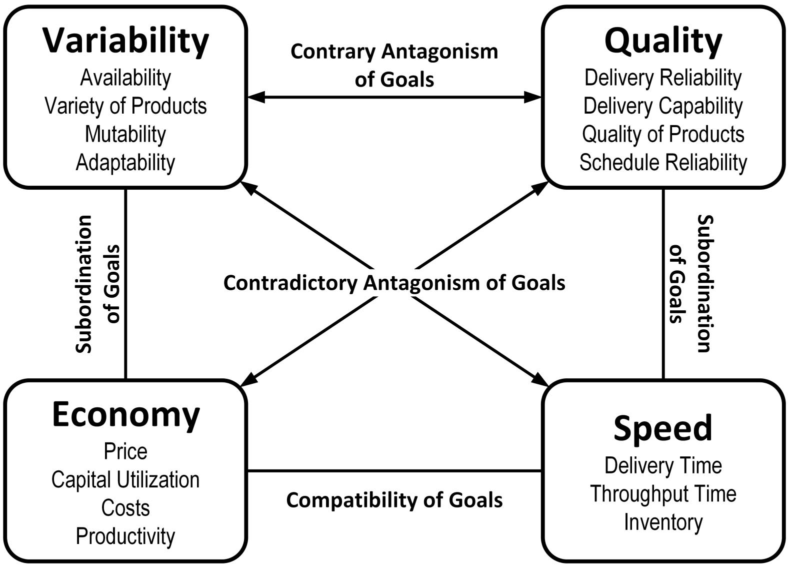


**Figure 1.2.:** Logical Four Square of Conflicting Goals of Production [Erl12]

the global marketplace even against its fast-growing emerging market competitors. Thus Germany has been and will remain an industrial heavyweight, creating one-third economy of the European Union (EU) [Hen14].

Production or Manufacturing processes can be modeled using business process modeling languages e.g. Business Process Execution Language (BPEL) [OAS07] or Business Process Model and Notation (BPMN) [OMG11]. After modeling, process models are deployed on compliant workflow engines for an automated execution. But these paradigms don't support adaptive and flexible execution of business processes in manufacturing sector. By not considering these adaptations, the manufacturing companies lose their revenue and edge in market by remaining reluctant to structural changes on time [SBLW15, WKNL07].

## 1.1. Problem Statement

Manufacturing processes need to be updated regularly to stay competitive in the market. With the emergence of new sensor technologies, *Internet of Things (IoT)* which is discussed later in Chapter 2.2, the manufacturing processes can be made smarter to leverage the next industrial revolution - commonly referred as *Industry 4.0*. We introduce Industry 4.0 in early part of the literature review in Chapter 2.1.

Sungur et al. [SBLW15] presented a novel approach to support *Context-sensitive Adaptive Production Process* in their research work. They extended production processes, which contain a sequence of predefined sets of sub-processes, with *Context-sensitive Execution Steps (CES)*. For each CES, context-relevant sub-processes are chosen and desired processes are elected, optimized, deployed and executed [SBLW15]. CES approach dictates a way in which processes can possibly adapt themselves to the execution context. In each context, there can be multiple alternatives for the same process goals and the best needs to be selected and executed at runtime [SBLW15]. All details relevant to context-sensitive workflows have been discussed thoroughly later in Chapter 3.

In this thesis work, we define a BPMN extension which do not change semantics of standard BPMN if it's needed at all and adds the necessary details to make manufacturing process models executable. To create this extension, we have analyzed the properties that make CESs unique and also scrutinized important and relevant BPMN properties which might be vital during creation of the CES extensions. These properties are later on used to derive our requirements from which we create our extension. A summary of the thesis work can be found below in Figure 1.3.

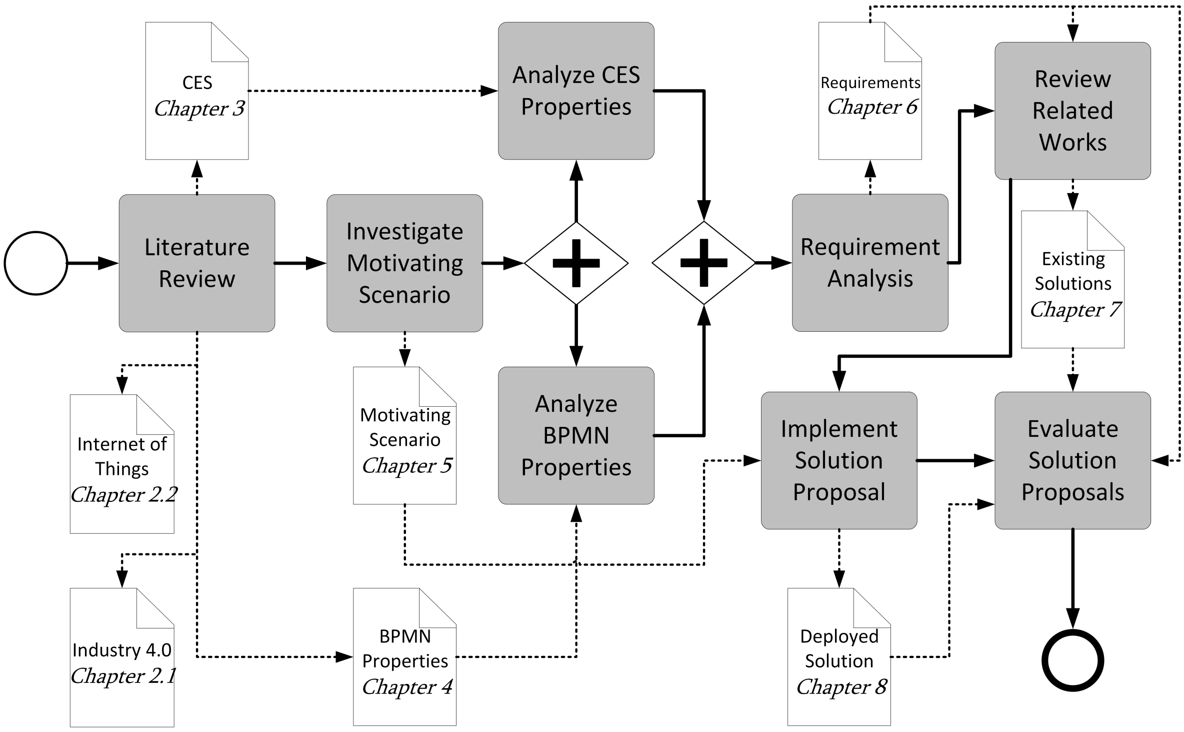


**Figure 1.3.:** The Thesis Methodology Flow-chart - Inspired from [Sun13]

## 1.2. Methodology and Outline

The remaining thesis document is structured in the following way:

- *Chapter 2 - Fundamentals:* The literature review of this thesis is carried out in three steps as suggested by Levy et al. [LE06]. We analyze literature related with Industry 4.0 and Internet of Things (IoT). Main focus during the literature review was to understand the current development in Industry 4.0 and it's implications in midst of the innovations in IoT technologies. Trends in the IoT field has also been discussed.
- *Chapter 3 - Context-sensitive Workflows:* In the next chapter, we analyze literature related with Context-sensitive Execution Step (CES). Properties and operational semantics

of CES are also discussed in the concluding section of the review. After necessary processing corresponding descriptions are touched upon in subsequent.

- *Chapter 4 - Business Process Model and Notation:* The last part of the literature review is focused upon analyzing properties of CES from the point of view of Business Process Management (BPM), and the efficacies of BPMN. This chapter has been added just before modeling the motivating scenario.
- *Chapter 5 - Motivating Scenario:* For the sake of analysis and apply the conceptual workflow modeling construct, we have described a motivating scenario depicting a real-world manufacturing scenario which is a mix of both manual- and automated tasks.
- *Chapter 6 - Requirement Analysis:* In this chapter, we derive our requirements from the properties that we have found related. By defining our requirements, we conclude the task requirement analysis in the methodology model Figure 1.3. All the relevant properties and requirements for the CES have been described in this chapter.
- *Chapter 7 - Related Works:* In the next task, we select and analyze few already existing extensions of BPMN or any ongoing work in same direction. We propose our solution which satisfy the requirements that we have previously defined to make sure that our approach proposed by Sungur et al. [SBLW15] can cater the best to the manufacturing sector.
- *Chapter 8 - Architecture and Implementation:* During the implementation of our conceptual construct, we use the BPMN extension methodology and we preserve the semantics of the existing BPMN properties. Architecture for the execution of modeled process is touched upon in this chapter.
- *Chapter 9 - Evaluation:* In our final task, we evaluate our approach by comparing it with the current state of art or related works already discussed in Chapter 7. We conclude this task by a thorough comparison between several existing solutions.
- *Chapter 10 - Summary and Outlook:* In the last chapter, we give a summary and an outlook about our contribution to the manufacturing world.

The thesis document also contains two appendices for the further look-up:

- *Appendix A - List of Acronyms:* The list containing all the abbreviations or acronyms which are used in this document is added in this appendix.
- *Appendix B - Glossary:* This appendix is intended to define terms or concepts cited in the documented that are out of the scope of our discussion.

# 2. Fundamentals

For much of human history, productivity growth was barely perceptible, and living standards improved at a snail's pace. Then approximately 200 years ago, a steep change in innovation occurred: the *Industrial Revolution* treated as *Industry 1.0*, in which the muscle power of all living beings was replaced by mechanical power that introduced steam engines and internal combustion engines to the mechanical production facilities. From the early part of the twentieth century, electrification and the division of labor led to the second industrial revolution which is referred as *Industry 2.0* now. The third industrial revolution referred as *Industry 3.0*, also known as the *Digital Revolution*, was set in around the 1970s, when advanced electronics and Information Technology (IT) developed further the automation of production processes. In the following decades industrial technological advancements were only incremental, especially compared with the breakthroughs that transformed IT, mobile communications, and e-commerce [EA12, HPO15, RLG$^+$15].

Productivity and economic growth accelerated sharply in consequence of these innovations. The number of manufacturing jobs decreased, new jobs emerged and the demand for new skills grew. Today, another workforce transformation is on the horizon as manufacturing experiences a new wave of technological advancement where it is possible to augment physical machines with digital intelligence. The conditions are ripe and early evidence suggests that this new wave of innovation is already upon us [EA12, LRS$^+$15].

In the next few sections, we have discussed about how the next industrial revolution will unfold itself, and its benefits for businesses and more broadly for economies around the world.

## 2.1. Industry 4.0

The term *"Industry 4.0"* that refers to the next industrial revolution became publicly known in 2011 at Hanover Fair, when an initiative named *"Industrie 4.0"* - an association of representatives from business, politics, and academia - promoted the idea as an approach to strengthening the competitiveness of the German manufacturing industry [KLW11]. The German Federal Government supported the idea by announcing that Industry 4.0 will be an integral part of its "High-Tech Strategy 2020 for Germany" initiative, aiming at technological innovation leadership. The subsequently formed "Industrie 4.0 Working Group" then developed first recommendations for implementation, which were published in April 2013 [HPO15].

Hermann et al. [HPO15] describe the fascination behind Industry 4.0 in 2 segments. Firstly, for the first time an industrial revolution is predicted a-priori, not observed ex-post that provides various opportunities for companies and research institutes to actively shape the future. Secondly, Industry 4.0 promises substantially increased operational effectiveness as well as the development of entirely new business models, services and products.

### 2.1.1. Definition

From the literature review of Hermann et al. [HPO15] and Kagermann et al. [KLW11],

**Definition 1** *Industry 4.0* is a collective term for contemporary automation, data exchange, and manufacturing technologies and concepts of value chain organization which draws together Cyber-Physical Systems (CPS), the Internet of Things (IoT), Smart Factories and the Internet of Services.[1]

Rüßmann et al. [RLG+15] explain it in a similar way as mentioned below.

**Definition 2** *Industry 4.0* is a new digital industrial technology that will connect sensors, machines, work-pieces, and IT systems along the value chain beyond the enterprise which in turn will interact with another using standard Internet-based protocols and adapt to changes.

In North America, similar ideas have been brought up under the name *Industrial Internet* by General Electric [EA12]. The technical basis is very similar to Industry 4.0, but the application is broader than industrial production. The various definitions have caused confusion rather than increasing transparency [DH14]. Hereafter Industrie 4.0 or Industrial Internet or Integrated Industry will be referred interchangeably with Industry 4.0.

### 2.1.2. Enablers of Industry 4.0

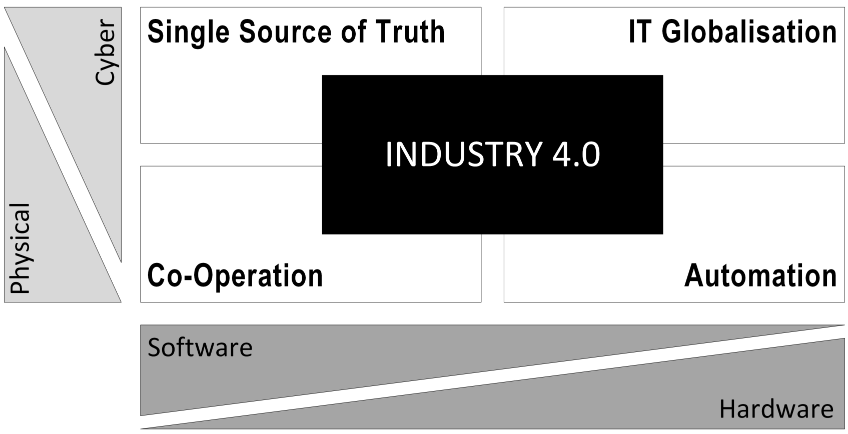


**Figure 2.1.:** Four Enablers of Industry 4.0 - Adapted from [SRHD15]

Industry 4.0 is not initiated on a shop-floor level and therefore companies have to take measures in their own hands to introduce its enablers into their companies to profit from the

[1] CPS, IoT, IoS and Smart Factory are the components of Industry 4.0. They are discussed later in Chapter 2.1.3.

current change in society and technology [KLW11]. These measures can be categorized by the aid of 2 dimensions. The first dimension describes whether a precondition is physical or cyber, whereas the second dimension allocates the precondition to hard- or software components. Industry 4.0 can be seen as a collaborated production by the inter-working of human-human, machine-human, and machine and production system as shown in Figure 2.1 [SRHD15].

- *Single Source of Truth* dictates to embed all product life-cycle data along the value chain within a single database using cloud storage and accesses to make all changes to product and production visible and avoid ambiguity during production and simulations [SRHD15].
- *IT-Globalisation* made computers achieve exponential growth in speed and cheap storage capacity. This will allow faster extensive simulations of different aspects of a company as well as the processing of huge amounts of data, which are already collected by companies, but cannot be used adequately [SRHD15].
- *Automation* leads to automated and decentralized processes which can be combined to collaboration networks and are able to adapt to dynamic requirements and therefore are self-optimizing [SRHD15].
- *Co-Operation* aims at the connection of all technologies and activities e.g. efficient sharing and exchange of engineering data within a network of engineers. Networks help to improve cooperation by communicating targets and empowering decision maker's in decentralized systems [SRHD15, KLW11].

### 2.1.3. Components of Industry 4.0

Advances in technology that powered Industry 4.0 are already used in manufacturing, but with Industry 4.0, they will transform production: isolated cells will come together as a fully integrated, automated, and optimized production flow, leading to greater efficiencies and changing traditional production relationships among suppliers, producers, and customers — as well as between human and machine [RLG$^+$15]. Major factors that propels this next industrial revolution has been listed below.

- *Cyber Physical Systems (CPS)* [2] are integrations of computation, networking and physical processes. Embedded computers and networks monitor and control the physical processes, with feedback loops where such processes affect computations and vice versa e.g. autonomous automotive systems [HPO15].
- *Internet of Things (IoT)* [3] allows field devices to communicate and interact both with one another and with more centralized controllers, as necessary. It also decentralizes analytics and decision making, enabling real-time responses [RLG$^+$15, HPO15].
- *Smart Factory* [4] is context-aware by assisting people and machines in execution of their tasks. It is achieved by systems working in background, so-called Calm-systems and

[2] CPS is explained with its architecture in Chapter 2.2.4.
[3] IoT is the prime driver of Industry 4.0 which is discussed in Chapter 2.2.
[4] Smart factory which thrives upon IoT is discussed in Chapter 2.2.6.

context aware means that the system can take into consideration information coming from physical and virtual world like the position and status of an object [HPO15].

- *Internet of Services (IoS)* enables service vendors to offer their services via the internet. The IoS consists of participants, an infrastructure for services, business models, and the services themselves. Services are offered and combined as value-added services by various suppliers; they are communicated to users as well as consumers and are accessed by them via various channels [HPO15].

- *Big Data and Analytics* based on large data sets has emerged only recently in the manufacturing world, where it optimizes production quality, saves energy, and improves equipment service. Big data is high volume, high velocity, and/or high variety information assets that require new forms of processing to enable enhanced decision making, insight discovery and process optimization [BL12]. In an Industry 4.0 context, the collection and comprehensive evaluation of data from many different sources - production equipment and systems as well as enterprise- and customer-management systems - will become standard to support real-time decision making [RLG+15, HPO15].

- *Cloud Computing* is a model for enabling ubiquitous, convenient, on-demand network access to a shared pool of configurable computing resources (e.g. networks, servers, storage, applications, and services) that can be rapidly provisioned and released with minimal management effort or service provider interaction as per definition of NIST [MG11]. It will make increased data sharing across sites and company boundaries possible for Industry 4.0. At the same time, the performance of cloud technologies will improve, achieving reaction times of just several milliseconds. As a result, machine data and functionality will increasingly be deployed to the cloud, enabling more data-driven services for production systems [RLG+15, HPO15].

- *Augmented Reality* based systems support a variety of services, such as selecting parts in a warehouse and sending repair instructions over mobile devices. These systems are currently in their infancy, but in the future, companies will make much broader use of augmented reality to provide workers with real-time information to improve decision making and work procedures [RLG+15].

### 2.1.4. Mechanisms to Increase Productivity

The significant increase of the productivity due to Industry 4.0 can be represented by the 4 mechanisms. Schuh et al. [SRHD15] discussed in their article how enablers of Industry 4.0 facilitate these mechanisms.

- *Revolutionary Product Life-cycles*: Integrated technologies and rapid prototyping facilitate companies to produce testable prototypes which supply viable information of the products potentials as customer feedback can be implemented immediately. Due to the new developments in ICT the costs of an iteration and the resulting changes are not as cost intensive as before and therefore lead to a new development process in terms of time and profit which can be seen in Figure 2.2 [SRHD15].

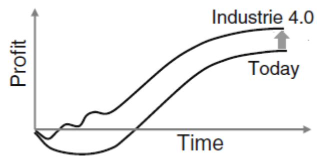


**Figure 2.2.:** Industry 4.0: Revolutionary Product Life-cycles [SRHD15]

- *Virtual Engineering of Complete Value Chains*: By the aid of Software tools companies now have the opportunity to simulate their whole production network. This virtualization and simulation can reveal possible capacity problems as well as problems within the general workflow. By simulating the value chain in a short amount of time one is able to counteract possible problems before they arise, which enhances the decision capability which can be seen in Figure 2.3. To get a valuable decision capability based on simulations it is necessary to execute an adequate number of simulations [SRHD15].

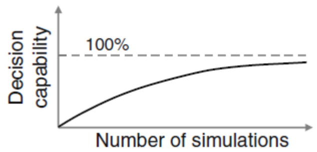


**Figure 2.3.:** Industry 4.0: Virtual Engineering of Complete Value Chains [SRHD15]

- *Revolutionary Short Value Chains*: Companies have to offer more and more individualized products in order to meet the customer requirements. This complicates the division of labor introduced by Taylorism as machines in general are only able to accomplish one specific task. In order to allow even more individualized products the integration of production steps and thus the integration of functions within production systems is inevitable. This leads to a reversion of Taylorism - instead of the division of labor by means of a conveyor belt production cells are to be established, allowing an employee to take over autonomous responsibility and give this specific employee decision [SRHD15].

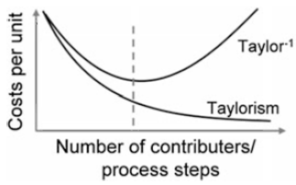


**Figure 2.4.:** Industry 4.0: Revolutionary Short Value Chains [SRHD15]

Within a production process for highly customized products there is an optimal number of contributors or process steps in one production cell which have to collaborate in order to achieve minimal costs for the produced product which can be seen in Figure 2.4 [SRHD15].

- *Better Performing than Engineered*: Companies must aim at the self-optimizing capabilities of production systems which are already theoretically possible. With the ongoing advancement of self-optimizing production systems machines should be able to reach a productivity level which exceeds the previously determined maximum due to cybernetic effects as shown in Figure 2.5. An example would be a productivity of 15,000 units whereas the estimated maximum before self-optimization was 10,000 units [SRHD15].

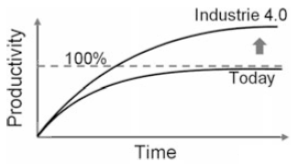


**Figure 2.5.:** Industry 4.0: Better Performing than Engineered [SRHD15]

### 2.1.5. Industrial Requirements

For Industry 4.0, the term revolution does not refer to the technical realization but to the ability to meet today's as well as future challenges. Some very basic requirements guide most of the work currently being done.

- *Investment Protection*: Industry 4.0 has to be introduced stepwise into existing plants with-out hampering business and investor's trust [DH14, RLG$^+$15].
- *Stability*: Industry 4.0 must provide stability and must not compromise production, neither by disturbances nor by a breakdown [DH14].
- *Infrastructure Development*: Industry 4.0 will require an adequate backbone. Data centers, broadband spectrum, and fiber networks are all components of the ICT infrastructure that will need to be further developed to connect the various machines, systems, and networks across industries and geographies [EA12].
- *Data Privacy*: Access to production related data and services has to be controllable to protect company know-how. Although countries will develop national guidelines, the development of international norms and standards will also be required. The focus should be on developing norms related to IP protection and international data flows [DH14, EA12].
- *Cybersecurity*: Industry 4.0 has to prevent unauthorized access to production systems to prevent environmental or economic damage and harm to humans.Products (devices and software) should contain embedded security features to maximize the layers of defense against cyber-threats [DH14, EA12].
- *Policymaking*: Cooperation with regulators, law enforcement, and the intelligence community can help improve the visibility of evolving threats. Courses of action include sharing threat information and mitigation efforts to build a stable foundation. The government should pursue the development and broad adoption of voluntary industry standards and best practices for cyber-security [EA12].

- *Talent Development*: The rise of the Industry 4.0 will require new talent pools to be created and grown. There will be a wave of new technical,analytical, and leadership roles that are explicitly cross-discipline e.g. Data scientists, User Interface (UI) experts, Next-generation engineers etc [EA12].
- *Enhance Competencies*: Producers have to set priorities among their production processes and enhance their workforce's competencies step-wise so that they can take advantage of Industry 4.0 in coming years [LRS+15].
- *Leverage Technologies*: Manufacturing-system suppliers need to understand how they can employ technologies in new use cases to offer the greatest benefits to their customers. These technologies can be leveraged for different offerings, such as the enhancement of networked embedded systems and automation, the development of new software products, and the delivery of new services, such as analytics-driven services [LRS+15, EA12].

Any future Industry 4.0 architecture has to fulfill these requirements as reconditions for industrial acceptance.

### 2.1.6. Benefits of Industry 4.0 in Manufacturing

Industry 4.0 promises to have a range of benefits spanning machines, facilities, fleets and industrial networks, which in turn influence the broader economy. Industry 4.0 opens the door to a variety of benefits for the industrial economy. Some companies have been early adopters, realizing benefits and overcoming challenges related to capturing and manipulating data streams. While its benefits would reverberate throughout the economy, the initial impact of the Industrial Internet is likely to be felt especially strongly in the area of advanced manufacturing [EA12].

Lorenz et al. [LRS+15] analyzed how the industrial workforce will evolve with Industry 4.0 by looking at the effects that these new technologies will have on Germany's manufacturing landscape, which is among the world's most advanced.

- Manufacturers will be able to increase their competitiveness, which will enable them to expand their industrial workforce at the same time that productivity increases [LRS+15, RLG+15].
- Manufacturers will be able to bring previously off-shored jobs back home as production becomes more capital intensive and the labor cost advantages of traditional low-cost locations will shrink [LRS+15].
- Manufacturers will be allowed to create new jobs to meet the higher demand resulting from the growth of existing markets and the introduction of new products and services [RLG+15, EA12, LRS+15].
- Robot-assisted production will cause the largest net decrease in jobs in the relevant manufacturing industries, because the efficiencies it creates will allow manufacturers to significantly reduce the number of jobs on the shop floor [LRS+15].

- The use of automation to assist workers with manual tasks will be particularly valuable in responding to the needs of the aging workforce in many developed countries w.g. a robot could lift a car's interior-finishing elements, such as a roof lining, into the chassis after manual alignment by a worker [LRS+15].
- Industry 4.0 will enable technology-assisted, predictive maintenance. By remotely reviewing a stream of real-time data on machine performance, the technician will be able to pro-actively identify defects and order spare parts before arriving at a site. Once on-site, the technician will be assisted in making repairs by augmented-reality technology and will be able to receive remote guidance from experts off-site. The work can also be automatically documented [LRS+15].
- Industry 4.0 will help to implement cost-efficient manufacturing by reducing *Capital costs* through optimization of value chains, *Energy costs* by efficient usage and smart control of their plant facilities, and *Personnel costs* with highly automated production processes [Hen14].
- The machine operators will require less machine- and product-specific training but will need enhanced capabilities for utilizing digital devices and software and accessing a digital knowledge repository. Standard operating procedures for any given task will be displayed on screens or glasses such that an operator can carry out the same types of responsibilities at several machines [LRS+15].

Industry 4.0 offerings need to be tailored specifically to the company and cannot be supplied "off the shelf". So the idea of Industry 4.0 can basically be conceived in very diverse contexts. Various projects developed by Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI), Fraunhofer, and companies such as Agco, Bosch Rexroth, Daimler, Festo, Siemens, HP, and SAP etc. have already shown the varied benefits associated with Industry 4.0 [Hen14].

Industry 4.0 creates tremendous opportunities for manufacturing industries and national economies. Although job losses will be high for some categories of work, such as assembly and production planning, job gains will be significant in other categories, particularly IT and analytics. The extent to which Industry 4.0 ultimately promotes higher employment will depend on how successfully companies use these technological advancements to develop new products, services, and business models. Enabling companies to retrain their workforce, education systems to close the IT skills gap, and governments to strengthen their support will be critical to realizing the promise of Industry 4.0 [LRS+15, EA12].

## 2.2. Internet of Things

The future is not going to be people talking to people; it's not going to be people accessing information. It's going to be about using machines to talk to other machines on behalf of people. We are entering a new era of ubiquity, we are entering the Internet of Things (IoT) era in which new forms of communication between human and things, and between things themselves will be realized [TW10]. The Internet revolution led to the interconnection between people at an unprecedented scale and pace. Industry 4.0 is going to be the leverage for the interconnection between objects to create a smart environment. Only in 2011 the number of interconnected devices on the planet overtook the actual number of people. Currently there are 9 billion interconnected devices and it is expected to reach 24 billion devices by 2020 [GBMP13].

The term Internet of Things was first coined by Kevin Ashton in 1999 in the context of supply chain management [Ash09]. However, in recent years, the definition has been more inclusive covering wide range of applications like health-care, utilities, transport, etc. Computers need to e empowered with their own means of gathering information, so they can sense the world themselves. The recent advances in sensor technology enables computers to observe, identify and understand the world - without the limitations of human-entered data [Ash09].

Integrated Sensor–Actuator–Internet framework will form the core technology around which a smart environment will be shaped: information generated will be shared across diverse platforms and applications. As we move from World-Wide Web (WWW - Static Web-pages) to Web 2.0 (Social-networking Web) to Web 3.0 (Ubiquitous-computing Web), there is a need to deploy large-scale, platform-independent, wireless sensor network infrastructure that includes data management and processing, actuation and analytics. Cloud computing promises high reliability, scalability and autonomy to provide ubiquitous access, dynamic resource discovery required for the next generation IoT applications. Consumers will be able to choose the service level by changing the Quality of Services (QoS) parameters [GBMP13].

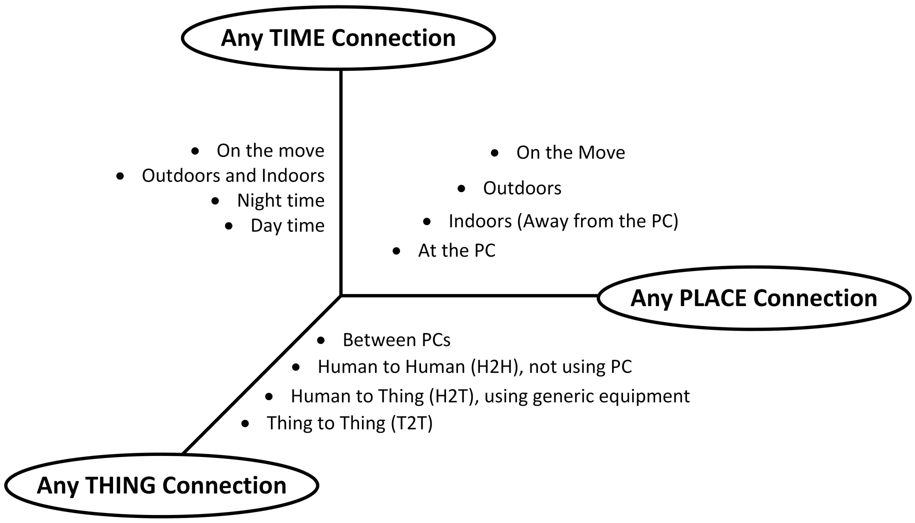


**Figure 2.6.:** IoT Dimensions [TW10]

### 2.2.1. Definition and Trends

Xia et al. [XYWV12] puts forward a general IoT definition in their editorial.

**Definition 3** *IoT* refers to the networked interconnection of everyday objects, which are often equipped with ubiquitous intelligence. IoT will increase the ubiquity of the Internet by integrating every object for interaction via embedded systems, which leads to a highly distributed network of devices communicating with human beings as well as other devices.

Gubbi et al. [GBMP13] explains IoT from the point of view of the Cloud applications.

**Definition 4** *IoT* means interconnection of sensing and actuating devices providing the ability to share information across platforms through a unified framework, developing a Common Operating Picture (COP) for enabling innovative applications, that is achieved by seamless ubiquitous sensing, data analytics and information representation with Cloud computing as the unifying framework.

Considering the functionality and identity as central Tan et al. [TW10] defines IoT as a new dimension that has been added to the world of ICT: from any *Time*, any *Place* connectivity for anyone to now connectivity for any *Thing* as shown in Figure 2.6.

**Definition 5** *IoT*s have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environment, and user contexts.

Similarly the Cluster of European Research Projects [SGFW10] explains Internet of Things as stated below.

**Definition 6** *Things* are active participants in business, information and social processes where they are enabled to interact and communicate among themselves and with the environment by exchanging data and information sensed about the environment, while reacting autonomously to the real/physical world events and influencing it by running processes that trigger actions and create services with or without direct human intervention.

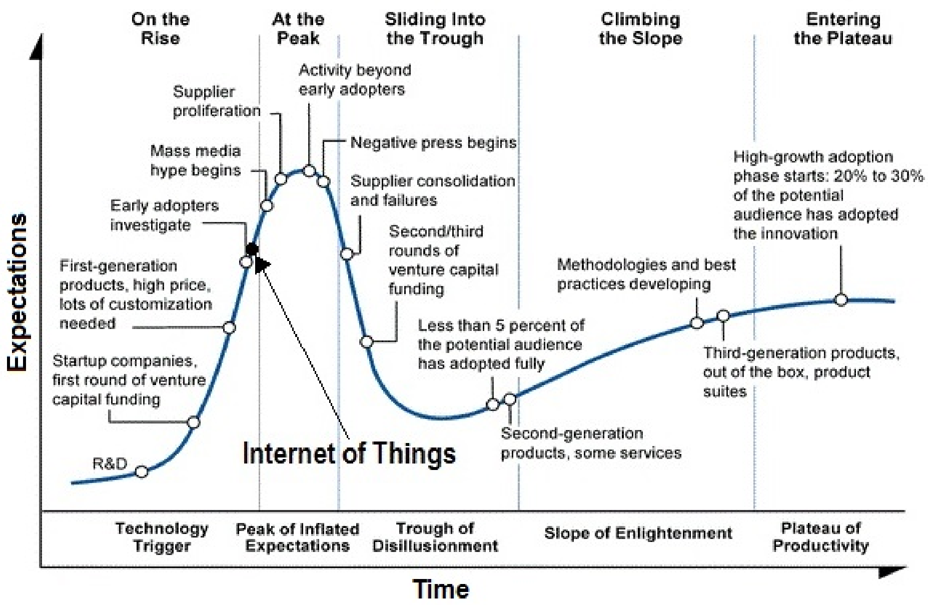


**Figure 2.7.:** IoT in Gartner Hype-Cycle - Adapted from [Bro11, RvdM15]

A *Hype Cycle* is a way to represent the emergence, adoption, maturity, and impact on applications of specific technologies [RvdM15]. IoT has been identified as one of the emerging technologies in IT as noted in Gartner's IT Hype Cycle - 2015 already shown in Figure 2.7. As per its estimation IoT will take 5–10 years for market adoption. IoT is opening tremendous opportunities for a large number of novel applications that promise to improve the quality of our lives. In recent years, IoT has gained much attention from researchers and practitioners from around the world [RvdM15, XYWV12].

### 2.2.2. Elements of Internet of Things

IoT is a technological revolution that represents the future of ICT. There are three IoT components which enables seamless ubiquitous computing: (a) *Hardware* made up of sensors, actuators and embedded communication hardware (b) *Middleware* like on demand storage and computing tools for data analytics and (c) *Presentation* for easy to understand visualization and interpretation tools which can be widely accessed on different platforms. Here we discuss a few enabling technologies which will make up components stated above. Things can be connected wired or wireless. In the IoT wireless connection will to be the main way [GBMP13, TW10]. Base on the existed infrastructure, there are many ways to connect a thing: Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), Digital Subscriber Line (DSL), General Packet Radio Service (GPRS), WiFi, 3G Universal Mobile Telecommunications System (UMTS), 4G Long-Term Evolution (LTE) etc.

#### 2.2.2.1. Radio Frequency Identification

Radio Frequency Identification (RFID) is a non-contact technology that identifies objects attached with tags that help in the automatic identification of anything they are attached to. Sometimes RFID has been labeled as a replacement of bar code, but RFID system can do much more than that [MWZ$^+$07, TW10].

RFID tags consist of a $\mu$Controller, an antenna (either wire or printed using conductive carbon ink), and polymer-encapsulating material that wraps around the antenna and the chip. Readers interrogate tags for their contents through antenna and interface to back-end databases for more functionalities. RFID can also identify mobile objects of high speed and it can identify certain amount of Tags simultaneously by its anti-collision mechanism [MWZ$^+$07]. In addition to identify items it also can track items in real-time to get important information about their location and status [TW10].

The passive RFID tags don't have own power source and they use the power of the reader's interrogation signal to communicate the tag to the RFID reader. This has resulted in many applications particularly in retail, supply chain management and access control applications as well. The passive tags are currently being used in many bank cards and road toll tags which are among the first global deployments. Many manufacturing enterprises, are taking advanced technologies to ensure its ordered and correct product procedures. Active RFID readers have their own power source and can instantiate the communication. Major application of active RFID tags is in port containers for monitoring cargo [GBMP13, MWZ$^+$07].

Nanotechnology and miniaturization can make embedded intelligence in things themselves which called smart devices. They can process information, self-configure, make decision independently, just until then there will be a real *thing to thing* Figure 2.6 communication [TW10].

#### 2.2.2.2. Wireless Sensor Network

Recent advances in Micro-Electro-Mechanical Systems (MEMS) technology, wireless communications, and digital electronics have enabled the development of low-cost, low-power, multi-functional sensor nodes which consist of sensing, data processing, and communicating components, leverage the idea of Wireless Sensor Network (WSN) [ASSC02, SSOK13]. The components that make up the WSN monitoring network include:

- *WSN Hardware*: A typical WSN node contains sensor interfaces, processing units, transceiver units and power supply [GBMP13].
- *WSN Communication Stack*: The nodes are expected to be deployed in an ad-hoc manner for most applications in an appropriate topology. Nodes in a WSN need to communicate among themselves to transmit data in single or multi-hop to a base station. Node drop outs, and consequent degraded network lifetimes, are pretty frequent [GBMP13, ASSC02].
- *WSN Middleware*: Middleware is a software layer that stands between the networked operating system and the application and provides well known reusable solutions to frequently encountered problems like heterogeneity, interoperability, security and dependability [ICG07]. Middleware such as Open Sensor Web Architecture (OSWA) are required to provide a mechanism to combine cyber infrastructure with Service Oriented Architecture (SOA) and sensor networks to provide access to heterogeneous sensor resources in a deployment independent manner [GBMP13].
- *Secure Data Aggregation*: An efficient and secure data aggregation method is required for extending the lifetime of the network as well as ensuring reliable data collected from sensors. Node failures are a common characteristic of WSN, the network topology should have the capability to heal itself. Ensuring security is critical as the system is automatically linked to actuators and protecting the systems from intruders becomes very important [GBMP13].

Some of the application areas of WSN are health, military, and security. For example, a node in a WSN might measure temperature values in a room while another node controls the air conditioning according to the sensed values and desired overall room temperature. WSN is a part of an enterprise context now, such as monitoring and optimizing energy consumption of buildings or enabling predictive maintenance of assets [SSOK13, ASSC02].

#### 2.2.2.3. Addressing Schemes

The ability to uniquely identify *Things* is critical as it will allow us to uniquely identify and control billions of devices remotely through the Internet. The few most critical features of creating a unique address are: uniqueness, reliability, persistence and scalability. The Uniform Resource Name (URN) can create replicas of the resources that can be accessed through the

Uniform Resource Locator (URL). Internet Protocol version 6 (IPv6) also gives a very good option to access the resources uniquely and remotely. Development of a lightweight IPv6 will make addressing home appliances uniquely feasible [GBMP13].

As Gubbi et al. mentions [GBMP13], WSN cannot possess IPv6 stack to address individually and hence a subnet with a gateway having a URN will be required. At the subnet level, the URN for the sensor devices could be the unique IDs rather than human-friendly names as in the WWW, and a lookup table at the gateway to address this device. Further, at the node level each sensor will have a URN (as numbers) for sensors to be addressed by the gateway. The entire network now forms a web of connectivity from users (high-level) to sensors (low-level) that is addressable through URN, accessible through URL and controllable through Uniform Resource Citation (URC) [GBMP13].

#### 2.2.2.4. Storage and Analytics

The data gathered from IoT devices have to be stored and used intelligently for smart monitoring and actuation. State-of-the-art non-linear, temporal machine learning methods based on evolutionary algorithms, genetic algorithms, neural networks, and other artificial intelligence techniques are necessary to achieve automated decision making. Cloud based storage solutions are becoming increasingly popular and in the years ahead, Cloud based analytics and visualization platforms are foreseen, since a centralized infrastructure to support storage and analytics is the most important need of the hour [GBMP13].

#### 2.2.2.5. Visualization

Visualization is critical for an IoT application as this allows the interaction of the user with the environment. It enables policy makers to convert data into knowledge, which is critical in fast decision making. Extraction of meaningful information from raw data is non-trivial. This encompasses both event detection and visualization of the associated raw and modeled data, with information represented according to the needs of the end-user [GBMP13].

### 2.2.3. Internet of Things Architecture

IoT is not a theory, it's an application technology which our life can benefit from. Current Internet has a five-layered TCP/IP architecture, which has worked well for a long time. However, in the IoT billions of objects are connected which will create much larger traffic and need much more data storages [TW10]. The vision of IoT can be seen from two perspectives - 'Internet' centric and 'Thing' centric. The Internet centric architecture will involve internet services being the main focus while data is contributed by the objects. In the object centric architecture, the smart objects take the center stage [GBMP13]. Tan et al. [TW10] proposed an Internet-centric approach in their work.

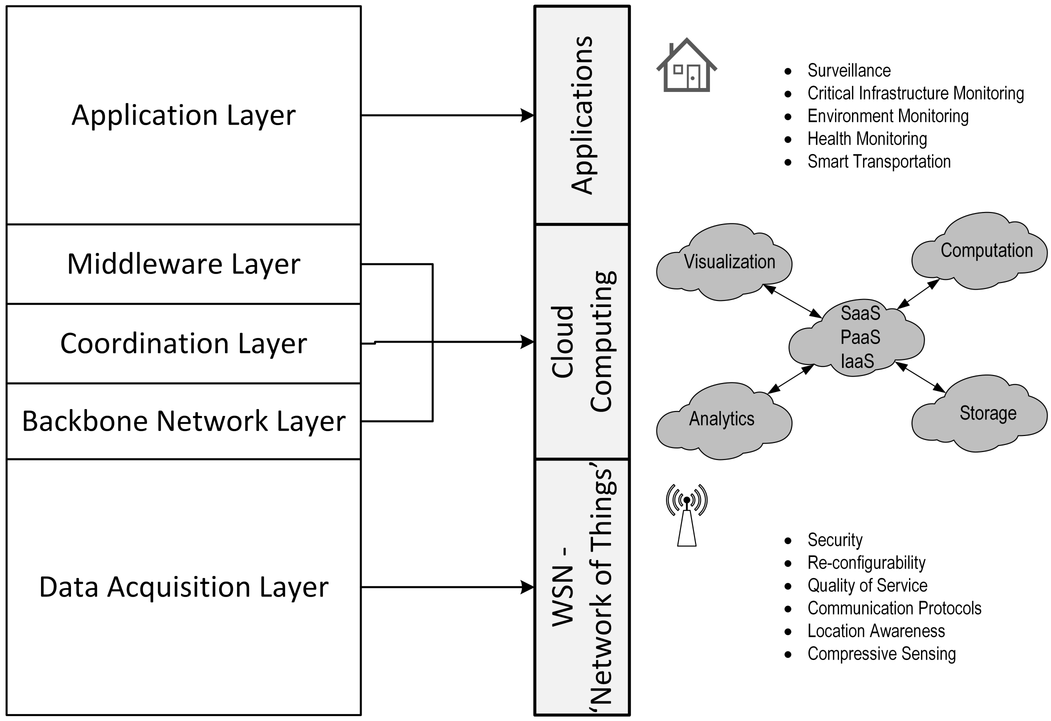


**Figure 2.8.:** Conceptual IoT Architectural Framework - Adapted from [TW10, GBMP13]

A simpler conceptual framework out of architecture proposed by Tao et al. [TW10] integrating the ubiquitous sensing devices and the applications is proposed by us which is shown in Figure 2.8 [5]. In order to realize the full potential of cloud computing as well as ubiquitous sensing, a combined framework with a cloud at the center seems to be most viable [GBMP13].

The *Backbone Network Layer* may be today's Internet, may be not or may be its expansion. The *Coordination Layer* responses to process the structure of packages from different application systems and reassemble them to an unified structure which can be identified and processed by every application system to make it inter-operable among the already existing systems and the newly deployed systems [TW10]. As per our evaluation of the model, the three layers in the middle (Middleware, Coordination and Backbone Network) of Tao et al. [TW10] can be integrated and realized as a single layer of Cloud Computing as proposed by Gubbi et al. [GBMP13].

According to Perera et al. [PZCG14] IoT should be facilitated by a hybrid architecture which comprises primarily two different architectural approaches, namely event driven and time driven. Some sensors produce data when an event occurs (e.g. door sensor); the rest produce data continuously, based on specified time frames (e.g. temperature sensor) [PZCG14].

Sensing service providers can join the network and offer their data using a storage cloud; analytic tool developers can provide their software tools; artificial intelligence experts can

[5] IaaS = Infrastructure as a Service
PaaS = Platform as a Service
SaaS = Software as a Service

provide their data mining and machine learning tools useful in converting information to knowledge and finally computer graphics designers can offer a variety of visualization tools. Cloud computing can offer these services as Infrastructures, Platforms or Software where the full potential of human creativity can be tapped using them as services [GBMP13].

### 2.2.4. Cyber-Physical Systems

Cyber-Physical Systems (CPS) are integrated automated systems that enable connection of the operations of the physical reality with computing and communication infrastructures. CPS goes with the trend of having information and services everywhere at hand, and it is inevitable in the highly networked world of today. Fields of applications for CPS include medical equipment, driving safety and driver assistance systems for automobiles, industrial process control and automation systems, assistance systems for controlling the power supply in terms of optimized use of renewable energies [Jaz14, HPO15].

A CPS consists of a control unit, usually one or more $\mu$Controller(s), which control(s) the sensors and actuators that are necessary to interact with the real world, and processes the data obtained as shown in Figure 2.9. CPS also requires a communication interface to exchange data with other CPS or a cloud. In other words, a CPS is an embedded system that is able to send and receive data over a network. The CPS connected to the Internet is often loosely referred to as the IoT [Jaz14].

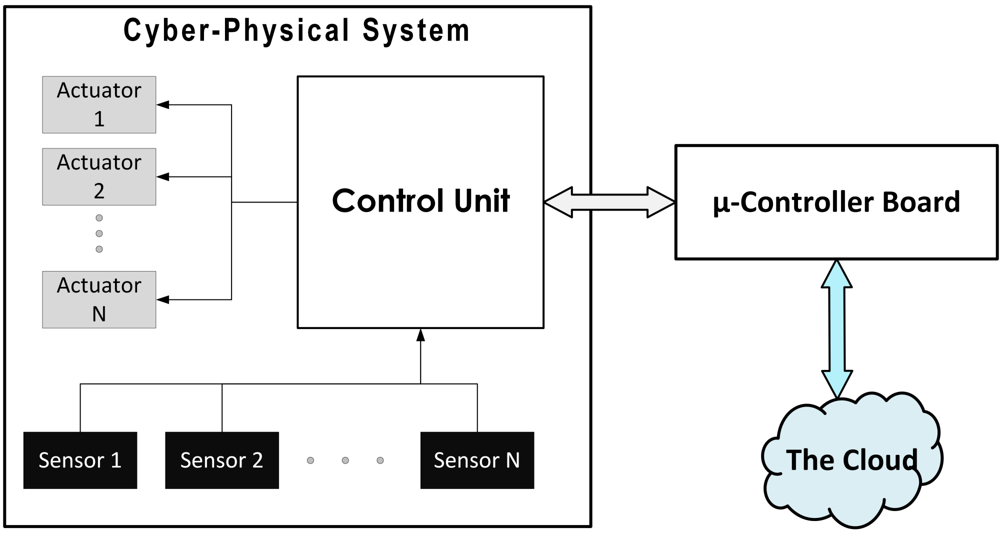


**Figure 2.9.:** Conceptual Architecture of a CPS - Adapted from [Jaz14]

The development of CPS is characterized by three phases. The first generation of CPS includes identification technologies like RFID tags, where storage and analytics have to be provided as a centralized service. The second generation of CPS are equipped with sensors and actuators with a limited range of functions. CPS of the third generation can store and analyze data, are equipped with multiple sensors and actuators, and are network compatible [HPO15]. To sum it up, a CPS requires three levels as pointed out by Drath et al. [DH14]:

- the physical objects,
- data models of the mentioned physical objects in a network infrastructure, and
- services based on the available data.

Due to the rise of CPS components, products, and other entities in industrial production would get their own identities in the network such that hey could be interconnected and simulated. Systems could be virtually integrated, tested, and optimized. The digital factory and the virtual commissioning would be accessible to everybody. Products could navigate autonomously through the production line. This will establish CPS as one of the the prime enablers of Industry 4.0 - the forthcoming industrial revolution [DH14, RLG+15].

### 2.2.5. Smart Factory and Industry 4.0

In manufacturing, there is great potential for CPS to improve the production process and the supply chain. The IoT has set in motion Industry 4.0 will disperse control. Consider processes that govern themselves, where smart products can take corrective action to avoid damages and where individual parts are automatically replenished. Such technologies already exist and could drive Industry 4.0 further. As suggested by Siegfried Dais in a conversation with Löffler et al. [LT13], two competencies must come together to drive development further: using what's truly new about new technologies and finding hum an resource who can design robust algorithms to make the system user-friendly and robust. The trend of separating design and production will continue to spread across other industries and sectors. Likewise, supply-chain integration will play a decisive role in new operating models [LT13].

Lean Production principles are widely accepted in industry which refers to the strict integration of humans in the production process, a continuous improvement and focus on value adding activities by avoiding of waste. If a plant implements lean manufacturing, it keeps its stocks to a minimum - neither one part too many nor too few. With the IoT, this system must extend beyond the limits of individual factories to interconnect multiple factories and even regions. Instruments to reach this increased automation are CPS. CPS can work autonomously and interact with their production environment. As a result, a factory becomes ***'Smart Factory'*** [KZ15, LT13].

The department of IFS at the German Research Center for Artificial Intelligence (DFKI) identified four enablers as shown in Figure 2.10 for the *Smart Factory* [KZ15]:

- *Smart Operator*: People can supervise and control ongoing activities in ease e.g. equipped with smart watches, employees receive error messages and error locations close to real time. CPS equipped with proper sensors can recognize failures and automatically trigger fault-repair actions on other CPS. [KZ15].
- *Smart Product*: It could collect process data for the analysis during and after its production. In contrast to manual data acquisition for value stream mapping it is possible to gather information individualized per product and production line automatically. This way of data acquisition is less labor-intensive and data are more precise [KZ15].

- *Smart Machine*: Especially the potential of CPS in production is not fully explored yet. Machines help employees to avoid mistakes. With their computing capacity and connectible sensors, CPS could be integrated fast and flexible in fault-prone processes for supporting [KZ15].
- *Smart Planner*: It could optimize processes in real-time. CPS could supports optimization of production processes by different business objectives, like throughput time or efficacy. Applied to Lean Production, this approach could enable Lean Production to be implemented not only in mass and batch production, but also in job shop production [KZ15].

In the context of Industry 4.0 new solutions are available for combining automation technology with Lean Production. As described above, the combination of automation technology and Lean Production can be beneficial. Contrary to popular belief, Lean Production does not exclude automation [KZ15]. It is essential to translate the physical world into a format that can be handled by IT which requires mathematical, domain, market, and domain know-how.

As suggested by Heinz Derenbach in a conversation with Löffler et al. [LT13], separating the physical world from business processes will be a foolish idea. It means a physical device or *'Things'* becomes an active part of a business process: delivering data, sending events, and processing rules. This notion is driving manufacturing sector and Industry 4.0. The next big step will be to think through the interdependencies among the machine, the production components, the manufacturing environment, and the IT that connects it all. This requires a high degree of standardization so that the machine knows what it needs to do to any given component, and the components can confirm that the machine has done it. Such IT linkage goes far beyond current manufacturing systems [LT13]. Due to the exponentially increasing

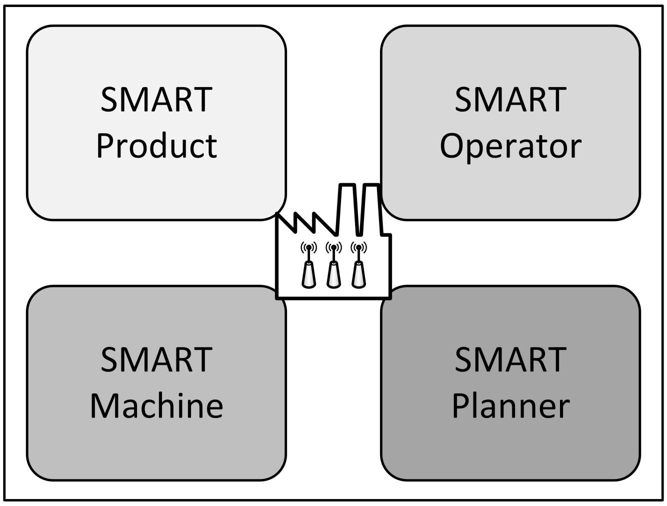


**Figure 2.10.:** Enablers of Smart Factory

amount of data and knowledge relevant for manufacturing planning and optimization, it is impossible for one or a team of production engineers to have all these information in mind. Therefore we search for a possibility to support manufacturing planning and optimization activities by enhancing digital tools with IoT enabled CPS. This is of a very interdisciplinary character. On the one hand there is the need for a detailed understanding of the production process being planned, based on knowledge and experiences of experts in the field of manufacturing engineering that usually have limited interest in ICT. On the other hand, the handling of this large amount and high complexity of information is a challenging task for IT experts who in turn do not have complete knowledge of the production processes [LC12].

Still IoT technology has a wide range of applications in many fields, including aerospace, automotive, communication, medical and, manufacturing industry, and so on. For example, in the field of aerospace industry, the application of IoT can effectively improve the product's safety and reliability by identifying the fake and shoddy parts or products. In the automotive industry, IoT is widely used in the production line, quality monitor and control, assemble line, logistics and product (or part) tracking, and the real-time link of customer service. Among the procedure, intelligent labels are posted on the components in every part of the link to make it easy to track or invoke, together with the associated attribute information, such as the manufacturer's name, serial number, product type, product code, the place and time of the production, as well as the exact location of the product [TZDXZ14, PZCG14].

### 2.2.6. Challenges Ahead for Internet of Things

The IoT is the wheel of Industry 4.0, but there are many issues need to be addressed. In this part we discuss three crucial issues among many issues such as, standardization, security and privacy, and energy efficiency [TW10, GBMP13].

There can be no real IoT without a global standard. But the fact is technological standardization of the IoT in most areas is still in its infancy, or remain fragmented. So efforts are needed, collaboration among International Organization for Standardization (ISO), European Telecommunications Standards Institute (ETSI), Internet Engineering Task Force (IETF), International Telecommunication Union (ITU), Institute of Electrical and Electronics Engineers (IEEE) and other related organizations is very important and urgent. As the WWW grew in last decade, many security and privacy problems came out, then we could do nothing but build patches and it seems that the security and privacy is an add-on feature. But the public acceptance for the IoT will happen only when the strong security and privacy solutions are in place. So we should take security and privacy a very important role from the early design and build phase in the IoT [TW10]. Sensor nodes carry limited, generally irreplaceable, power sources. Therefore, while traditional networks aim to achieve high QoS provisions, sensor network protocols must focus primarily on power conservation. They must have inbuilt trade-off mechanisms that give the end user the option of prolonging network lifetime at the cost of lower throughput or higher transmission delay [ASSC02].

Manufacturing industry can benefit immensely from the IoT. Though the future is bright, there still are many technical issues need to be addressed and a long path to realize IoT. As per Löffler et al. [LT13], "Process and Device" will be inseparable; physical things become part of the process. Machines and workflows will merge to become a single entity. IoT activities are gathering momentum around the world, with numerous initiatives underway across industry, academia and government, as key stakeholders seek to map a way forward for the coordinated realization of this evolution towards Industry 4.0 [TW10, GBMP13, LT13].

# 3. Context-sensitive Workflows

Business processes that have been carried out manually and through a diversity of non-integrated systems can be integrated by employing workflow management systems (WFMS). Industrial production processes are hugely dependent upon the physical world data, which is often obtained with a huge amount of sensors. Therefore the development of applications that can adapt to their environmental changes automatically by their own is cumbersome. To facilitate production processes in the manufacturing industry to be more dynamic, intelligent applications could be designed which can adapt to changing situations in runtime [WKNL07].

## 3.1. Definitions

Workflow technology should be able to handle information about the physical world, referred as *"Context"*. The term context has been defined by many researchers. The most general definition provided by Abowd et al. [ADB+99] can be relevant for our further research work.

**Definition 7** *Context* is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves.

A workflow that considers context is called *"Context-sensitive"*. Many researchers refer such workflows as "Context-aware" workflows. Abowd et al. [ADB+99] again provides the basic definition to context-aware workflows. Hereafter "Context-aware" will be referred interchangeably with 'Context-sensitive'.

**Definition 8** A system is *Context-aware* if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task.

The context model that is used by a given context-sensitive application is usually explicitly specified by the application developer which can evolve over time. Henricksen [Hen03] provides the basic definition to context attributes that can be treated as the building block of a meaningful context [PZCG14].

**Definition 9** *Context Attribute* is an element of the context model describing the context. A context attribute has an identifier, a type and a value, and optionally a collection of properties describing specific characteristics.

The basis for context-sensitive workflows is context information such as the position of workers, tools, machines and also the state of all objects. Context data is sensed via sensor modules mounted to the tools [WKNL07].

Digital tools are capable of modeling and simulating manufacturing facilities and operations to handle the complexity. But there is no feedback available from the digital tool about the quality of context (QoC). The digital tools are not able to provide knowledge in sense of creating new information by tagging available information in an (semi-) automatic way [LC12].

Different researchers have identified context types differently based of different perspectives. For our research work, we have followed the mechanisms of context categorization introduced by Abowd et al. [ADB+99].

- *Operational Perspective* allows us to understand the issues and challenges in gathering context from IoT devices, as well as quality and cost factors related to context. Furthermore this identifies any information retrieved without using existing context and without performing any kind of sensor data fusion operations as *'Primary Context'* e.g. Raw Global Positioning System (GPS) Locations. Any information that can be computed using primary context is called *'Secondary Context'* e.g. distance between two machines using their GPS coordinates [PZCG14, ADB+99].
- *Conceptual Perspective* allows an understanding of the conceptual relationships between context. It confirms the location, identity, time, and activity as its main attributes that makes it comprehensive and flexible. It also allows to model mental reasoning behind context [PZCG14, ADB+99].

The IoT paradigm needs to establish comprehensive categorization schemes in a hierarchical manner, such as major categories, sub categories and so on. We have to integrate perspectives in order to model context precisely for our research work [PZCG14].

## 3.2. Context Management Life-cycle

A data life-cycle shows how data moves from phase to phase in a software system. Moreover, it explains where and how the data is generated and where and how the data is consumed. In this section we consider movement of such data (context) in 'Context-aware' systems. In simplest terms, the context life-cycle consists of four phases as shown in Figure 3.1 [PZCG14].

- **Context Acquisition**: Context needs to be acquired from various sources that can be varied based on responsibility, frequency, context source, sensor type, and acquisition process. These five factors need to be considered when developing context-aware middleware solutions in the IoT paradigm [PZCG14].
  - *Based on Responsibility*: Context acquisition can be primarily accomplished using two methods: either the sensors can *push* data to the software component which is responsible for acquiring sensor data or the software component can *pull* the sensor data by making a request to the sensor over some medium [PZCG14].
  - *Based on Frequency*: Context can be gathered based on two different event types namely, *instant events* which don't span across certain amount of time e.g. switching a light, and *interval events* that span a certain period of time e.g. sensing a wire after every 20 seconds [PZCG14].

– *Based on Source*: Context can be acquired *directly from sensor* by communicating with the sensor hardware and related device drivers. IoT applications can acquire sensor data by *middleware solutions* such as Nexus [LCW09] where heterogeneous sensors are deployed. Context can also be acquired from several other *context storages* e.g. databases via different mechanisms such as web-service calls [PZCG14].

– *Based on Sensor Types*: There are different types of sensors that can be employed to acquire context. *Physical sensors* generate sensor data by themselves. *Virtual sensors* retrieve data from many sources and publish it as sensor data e.g. Twitter tweets. *Logical (Software) sensors* combine both aforementioned sensors in order to produce more meaningful information e.g. a web service dedicated to providing weather information [PZCG14].

– *Based on Acquistion Process*: There can be three ways to acquire context: *sense*, *derive* data by computing already sensed data, and *manually provided* data by predefined configurations [PZCG14].

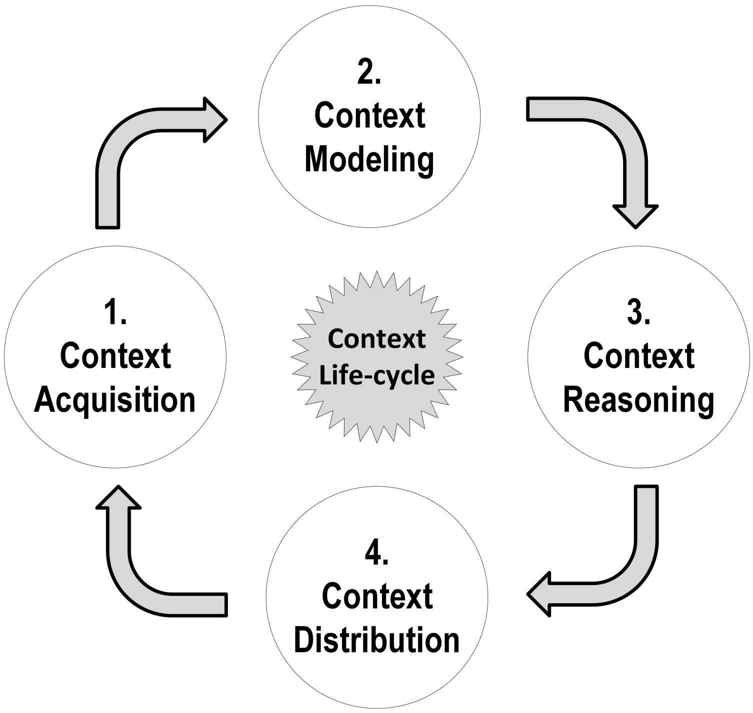


**Figure 3.1.:** Context Life-cycle - Adapted from [PZCG14]

- **Context Modelling**: The acquired data needs to be modeled and represented according to a meaningful manner. New context data needs to be defined in terms of attributes, characteristics, relationships with previously specified context, QoC attributes and the queries for synchronous context requests. After the resulting data gets validated, the context data needs is pushed to the existing context information repository. Finally, the new context information is made available to be used when required. Perera et al. [PZCG14] have mentioned and compared many methods to model context data such as *Key-Value Scheme*, *Markup Scheme (e.g. XML)*, *Graphical* (e.g. databases), *Object-based*, *Logic-based* and *Ontology-based* etc.

- **Context Reasoning**: It is a method of deducing new knowledge out of the modeled data based on the available context. Imperfection and uncertainty are the main reasons we need phase before distribution of context data. Large number of different context reasoning decision models exist such as *Decision Tree*, *naive Bayes*, *hidden Markov Models*, *k-Nearest Neighbor*, *Neural Networks*, *Ontology-based*, *Fuzzy logic* and many more [PZCG14].
- **Context Distribution** Finally, the context data needs to be delivered to the context consuming agents. Context can be distributed either by a *query* (request) from consumer or consumers can *subscribe* for a specific sensor or to an event, that will make the process real-time [PZCG14].

Now we have reached the phase where we can define three more definitions proposed by Wieland et al. [WKNL07] which will be used across our literature of research in context-aware applications.

**Definition 10** *Context Query* is a synchronous query designed in a specific query language, that supports object selection based on spatial predicates and filtering of the results, to access context data from context repository.

**Definition 11** *Context Event* is an asynchronous event triggered by context changes. The listening for this special environment state is done in parallel to the normal workflow.

**Definition 12** *Context Decisions* are used to route process control flow based on context data using context-aware operators or context-conditions.

## 3.3. Proposed System

The approach introduced here presents the capability of creating new information with help of an intelligent manufacturing knowledge modeling.

## 3.4. Operational Semantics

## 3.5. Realization Architecture

# 4. Business Process Model and Notation

## 4.1. Motivation

## 4.2. Reason for Selecting BPMN

## 4.3. Properties of BPMN

# 5. Motivating Scenario

# 6. Requirements Analysis

# 7. Related Works

| | |
|---|---|
| Name | **Enrich Topology** |
| Goal | The developer wants to enrich the application topology as per the requirements. |
| Actor | Application Developer |
| Pre-Condition | The application developer has access to the winery system and has the application requirements ready. |
| Post-Condition | Here goes the post-condition in normal case |
| Post-Condition in Special Case | Here goes the post-condition in special case |
| Normal Case | 1. Step 1 normal case<br>2. Step 2 normal case<br>3. ... |
| Special Cases | 1a. Step 1a special case<br>a) ...<br>2a. Step 2a special case<br>a) ...<br>2b. Step 2b special case<br>a) ... |

**Table 7.1.:** Description of Use Case *Enrich Topology*.

# 8. Architecture and Implementation

# 9. Evaluation

# 10. Summary and Outlook

# Appendix A.

## List of Acronyms

The following list contains all the acronyms which are used in this document.

**BPEL** Business Process Execution Language

**BPM** Business Process Management

**BPMN** Business Process Model and Notation

**CES** Context-sensitive Execution Steps

**COP** Common Operating Picture

**CES** Context-sensitive Execution Step

**CPS** Cyber-Physical Systems

**DFKI** Deutsches Forschungszentrum für Künstliche Intelligenz

**DSL** Digital Subscriber Line

**ETSI** European Telecommunications Standards Institute

**EU** European Union

**GPS** Global Positioning System

**GPRS** General Packet Radio Service

**IaaS** Infrastructure as a Service

**ICT** Information and Communication Technology

**IEEE** Institute of Electrical and Electronics Engineers

**IETF** Internet Engineering Task Force

**IFS** Innovative Factory Systems

**IoS** Internet of Services

**IoT** Internet of Things

**IP** Internet Protocol

**IPv6** Internet Protocol version 6

**ISO** International Organization for Standardization

**IT** Information Technology

**ITU** International Telecommunication Union

**LTE** Long-Term Evolution

**MEMS** Micro-Electro-Mechanical Systems

**NIST** National Institute of Standards and Technology

**OSWA** Open Sensor Web Architecture

**PaaS** Platform as a Service

**QoC** Quality of Context

**QoS** Quality of Services

**RFID** Radio Frequency Identification

**SaaS** Software as a Service

**SOA** Service Oriented Architecture

**TCP** Transmission Control Protocol

**UI** User Interface

**UMTS** Universal Mobile Telecommunications System

**URC** Uniform Resource Citation

**URL** Uniform Resource Locator

**URN** Uniform Resource Name

**WFMS** Workflow Management System

**WSN** Wireless Sensor Network

**WWW** World-Wide Web

**XML** Extended Markup Language

# Appendix B.

## Glossary

The following list contains all the acronyms which are used in this document.

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Debasis Kar

## Declaration

I hereby declare that the work presented in this thesis is entirely my own. I did not use any other sources and references that the listed ones. I have marked all direct or indirect statements from other sources contained therein as quotations. Neither this work nor significant parts of it were part of another examination procedure. I have not published this work in whole or in part before. The electronic copy is consistent with all submitted copies.

Stuttgart, December 22, 2015 ______________________________

(Signature)