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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 products exhaustively, economists around the globe assert manufacturing to be a wealth-producing sector of an economy as most developed economies are predominantly dependent upon manufacturing sector. Westkämper [Wes06] suggests that the focus of supply and demand are shifting due to modern innovations in Information and Communication Technology (ICT), thus manufacturing industry is experiencing more complicated supply chains than before. Customers demanding high levels of individualized products are driving fierce competitions in pricing and compelling manufacturers to endeavor highest levels of efficiencies. The kind of turbulences a manufacturer can expect to be adapted easily using automated processes are shown in Figure 1.1. Furthermore manufacturers can develop effective survival strategies in midst of all these turbulences, if they are able to continuously adapt their organizational structures, technical changes and learn from their previous mistakes [Wes06].

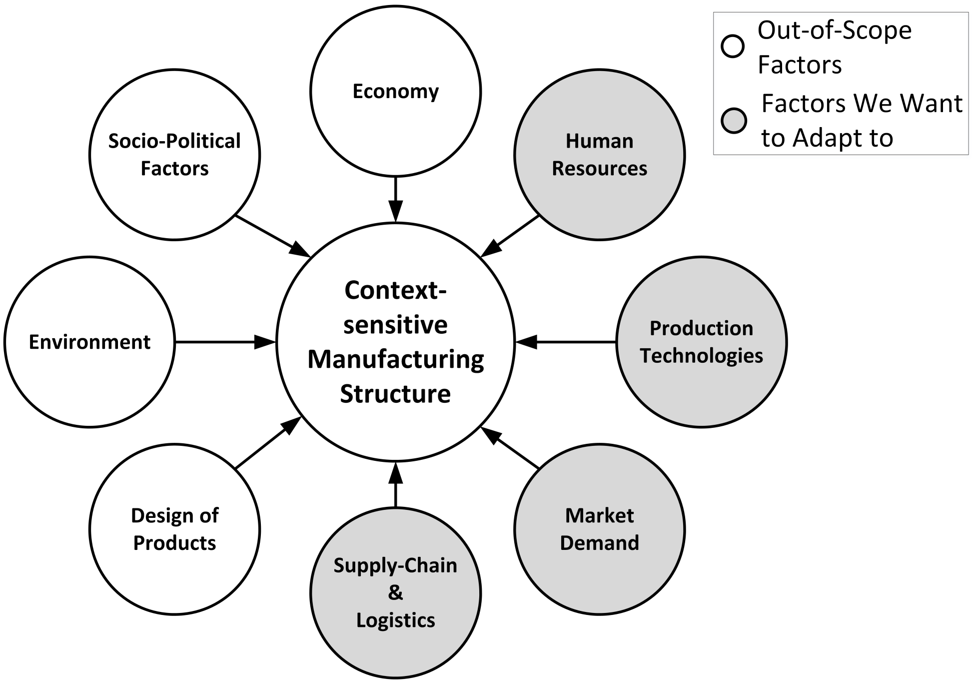

Figure 1.1.: Sources of Turbulences in Manufacturing (Adapted from [Wes06])

According to Graybill [Gra14], adaptive smart manufacturing thrives upon many challenges, e.g., accessing all available information when it is needed, where it is needed, and how it is needed to deduce optimal actions and responses. Adaptive manufacturing facilitates manufacturers to generate and apply data-driven manufacturing intelligence throughout the life-cycle of design, procurement, planning, production, and logistics [RLG+15, Erl12].

The advent of a new wave of technological changes has already started driving a paradigm shift in manufacturing. Manufacturing sector is at the verge of a new industrial revolution which assures smarter industrial production process flow, optimized new business models and highly tailor-made 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 [RLG+15, HPO15].

According to Erlach [Erl12], the ultimate intent of business process are known as the *"Holy Trinity"* of cost, quality, and time. Some authors do refer this trio as *"Iron Triangle"* [Bas14] and few others add variability or changeability to these three intents [Erl12]. Achievement of production goals are dependent upon factors such as low production costs, high quality of products, short lead times in production and order processing, and moreover the product variety on demand. Products within the lowest price segment can only be distinguished from competition by innumerable individualized (customized) products [Erl12].

Erlach [Erl12] further explains the interrelation between the four goal dimensions and the relevant goal conflicts as shown in Figure 1.2. In sum, the possible relationships between the four goal dimensions can be characterized into following four types:

1. The contradictory antagonism of goals is the strongest type of conflict where goal achievement for the one goal deteriorates that of the other goal [Erl12].
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 [Erl12].
3. The subordination of goals is possible when attainment of some goals are basically easier to accomplish than others due to their lower implementable requirements [Erl12].
4. The compatibility of goals exists if two goals can be accomplished independently [Erl12].

Though Erlach [Erl12] suggests that in some scenarios improving individual goals does not affect another goal to the same degree. The objective of production optimization is to counterbalance this four goal dimensions in such an order so that business goals are achieved efficiently at specific production sites.

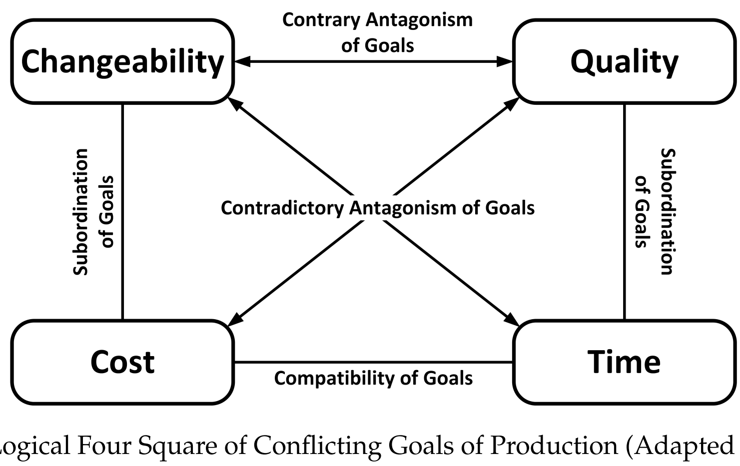

Figure 1.2.: Logical Four Square of Conflicting Goals of Production (Adapted from [Erl12])

Heng [Hen14] appraises automation, optimization, and dynamic adaptability as the most important requirements in manufacturing sector to increase the efficiency of production process. Since the dawn of sensors and networking technologies, vital information can be gathered before-hand 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. According to the suggestions of Sungur et al. [SBLW15], 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. Similarly Wieland et al. [WKNL07] recommend usage of modern world smart-systems to observe situations that will enable the application of well-adopted business process modeling and execution solutions in the context of manufacturing.

To strengthen the case, a recent sector research work by Deutsche Bank [Hen14] can be looked upon. In this research, Heng [Hen14] predicts that Germany has a major long-term opportunity to fortify itself as the leader in the global marketplace with its favorable market fundamentals. Industry 4.0 will help Germany to hold the grounds in manufacturing sector even against its fast-growing developing market competitors such as China and India. Thus Germany can remain an industrial heavyweight in the manufacturing sector being the undisputed economic powerhouse of the European Union (EU).

According to Sungur et al. [SBLW15], production processes contain both manufacturing and all associated business processes to finish production on time, whereas manufacturing processes only involve the processes to transform raw materials to final products. Wiendahl et al. [WEN+07] have depicted production process as a macro-level process whereas manufacturing process as micro-level. Both Production and 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 manufacturers might lose substantial 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 and optimized at regular intervals 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 proposed to extend a production process by 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 in runtime [SBLW15]. This approach dictates a way in which processes can possibly adapt themselves to the changing execution environment or context. All details relevant to context-sensitive workflows have been discussed thoroughly later in Chapter 3. In this thesis work, we implement the CES flow, which is actually process

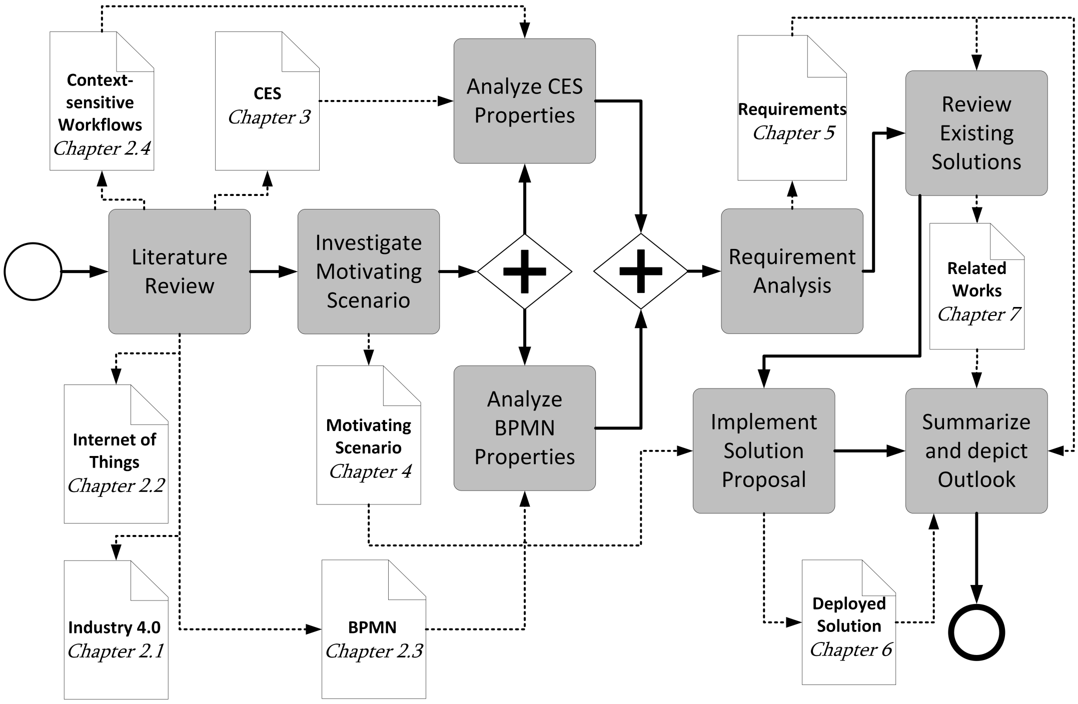

Figure 1.3.: The Thesis Methodology (Adapted from [Sun13])

language agnostic such that it can be integrated with any BPMN engine without changing the semantics of standard BPMN. We might extend the BPMN keeping its semantics intact if and only if it's needed at all and add the necessary details to make manufacturing process models executable. To create this implementation, we have analyzed the properties that make CES unique and also scrutinized important and relevant BPMN properties which might be vital during implementation of the CES. These properties are later on used to derive our requirements from which we model our implementation. A summary of the thesis work can be found below in Figure 6.1 that is discussed in the section.

1.2. Methodology and Outline

The remaining master thesis document is structured in the following way as shown in the Figure 6.1.

- *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, Internet of Things (IoT), Business Process Model and Notation (BPMN), and Context-sensitive Workflows. Main focus was to understand the current development in Industry 4.0 and it's implications in midst of the innovations in IoT technologies. Chapter 2.3 is focused upon analyzing properties of CES from the point of view of Business Process

Management (BPM), and the efficacies of BPMN. In Chapter 2.4 we analyze literature related with context and context-sensitive workflows.

- *Chapter 3 - Context-sensitive Execution Step:* Properties and operational semantics of Context-sensitive Execution Step (CES) are discussed in this chapter. After subsequent description, formal algorithm of our intended approach has been discussed.
- *Chapter 4 - 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 5 - 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 6.1. All the relevant properties and requirements for the CES have been described in this chapter.
- *Chapter 6 - 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 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 - 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 an appendix 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.

1.3. Summary

In this chapter, we have provided introduced the need of adaptability in manufacturing industry by discussing the challenges the production and manufacturing companies going to face in next decades. Even though some sections discussed here are not relevant for our main goals, they are relevant for the better understanding of the reader. Finally we have highlighted briefly the thesis methodology that we are going to follow for our research work.

2. Fundamentals

Productivity growth was barely perspicuous for much of human history and living standards improved at a snail's pace. Then in the late eighteenth century, an disruptive innovation took place: 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 late twentieth century, when Information and Communication Technology (ICT) developed further the automation of production processes. [EA12, HPO15, RLG$^+$15].

Innovations in IT world accelerated sharply the productivity and economic growth. The number of manufacturing jobs reduced, new jobs emerged and the demand for new skill-sets grew. Ar present, another workforce changeover is on the horizon as manufacturing industry is on the threshold of another technological advancement where digital virtual intelligence will augment physical machines. The conditions are full grown and early evidences manifest that this new wave of innovation is already upon us [EA12, LRS$^+$15].

In the next few sections, we discuss about how the next industrial revolution will evolve in the following decade and its benefits for business processes and more broadly for economies around the world.

2.1. Industry 4.0

According to Hermann et al. [HPO15], the term *"Industry 4.0"* became publicly familiar in 2011 at Hanover Fair, where Kagermann et al. [KLW11] - a group of industrialists, politicians, and academicians had advertised *"Industrie 4.0"* as an approach to enhance the competitiveness of the German manufacturing industry. The German Federal Government [1] supported their idea by announcing that Industry 4.0 will be an integral part of its "High-Tech Strategy 2020 for Germany[2]" initiative. A group termed as "Industrie 4.0 Working Group" was formed later and it developed and published the first draft of recommendations for its implementation in April 2013 [HPO15].

Hermann et al. [HPO15] have provided rationale for the fascination behind Industry 4.0. Firstly, Industry 4.0 is more theoretical [DH14] than empirical like the previous ones which provides possibilities to the industry and academia to shape the bright future ahead. Secondly, Industry 4.0 promises substantial increase in operational effectiveness along with revenue as well as the development of entirely new business models, services and products.

[1] Die Bundesregierung der Bundesrepublik Deutschland

[2] http://www.hightech-strategie.de/

2.1.1. Components of Industry 4.0

According to Rüßmann et al. [RLG+15], with Industry 4.0, modern ICT will transform relationship among suppliers, producers, and customers - as well as between machine and human because production processes will no longer remain isolated from each other. Industry 4.0 will change isolated flows into an integrated, optimized, and automated production flow. Rüßmann et al. [RLG+15] and Hermann et al. [HPO15] have discussed many major factors that propels this next industrial revolution among which we have listed the most important ones in our opinion.

- *Smart Factory* [3] is a context-sensitive system that assists people and machines in execution of their tasks. Smart factory is like Calm-systems that keeps on working in the background and it is context-sensitive, i.e., the system can consider information coming from physical and virtual world like the position of an object [HPO15].
- *Cyber Physical Systems (CPS)* [4] are integrated network of computation, networking and physical processes that monitor and control the physical processes with input coming from physical world and output going back to physical world too, e.g., autonomous automotive systems [HPO15].
- *Internet of Things (IoT)* [5] allows sensors and field devices to interact with each other with limited intelligence. Decentralization of business analytics and decision making is made possible in manufacturing by the usage of IoT as field devices can now act reactively to the changes in the environment [RLG+15, HPO15].
- *Internet of Services (IoS)* enables service vendors to offer their services over the internet which consists of participants, an infrastructure for services, business models, and the services themselves. Services are created using Enterprise Service-Oriented Architecture (SOA) and accessed as value-added services by consumers via various channels. In the context of Industry 4.0, IoS will offer production technologies and can either be used as manufacture process or compensation process [OH12, HPO15].
- *Big Data and Analytics* based on large data sets can be used to optimize production quality, save energy, and improve Quality of Service (QoS). As per Gartner [BL12] 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". In the context of Industry 4.0, Big Data can facilitate the collection and comprehensive evaluation of data from many different sources such as production equipments as well as management information systems which can augment and make enterprise decision making more robust and consistent [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

[3] Smart factory which thrives upon IoT is discussed in Chapter 2.2.5.
[4] CPS is explained with its architecture in Chapter 2.2.4.
[5] IoT is the prime driver of Industry 4.0 which is discussed in Chapter 2.2.

[MG11]. In the context of Industry 4.0, Cloud Computing will make increased data sharing among the devices across various production sites happen such that reaction times to changes gets reduced. More the machines data and functionality will be deployed to the cloud, more data-driven services for production systems would be available [RLG+15, HPO15].

- *Augmented Reality* based systems support a lot of services, such as sending repair instructions over mobile devices or selecting machine parts in a warehouse. Though these systems are still in their infancy, but in the future, manufacturers will use augmented reality to provide real-time information to workers at production sites to improve decision making and in some cases workers can be trained using augmented reality technologies [RLG+15].

2.1.2. Definition of Industry 4.0

From the literature review of Hermann et al. [HPO15] and Kagermann et al. [KLW11], *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 (IoS) together.

Rüßmann et al. [RLG+15] explain it in a similar way as a new industrial revolution - "*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." [RLG+15].

We will accept the first definition for our research work as it is clear, unambiguous and more consistent than the latter. This definition by Herman et al. [HPO15] portray Industry 4.0 as the facilitator of Smart Factory. In North America, General Electric [EA12] has brought similar ideas under the name *Industrial Internet*. Though the technical background is very similar to Industry 4.0, but the application is broader than just industrial production. These different names 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.

2.1.3. Enablers of Industry 4.0

Industry 4.0 is a-priori industrial revolution [DH14] and therefore manufacturers have to take empirical measures by their own selves to introduce its enablers into their production premises to gain maximum profit [KLW11]. According to Schuh et al. [SRHD15], following four enables can be categorized with respect to two dimensions as shown in Figure 2.1. The first dimension describes whether a precondition is physical or virtual, whereas the second dimension describes whether the precondition is hardware or software components. Industry 4.0 can be viewed as a collaborated production phenomenon by the inter-working of machine, human and production system.

- *Single Source of Truth* dictates to embed all product life-cycle related data along the value chain within a single central database using cloud storage and accesses to make all changes to product and production visible and avoid ambiguity during production and simulations [SRHD15].

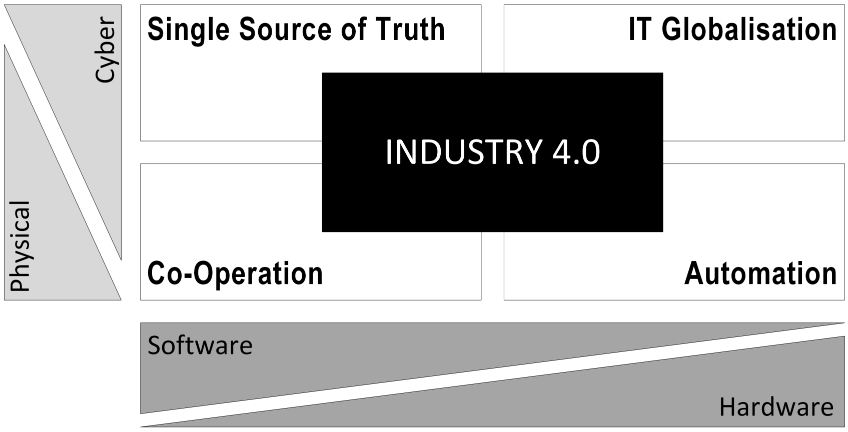

Figure 2.1.: Four Enablers of Industry 4.0 (Adapted from [SRHD15])

- *IT-Globalization* made computers achieve exponential growth in speed and cheap storage capacity. This will allow faster extensive simulations of different business processes as well as faster processing of huge amounts of data gathered by companies to get relevant information for improving the existing processes [SRHD15].
- *Automation* leads CPS to be decentralized processes which are able to adapt to dynamic requirements. Thus CPS become self-optimizing [SRHD15].
- *Cooperation* focuses upon connecting all technologies and business activities to empower decision making of decentralized CPS, e.g., efficient sharing of business process data within a network of business analysts [SRHD15, KLW11].

2.1.4. Mechanisms of Industry 4.0 that Increase Productivity

Schuh et al. [SRHD15] have discussed in their article how enablers of Industry 4.0 facilitate four mechanisms which increases the productivity significantly.

- *Revolutionary Product Life-cycles*: Rapid prototyping technologies in the context of Industry 4.0 facilitate companies to produce testable prototypes of the product so that customer feedback can be looped back into the system immediately. Process changes in such iterative model are not as cost intensive as before and therefore lead to advantages in profit and shorter production cycle time [SRHD15].
- *Virtual Engineering of Complete Value Chains*: Sophisticated software tools are available to simulate the whole production workflows which can reveal possible problems such as capacity problems within it. To get a valuable decision making capability based on simulations, it is necessary to execute a reasonable number of simulations [SRHD15].

- *Revolutionary Short Value Chains*: High individualization of products complicates the division of labor introduced by Taylorism as machines are made to accomplish one specific task. In order to manufacture individualized products, the integration of production steps within production systems can't be avoided which leads to a reversion of Taylorism, which further inflates the price. Yet there exists an optimal threshold for number of process steps in a production system which have to be incorporated to achieve minimal costs for the final product [SRHD15].

- *Better Performing than Engineered*: New innovations in technology can realize into self-optimizing systems which do exist theoretically. Such a production system would be able to reach a higher productivity level than expected due to cybernetic effects is predicted by Schuh et al. [SRHD15]. An example would be a productivity of 10,000 units whereas the estimated maximum before self-optimization was 8,000 units [SRHD15].

2.1.5. Benefits of Industry 4.0 in Manufacturing

Industry 4.0 promises a range of benefits that spans across machines, industries, and societies which will influence the broader industrial economy. Some companies have already embraced it at this early stage realizing the huge benefits it pledges. Companies now need to overcome challenges that is hindering them from adopting this new wave of change. The initial strong impact is likely to be felt in the area of advanced manufacturing as predicted by General Electric [EA12]. Lorenz et al. [LRS+15] have analyzed what Industry 4.0 has in its store for the manufacturing industry by looking at the effects that this will have on Germany's manufacturing sector, which is one among the best in the world.

- Manufacturers will be able to boost up their competitiveness that will ease the expansion of their workforce as well as the increase in productivity [LRS+15, RLG+15].

- Manufacturers won't need to off-shore the factories to developing countries anymore as the labor cost advantages of those locations will be certainly nullified [LRS+15].

- Manufacturers will be able to create new jobs to cope up with the higher demand resulting from the new individualized products and services [RLG+15, EA12, LRS+15].

- Manufacturers can have robot-assisted production units that will reduce most number of jobs on the shop floor [LRS+15].

- The factory workforce will require less training for machine operation and production since production system will require very little manual intervention which will be highly automated fitted with augmented reality measures [LRS+15].

- Manufacturers in developed countries can maintain their productivity despite the aging workforce by the use of automation to assist workers with manual tasks, e.g., a robot could lift a car's interior-finishing elements, such as a roof lining, into the chassis after manual alignment by an aging worker [LRS+15].

- Technology-assisted predictive maintenance would be enabled by Industry 4.0, e.g., a technician can identify defects and order spare parts just by remotely reviewing real-time sensor data on machine performance. Later, while making repairs, the technician can be assisted by augmented-reality technology in addition to the automatically documentation of whole process [LRS+15].

- *Capital costs* can be reduced through value-chain optimization, *energy costs* can be cut by smart control of production facilities, and *personnel costs* can be brought down with highly automated production processes promised by Industry 4.0, which will make manufacturing more cost-efficient than before [Hen14].

Accroding to Heng [Hen14], Industry 4.0 implementation will be tailor-made for each company and cannot be supplied as "off the shelf" package. Deutsches Forschungszentrum für Künstliche Intelligenz (DFKI), Fraunhofer, and companies such as Bosch Rexroth, Daimler, Siemens, Hewlett-Packard (HP), SAP, etc. have already shown the varied benefits associated with Industry 4.0 developing various projects [Hen14].

According to Lorenz et al. [LRS+15], Industry 4.0 might become cause for job losses for some categories of work, such as assembly and production planning. But categories such as IT and analytics will gain as more people from these fields would be required to oversee the production. To realize the enormous promises of Industry 4.0, Governments need to strengthen their support to their economies and industries, academia need to close the IT skills gap, and early enabling companies need to retrain their workforce to remain updated and support this next wave of revolutions going forward by guiding late adopters [EA12].

2.2. Internet of Things

The Internet revolution in the twenty-first century led to the interconnection between people at an exceptional scale and pace. The number of interconnected devices is expected to reach 24 billion devices by 2020 as per the estimates by [GBMP13]. Industry 4.0 is leveraging the creation of a smart environment by connecting objects with objects. The future is thriving upon a new era of ubiquity, i.e., Internet of Things (IoT) era in which human-thing communications and thing-thing communication themselves will be of prime importance [TW10].

Kevin Ashton [Ash09] had coined the term *"Internet of Things (IoT)"* in the context of supply chain management in 1999. Since then, the definition of IoT has covered wide range of applications, e.g., transport, health-care, utilities, etc. Kevin Ashton [Ash09] had predicted that the recent advances in sensor technology will enable computers to sense and act upon the physical world without any intervention of human. According to Gubbi et al. [GBMP13] integrated *Sensor–Actuator–Internet* framework will be the core technology behind IoT based smart environment. Gubbi et al. [GBMP13] further propose that only Cloud Computing can fulfill the requirements of the next generation IoT applications since it can provide reliable ubiquitous access, dynamic resource discovery and flexibility of choosing different service levels.

2.2.1. Definition of Internet of Things and Its Trends

IoT is a very broad vision and the research into the IoT is still in its infancy. Therefore, there are not any standard definitions for IoT. The following definitions were provided by different researchers.

Xia et al. [XYWV12] put forward a general IoT definition in their editorial - "*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." [XYWV12].

Gubbi et al. [GBMP13] explain IoT from the point of view of the Cloud applications - "*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." [GBMP13]. Tan et al. [TW10] define IoT focusing mainly upon its functionality

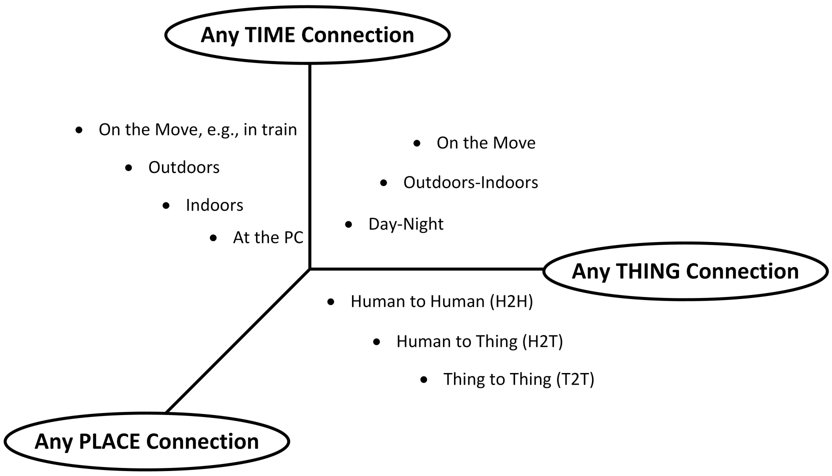

Figure 2.2.: IoT Dimensions (Adapted from [TW10])

and identifies IoT as a new dimension that has been added to the world of ICT, i.e., from any *Time*, any *Place* connectivity for anyone to now connectivity for any *Thing* as shown in Figure 2.2 - "*IoT*s have identities and virtual personalities operating in smart spaces using intelligent interfaces to connect and communicate within social, environment, and user contexts." [TW10].

Similarly the Cluster of European Research Projects [SGFW10] explains Internet of Things in a more abstract manner - "In the *IoT*, *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." [SGFW10].

We accept the definition provided by Xia et al. [XYWV12] for our research work, because we believe, this definition encapsulates the broader vision of IoT.

Gartner [RvdM15] defines a *Hype Cycle* as "a way to represent the emergence, adoption, maturity, and impact on applications of specific technologies". 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 2.3. As per its estimation IoT will take five to ten years for market adoption. In recent years, IoT has gained much attention from researchers, academia and industries from all over the globe [RvdM15, XYWV12].

2.2.2. Elements of Internet of Things

IoT is a technological revolution that represents the future of ICT [TW10]. Ubiquitous Computing (Ubicomp) is the method of enhancing computer usage such that it will be omnipresent in the physical environment, yet mostly invisible to the user [Wei93]. According to Gubbi et al. [GBMP13], three IoT components enable the scene behind seamless Ubicomp: (i) *Hardware* made up of sensors, actuators and embedded communication hardware, (ii) *Middleware* [ICG07] like on demand storage and computing tools for data analytics, and (iii) *Presentation* for user-friendly intuitive visualization and interpretation tools that can be widely accessed on different platforms. Things can be connected wired or wireless [GBMP13]. Base on the existing ICT infrastructure, there are many ways to connect a things, e.g., Radio Frequency Identification (RFID), Wireless Sensor Network (WSN), WiFi, 3G Universal Mobile Telecommunications System (UMTS), 4G Long-Term Evolution (LTE), etc. Here we discuss two few enabling technologies, i.e., RFID and WSN in brief for the sake of our research work.

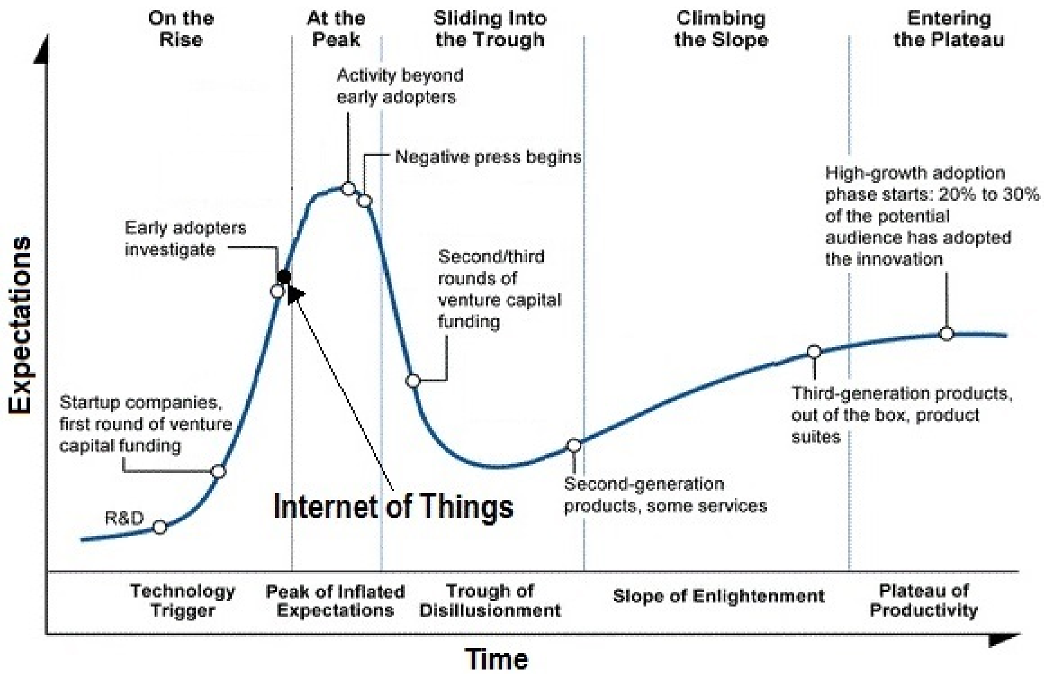

Figure 2.3.: IoT in Gartner Hype-cycle - 2015 (Adapted from [Bro11, RvdM15])

- *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 [MWZ+07, TW10]. The passive RFID tags without own power source are pretty common in supply-chain, bank cards, inventory management and road toll tags. Active RFID readers with own power source are mostly used in port containers for monitoring cargo [GBMP13, MWZ+07].

- *Wireless Sensor Network (WSN)* is a dynamic, ad-hoc sensor network that comprises tiny, low-cost, and low-power sensor nodes communicating between themselves using only wireless technologies. Some of the application areas of WSN are health, military, and security, e.g., 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 [SSOK13, ASSC02, GBMP13].

2.2.2.1. Addressing Schemes

According to Gubbi et al. [GBMP13], unique identification of *Things* is critical to uniquely identify and control billions of devices remotely through the Internet. Uniform Resource Identifier (URI) gives the most convenient approach to uniquely address each and every sensor nodes. Internet Protocol version 6 (IPv6) can work as an URI to access the resources uniquely and remotely [GBMP13].

2.2.2.2. Storage, Analytics and Visualization

According to Gubbi et al. [GBMP13], the data accumulated by IoT devices have to be stored, analyzed and visualized using a centralized infrastructure, i.e., Cloud Computing. State-of-the-art techniques, e.g., r, temporal machine learning methods, genetic algorithms, neural networks, and other artificial intelligence (AI) are capable of making decisions. Similarly, visualization enables business experts to convert raw data into business knowledge, which is most important in fast decision making. Extracting such meaningful information from raw data is the most significant challenge [GBMP13].

2.2.3. Internet of Things Architecture

According to Tan et al. [TW10], IoT is an application technology which will give us reliable ubiquitous access can't be designed and deployed over a five-layered TCP/IP architecture. In the IoT billions of nodes are connected which will create much larger traffic and need much more data storages. Gubbi et al. [GBMP13] discuss that IoT can be seen from two perspectives, i.e., *Internet-centric* and *Thing-centric*. The *Internet-centric* architecture will revolve around internet services while data is contributed by *Things*. In the *Thing-centric* architecture, smart objects take the center stage [GBMP13]. Tan et al. [TW10] propose of an Internet-centric approach in their research work.

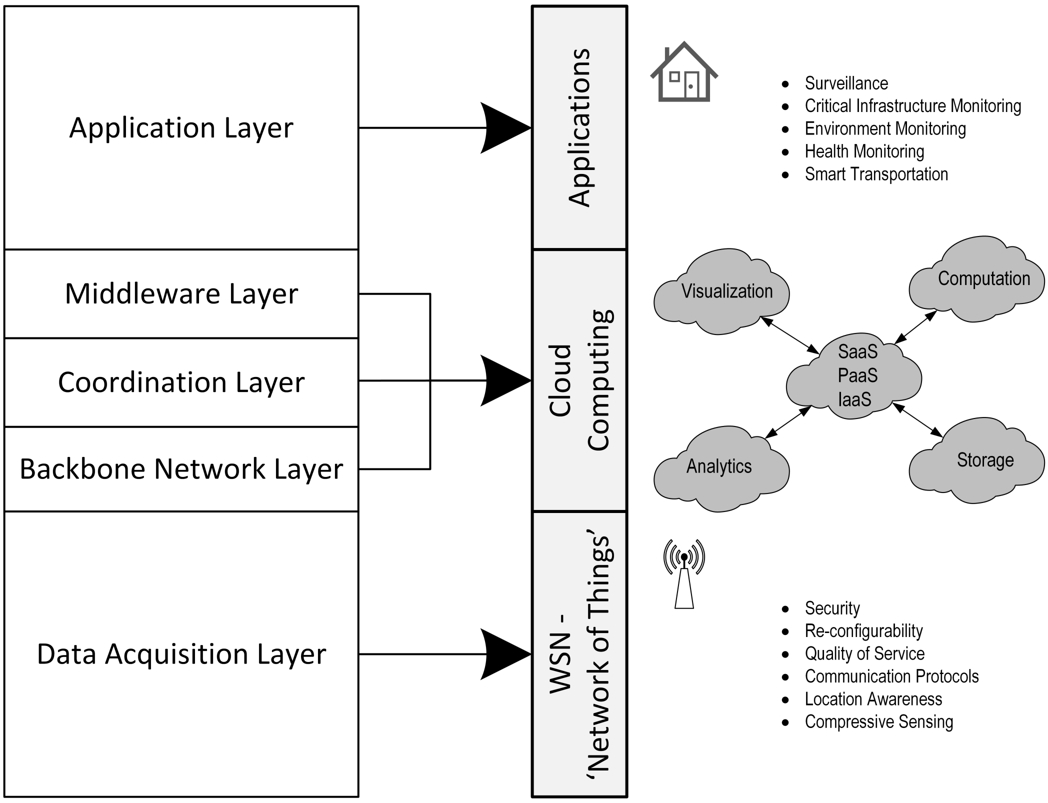

Figure 2.4.: Conceptual IoT Architectural Framework (Adapted from [TW10, GBMP13])

A simpler conceptual framework shown in Figure 2.4 [678] is inspired from architecture proposed by Tan et al. [TW10] that integrates the ubiquitous sensor nodes and the applications is of our interest. It also satisfies the proposition laid out by Gubbi et al. [GBMP13] that realization of the full potential of Cloud Computing and Ubicomp is most viable by combining two approaches with a cloud at the center.

The *Backbone Network Layer* can be thought as the Internet of present day or its expansion. The *Coordination Layer* processes the data received out of different application systems in an unified structure so that the application system becomes inter-operable among the already existing systems and the newly deployed systems [TW10]. Middleware is a software layer that provides reusable solutions to application layer such that gathered data can be reused seamlessly [ICG07, TW10]. As per our evaluation of the model, the three layers in the middle (Middleware, Coordination and Backbone Network) of Tan et al. [TW10] can be integrated and realized as a single layer of Cloud Computing as proposed by Gubbi et al. [GBMP13]. Gubbi et al. [GBMP13] further mention that sensor providers can offer their data using a storage cloud; analytic tool developers can provide their software tools; AI experts can provide their data mining tools and computer graphics designers can offer their visualization tools as Infrastructures, Platforms, or Software over a cloud.

[6] IaaS = Infrastructure as a Service
[7] PaaS = Platform as a Service
[8] SaaS = Software as a Service

Among other researchers, Perera et al. [PZCG14] propose a different architectural approach, i.e, *event-driven* and *time-driven* for IoT applications, e.g., door sensor produces data when an event occurs whereas temperature sensor produces data continuously at specific intervals.

2.2.4. Cyber-Physical Systems

Cyber-Physical Systems (CPS) are “integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa.” [Lee08]. CPS are being used almost everywhere, e.g., medical equipments, driver safety systems for automobiles, industrial automation systems etc. [Jaz14].

According to Jazdi [Jaz14], a typical CPS consists of a control unit and usually one or more μController(s). The μController is responsible for controlling the sensors and actuators to communicate with the physical world and further it processes the data gathered by the control unit as shown in Figure 2.5. A CPS may need to communicate with other CPS or a Cloud over a communication interface. Jazdi [Jaz14] goes on to define CPS as an embedded system capable of exchanging data over a network. Thus sometimes CPS connected to the Internet and IoT are regarded as same things.

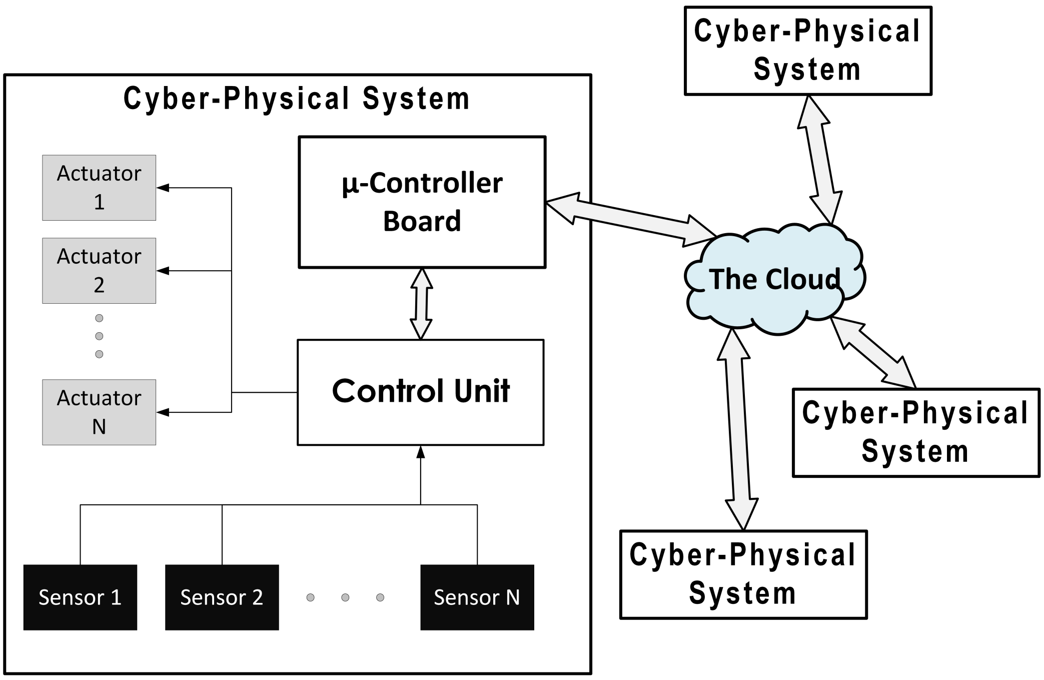

Figure 2.5.: Conceptual Architecture of a CPS (Adapted from [Jaz14])

Ultimately CPS requires three components as pointed out by Drath et al. [DH14] similar to the explanations of Jazdi [Jaz14]: "(i) the physical objects, (ii) data models of the mentioned physical objects in a network infrastructure, and (iii) services based on the available data." [DH14]. Drath et al. [DH14] opine that CPS will ease out the interconnection, integration, testing and simulation components and products in industrial production. This will ascertain

CPS as one of the prime technology drivers of Industry 4.0 - the forthcoming industrial revolution [RLG+15].

2.2.5. Smart Factory

Production processes and the supply-chain in the manufacturing industry can be further improvised by CPS and IoT technologies. As suggested by Dais in a conversation with Löffler et al. [LT13], innovating truly new technologies and finding competent human resource for robust algorithm design can together leverage the rise of Industry 4.0. More and more industries will continue to have separate design and production processes where supply-chain integration will play a decisive role [LT13].

Lean Production principles discussed by Shah et al. [SW07] are popular in industries that is intended for removal of waste out of production processes by continuous improvement and emphasis on value adding activities. If a plant implements lean manufacturing, CPS monitor physical processes and make decentralized decisions by communicating and cooperating with each other and human over the IoT. IoS provides services that are utilized by participants of the value chain [HPO15]. As a result, a factory becomes *"Smart Factory"* [KZ15, LT13].

Lucke et al. [LCW08] define Smart Factory as "a context-sensitive manufacturing environment that can handle turbulences in real-time production using decentralized information and communication structures for an optimum management of production processes." [LCW08]. The department of Innovative Factory Systems (IFS) at the German Research Center for

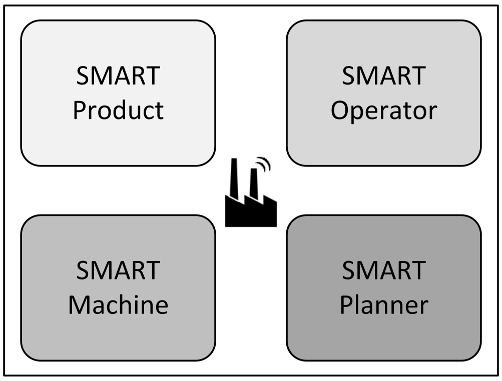

Figure 2.6.: Enablers of Smart Factory (Adapted from [KZ15])

Artificial Intelligence (DFKI) identified four enablers as shown in Figure 2.6 for the *Smart Factory* [KZ15]:

- *Smart Operator* could administer ongoing activities in ease equipped with smart sophisticated tools, e.g., CPS can auto-detect failures and trigger repair steps [KZ15].
- *Smart Product* could collect precise process data for the analysis during and after its production which is less labor-intensive [KZ15].
- *Smart Machine* like CPS could be integrated into error-prone production process to make it modular and flexible [KZ15].

- *Smart Planner* could optimize processes in real-time, e.g., CPS can optimize a production process by different business objectives, like time, cost or efficiency [KZ15].

As suggested by Derenbach in a conversation with Löffler et al. [LT13], it's impossible to separate the physical world from business processes, hence translation of physical world to a IT understandable format will require deep insights of mathematical, domain and market know-how. Interdependencies among the manufacturing components and manufacturing environment will be dominated by the usage of ICT [LT13]. In the context of Industry 4.0, the combination of industrial automation and Lean Production can be instrumental as discussed above and Smart Factory is such a case in point [KZ15].

According to Landherr eta al. [LC12], planning and optimization of manufacturing processes with IoT enabled CPS is of a very interdisciplinary nature because manufacturing experts have very limited interest in ICT and ICT experts don't have adequate knowledge of the manufacturing processes [LC12].

2.3. Business Process Model and Notation

Business Process Model and Notation (BPMN) is is a standard visual notation for capturing business processes in a business process model [DDO08]. Business Process Management Initiative (BPMI.org) developed BPMN, which has been maintained by the Object Management Group (OMG) since both merged their respective Business Process Management (BPM) activities in June 2005. Version 2.0 of BPMN was released in January 2011 and the name was adapted to *Business Process Model and Notation* from *Business Process Modeling Notation* as execution semantics were also introduced alongside the notational and diagramming elements. Hereafter BPMN 2.0 will be used interchangeably with BPMN [OMG11].

2.3.1. Motivation for Choosing BPMN

Kiper et al. [KAA97] observe that it's easier for non-programmers, e.g., business experts to model their business processes in a graphical (pictorial) way. Though Unified Modeling Language (UML) [OMG15] is an already established standard by and its behavioral diagrams such as activity diagrams are suitable for visual depiction, UML is not aimed for modeling business processes rather software systems. Business experts would prefer an executable model for workflow modeling which is not provided by UML. For such situations BPMN is suitable, because BPMN has its operational semantics [Sun13, OMG11].

Because the business processes reflected in our research work will be executable business processes on workflow engines, we opt for BPMN to model such processes. BPMN has the characteristics that satisfy our requirements, i.e.,

- BPMN has a well-known visual representation and is commonly used as it inherits and combines elements from earlier proposed notations for business process modeling such as XML Process Definition Language (XPDL) [WFM12] and the activity diagrams component of UML [DDO08].

- BPMN is executable [OMG11].
- There are many open-source workflow engines which support BPMN are available, e.g., Activiti[9], Stardust[10], Camunda BPM[11], etc.
- BPMN is highly intuitive especially at the level of domain analysis and high-level systems design from business expert's point of view that bridges the gap between business- and ICT experts as mentioned by Dijkman et al. [DDO08] in their work.
- BPMN can be extended in case it is needed [OMG11].
- Direct mapping from BPMN to Business Process Execution Language (BPEL) [OAS07] is possible to some extent for which execution engines and formalizations exist. BPEL is an Organization for the Advancement of Structured Information Standards (OASIS) standard executable language for specifying actions within business processes with web services [WvdAD+06, OAS07].

However, standard BPMN might be an abstraction and an extension might be needed to address domain specific properties of CES construct which is going to be discussed in Chapter 2.4.

2.3.2. Properties of BPM and BPMN

BPMN is the de-facto standard for representing in a very expressive graphical way and most business experts model their business processes mostly using BPMN [CT12]. The current BPMN models are treated to be more readable, flexible and expandable than before [Sun13]. In this section, we will give some properties of general BPM concepts and BPMN.

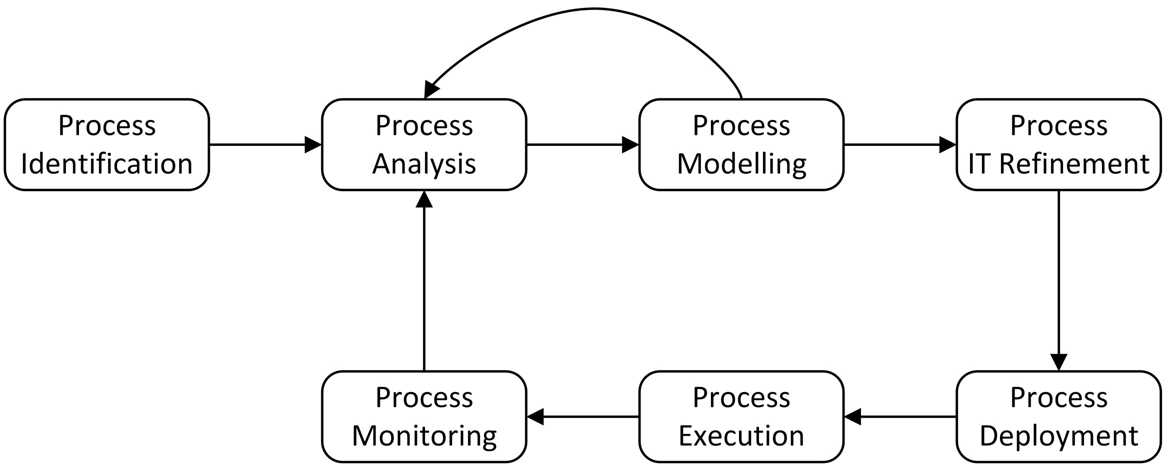

Figure 2.7.: BPM Life-cycle (Adapted from [DLRMR13, LR00])

[9] http://www.activiti.org/
[10] https://www.eclipse.org/stardust/
[11] https://camunda.org/

2.3.2.1. Dimensions of Workflows (BP1)

Hollingsowrth [Hol95] defines *Workflow* as "the computerized facilitation or automation of a business process, in whole or part." [Hol95]. The BPMN users can orchestrate their workflows as the new version 2.0 of OMG standard BPMN has its operational semantics and can be executed on its own workflow engine [Ley10]. The life-cycle of a business process is shown in Figure 2.7. In general, we need three dimensions to define workflow items of any workflows [LR00]:

- *"What"*: What is the work item?, e.g., 'Check Sensor Status'.
- *"With"*: With what should this work item be accomplished?, e.g., 'a Web Service'.
- *"Who"*: Who will work upon this work item?, e.g., 'A Machine or Human'.

2.3.2.2. Hierarchies of BPMN Modeling (BP2)

Conceptually BPMN has 3 levels of modeling, i.e., *Descriptive Modeling (L1)*, *Analytical Modeling (L2)* and *Executable Modeling (L3)*. L1 documents the workflows within a process model using basic BPMN shapes by describing the order of activities and the role or organization performing them. L2 documents the process in an unambiguous manner following BPMN semantics and validation rules. In L1, there can be errors in the model whereas in the L2 there is expected to be no errors. L3 targets the developers by adding language based execution details in the meta-model underlying the scheme. The generated BPMN serialized file is executed on a business process engine and it orchestrates defined set of activities [Sil11, OMG11].

2.3.2.3. Flexibility of BPMN Models (BP3)

Weske [Wes12] views business process models as the representations of internal business processes which can executed by automated execution engines. Such business models need to be refined and optimized after each execution. BPMN provides ways to alter the business models, that will be effortless for a business expert [OMG11, Sun13].

2.3.2.4. Extensibility Mechanism of BPMN (BP4)

For certain domain specific applications, modeling elements of BPMN might not be sufficient. In these circumstances domain experts tend to extend BPMN meta-model to capture a better manifestation of their own application domains [Sun13, OMG11]. Generally, it can be achieved in two ways, i.e.,

- BPMN extensions are done by adding new elements and attributes to existing BPMN elements such that they do not contradict with already existing elements and attributes. This approach guarantees interchangeability of existing BPMN constructs. It's often done by defining desired properties in an external schema and referencing this schema from the internal schema [OMG11, AtAC15].

- There are some BPMN open-source vendors, e.g., Activiti, Stardust, etc. who have their own workflow engines. Such BPMN vendors provide certain extensions points that they think will be useful in most of the business scenarios [AtAC15, Com15].

2.3.2.5. Cognitive Potency of BPMN (BP5)

The cognitive efficacy of any visual notation is most important for a better common understanding. Genon et al. [GHA11] analyzed BPMN using principles of the 'Physics of Notation' theory of Moody [Moo09] and how BPMN provides cognitive effectiveness is explained including its drawbacks. BPMN constructs are evaluated to have a one-to-one relation with its semantic description which satisfies the property of 'Semiotic Clarity', one of the prime factors that make a notation more intuitive [Moo09, GHA11].

2.4. Context-sensitive Workflows

Business workflows can be defined, managed and executed through a diversity of software-integrated systems by employing *Workflow Management Systems* (WFMS) that is driven by a workflow logic [Hol95]. Industrial production processes communicate with physical world with IoT nodes so that they can adapt to their environmental changes. Such dynamic workflows will facilitate manufacturing processes to be more intelligent which can adapt to changing situations in runtime [WKNL07]. We will define few terms here which will be used throughout research work.

2.4.1. Definitions of Context and Context-sensitivity

Workflow technology should be able to handle information about the physical world, referred as *"Context"* [WKNL07]. The most general definitions that is provided by Abowd et al. [ADB+99] can be relevant for our further research work - "*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." [ADB+99].

A workflow that considers context is called *"Context-sensitive"*. Many researchers refer such workflows as *"Context-aware"* workflows. Hereafter Context-aware will be referred interchangeably with Context-sensitive. Abowd et al. [ADB+99] refer a system as *Context-sensitive* "if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task". [ADB+99].

Henricksen [Hen03] defines *"Context Attribute"* as an element of the context model that describes the context. A context attribute has an identifier, a type and a value, and optionally a collection of properties that can be treated as the building block of a meaningful context, e.g., <sensor-name, sensed-value> key-value pair can be a context attribute for a sensor node. [PZCG14]. The basis for context-sensitive workflows is context information such as the GPS position of workers and components, the state of all factory objects etc. Context data is sensed via sensor modules mounted to the components [WKNL07].

2.4.2. Context Management Life-cycle

A context life-cycle shows how context move from phase to phase in a context-sensitive software system or WFMS. In this section we discuss about the movement of context in Context-sensitive systems. In simplest terms, Perera et al. [PZCG14] describe the context life-cycle in four phases as shown in Figure 2.8 [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 realized using two methods, i.e., 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, i.e., *instant events* which don't span across certain amount of time, e.g., switching a light, and *interval events* that span a certain interval 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 provide 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].
- **Context Modeling**: The acquired data needs to be modeled and represented in terms of previously specified context, QoC attributes and the queries for context requests. After the validation of initial data, the context data can be pushed to an existing context repository. Perera et al. [PZCG14] have mentioned and compared many methods to model context data, e.g., *Key-Value Scheme*, *Markup Scheme (e.g., Extended Markup Language (XML))*, *Graphical* (e.g., databases), *Object-based*, *Logic-based*, *Ontology-based* etc.

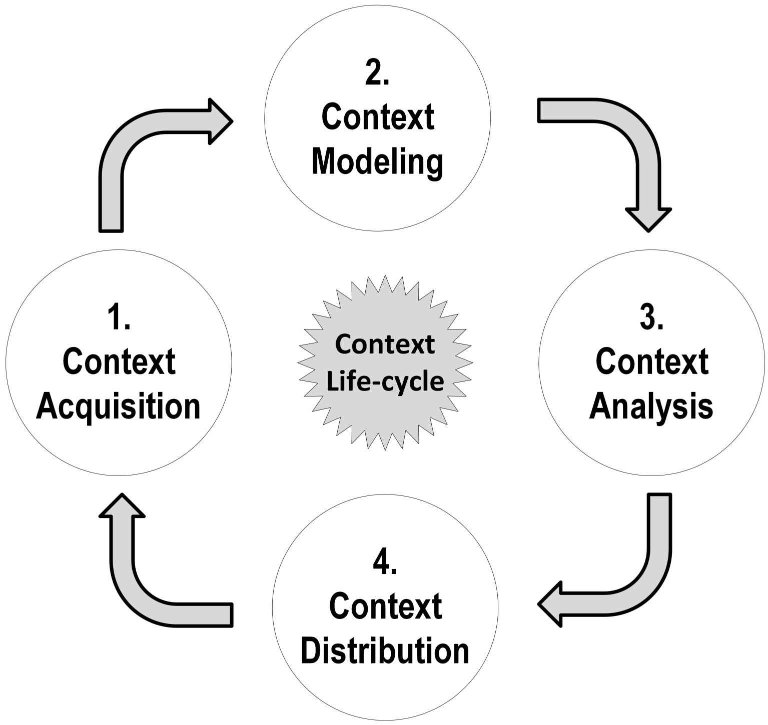

Figure 2.8.: Context Life-cycle (Adapted from [PZCG14])

- **Context Analysis**: This phase is primarily meant for the cleaning of sensor data, consolidation of multiple sensor data and inferencing preliminary high level information from using lower-level context such that any remaining uncertainty and imperfection gets removed. Many different context reasoning decision models exist, e.g., *Decision Tree*, *hidden Markov Models*, *k-Nearest Neighbor*, *Neural Networks*, *Ontology-based*, *Fuzzy logic* etc [PZCG14].
- **Context Distribution**: Finally, the context data needs to be delivered to the context consuming software 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].

2.4.3. Definitions of Context- Query, Event, Condition and Decision

Now we have reached the stage where we can define few more definitions proposed by Wieland et al. [WKNL07] which will be used across this research work.

- *Context Query* is a synchronous query designed in a specific query language, which supports object selection based on spatial predicates and filtering of the results, to access context data from context repository or database [WKNL07].
- *Context Event* is an asynchronous event triggered by change in context being monitored. The listening for this special environment state is done in parallel to the normal workflow [WKNL07].

- *Context Condition* is a predicate or operator in a specific language, e.g., XML Path Language (XPath) [W3C15] upon which context-decisions are evaluated [WKNL07].
- *Context Decision* is used to route process control flow based on context data using context-conditions [WKNL07].

2.5. Summary

In this chapter, we have provided background on Industry 4.0, IoT, BPMN and general Context-sensitive workflows. Even though some sections discussed here are not relevant for our main goals, they are relevant for future reference and we need to keep them in our minds during the process of the implementation.

- **CPS** are "integrations of computation and physical processes. Embedded computers and networks monitor and control the physical processes, usually with feedback loops where physical processes affect computations and vice versa" [Lee08].
- **Smart Factory** is "a context-sensitive manufacturing environment that can handle turbulences in real-time production using decentralized information and communication structures for an optimum management of production processes" [LCW08].
- **IoT** is "a 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" [XYWV12].
- **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 (IoS) together" [HPO15, KLW11].
- **BPMN** is the de-facto standard for representing in a very expressive graphical way and most business experts model their business processes mostly using BPMN [CT12].
- **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" [ADB+99].
- **Context-sensitive** system is "a system that uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [ADB+99].
- **Context Query** is a synchronous query designed in a specific query language, which supports object selection based on spatial predicates and filtering of the results, to access context data from context repository or database [WKNL07].
- **Context Decision** is used to route process control flow based on context data using context-conditions [WKNL07].

3. Context-sensitive Execution Step

According to Perera et al. [PZCG14], IoT envisions a generation where thousands of sensor nodes would be deployed throughout manufacturing facilities connected over Internet and only Context-sensitive applications can decide which sensor devices to look for in an era of pervasive and ubiquitous computing. This enthralled many researchers and engineers across various disciplines to design prototypes, methods, or systems using Context-sensitive techniques. Similarly Sungur et al. [SBLW15] propose an approach by which manufacturing companies can remain competent in the ever changing global market by having an adaptive production process which is Context-sensitive too.

3.1. Definitions and Facets of Context-sensitive Execution Step

The approach introduced by Sungur at al. [SBLW15] presents the capability of capturing new information and adapting to it with an innovative modeling of manufacturing activities and manufacturing know-how. Before diving into any more conceptual details, we will define the basic terms that governs this approach.

Sungur et al. [SBLW15] propose a new process modeling construct named *"Context-sensitive Execution Step (CES)"*. Though CES constructs are visioned as sub-process structures of BPMN, we visualize it as BPMN task structures that are activated when the incoming flows are activated upon some conditions. Primarily a CES task contains its own input data and output variable to hold its generated output. A meta-model proposed by Sungur at al. [SBLW15] is adapted to our requirements can be seen in Figure 3.1.

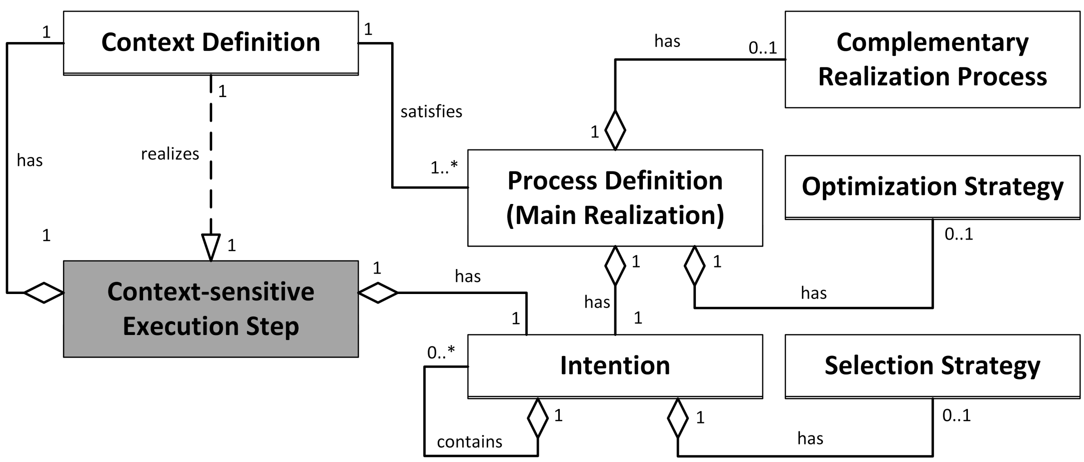

Figure 3.1.: Meta-model of a CES (Adapted from [SBLW15])

As depicted in Figure 3.1, a CES can be associated with following facets related to Context-sensitive modeling, i.e.,

- *Context Definition* specifies the required Contexts (C_i) and related Context Conditions (σ) that will validate an underlying process definition in a certain scenario and thus makes CES adaptive, e.g., repairing a machine if its sensor senses so [SBLW15].
- *Main-Intention* contains the prime goal of the process, e.g., performing a specific task which is very specific in nature [SBLW15].
- *Sub-Intentions* are the refined intentions, i.e., sub-goals that will be associated with a Main-intention to model a certain business requirement, e.g., high automation or high maintenance activity etc. [SBLW15].
- *Process Definitions* (N_i) are the main realization processes to achieve all defined intentions. A Context Definition can satisfy multiple process definitions by satisfying a set of correlated intentions (δ), e.g., different process models to achieve same target [SBLW15].
- *Complementary Realization Processes* (β) are the processes that are emphasized to run during the realization of main process definition for better business value and quality, e.g., a maintenance routine to take care of the machines [SBLW15].
- *Selection Strategy* (Ω) is used for choosing between multiple processes with same goals and Context Definitions that are generally contained by Main-intention, e.g., choosing a process based upon its probabilistic weight determined heuristically [SBLW15].
- *Optimization Strategy* (α) provides means of an automated optimization of the process to be run, e.g., an activity of optimizing resources before the main business process starts [SBLW15]. Providing dynamic flexibility or optimization during the execution of a BPMN model is out of the scope of our research work.

The set of all required contexts for the activation of a CES entity is denoted as RC. Similarly all defined intentions of a CES entity that consists of its Main-intention and Sub-intentions are denoted by a set GO.

3.2. Operational Semantics

As per the specifications of Sungur et al. [SBLW15], after the activation of a CES construct, the execution goes along with the flow shown in Figure 3.2. A CES can wait for its initial input data (if it exists) (S1.1), else it can directly reach the step where it gathers Contexts from some source (S1.2). CES must avoid any non-existing data usage as that might not be available in runtime.

If no Context Definition has been found, the process behaves as if all the underlying process alternatives satisfy the cause and execution proceeds to the Intention matching step (S3). Otherwise, the available Context Definitions are evaluated to the gathered Contexts (S2) and the context-satisfying set of processes (P_c) are sent for Intention matching (S3). After the matching process of Intentions of all the processes, a set of intentions-satisfying processes (P_g) are generated, and the processes that are present in both P_c and P_g are sent for redundancy check (S4). If there are more than one process definitions for reaching a Main-intention is available, elimination is carried out based upon some Selection Strategy (Ω). If Ω is not available and Optimization Strategy (α) is available, execution goes to optimization phase (S5). Otherwise, selected process definition goes for execution and deployment in the last step without any intermediate optimization (S6). Sungur et al. [SBLW15] again propose

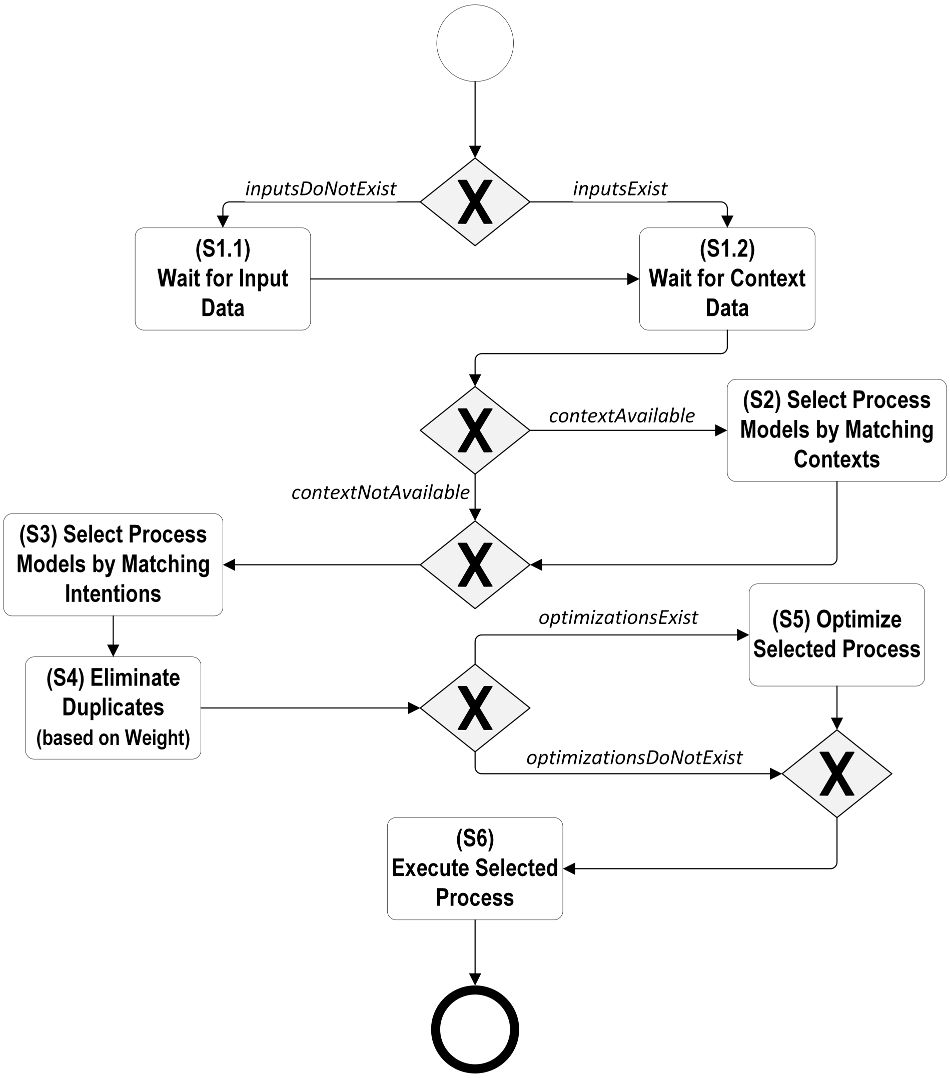

Figure 3.2.: Operational Semantics of a CES (Adapted from [SBLW15])

the semantics for the successful execution criteria for a CES task. After the completion of a main realization process, complementary realization processes are enacted by the workflow engine. If the main realization process has succeeded and associated complementary process terminates unexpectedly, the execution is termed successful with a warning [SBLW15].

We can formalize the whole operational semantics in the form of an algorithm for better understanding as shown in Algorithm 3.1. Prior to that, we will define *Process Definitions Repository (PR)* that contains process definition descriptor (d), Context Conditions (σ), Complementary Realization Processes (β), Selection Strategy (Ω) and Optimization Strategy (α). *Context Store*

(CS) will store Contexts as key(k)-value(v) pairs, i.e., $CS = (\{C_i\})_{i\in[1,n]} = \{(k,v)\}$. Explicit input data set and output variable set will be denoted as *IN* and *OUT* respectively. *OUT* will contain final result to be returned to the callee or workflow engine (λ) and success identifier (μ). μ assumes the value 1 if CES entity executes successfully, 0 otherwise.

Algorithm 3.1 Pseudocode for Operational Semantics of a CES

Input/Precondition:
Set $PR = (\{N_i\})_{i\in[1,n]} = \{(d,\sigma,\delta,\beta,\alpha,\Omega)\} \neq \phi$, Set $GO \neq \phi$, Set $RC \neq \phi$ and Set IN.
Output/Postcondition:
Set $OUT = (\lambda, \mu)$

procedure EXECUTECES(GO, RC, IN, PR) ▷ GO, RC, IN, and PR are the input data
    $OUT(\lambda) \leftarrow \phi$, $P_g \leftarrow \phi$, $P_c \leftarrow \phi$
    $OUT(\mu) \leftarrow 0$, $initCon \leftarrow true$
    for all $context \in RC$ **do** ▷ Get value of each Required Context
        $value \leftarrow \text{GETCONTEXT}(context)$ ▷ This will query Middleware
        if $value \neq -1$ **then**
            $CS_i.k \leftarrow context.name$ ▷ Storing fetched Data in CS
            $CS_i.v \leftarrow value$
        else
            $initCon \leftarrow false$ ▷ No Context Available
    for all $cond \in N_i.\sigma \wedge initCon = true$ **do** ▷ Context Matching
        $conVal \leftarrow \text{EVALUATE}(cond)$ ▷ Evaluate Context Conditions
        if $conVal = 1$ **then**
            $P_c \leftarrow P_c \cup N_i.d$ ▷ Store Process Descriptors
    for all $goal \in GO \wedge \exists N_i \mid goal \in N_i.\delta$ **do** ▷ Goal/Intention Matching
        $P_g \leftarrow P_g \cup N_i.d$ ▷ Store Process Descriptors
    $P_g \leftarrow P_g \cap P_c$ ▷ Filtering Mutually-exclusive Processes
    for all $id \in P_g \wedge \exists N_i \mid id = N_i.d$ **do** ▷ Process Selection
        if $N_i.\Omega \neq \phi$ **then**
            $proDesc \leftarrow \text{STRATEGYSELECT}(P_g, PR)$ ▷ Select based on Strategy
        else
            $proDesc \leftarrow \text{RANDOMSELECT}(P_g)$ ▷ Select randomly
    if $proDesc.\alpha \neq \phi$ **then** ▷ Checking Optimization Strategy Existence
        $\text{OPTIMIZE}(N_i.\alpha)$ ▷ Execute Optimization Process
    $OUT(\lambda) \leftarrow \text{RUN}(proDesc, IN)$ ▷ Execute Main Realization Process
    $OUT(\mu) \leftarrow 1$ ▷ Successful execution
    $\text{RUN}(proDesc.\beta)$ ▷ Execute Complementary Realization Process

In our proposed implementation, we would like to have a Selection Strategy based upon *Weights* (Ω_W) (statistical probabilities) associated with each of the process alternatives. These weights can be assigned to a process heuristically or by auditing the past logs of processes in execution and thus arriving at a value statistically. Sometimes it's better to have a CES system with a naive selection strategy shown in Algorithm 3.2 than nothing at all.

Algorithm 3.2 Pseudocode for a naive Selection Strategy based on Weights

Input/Precondition:
Set $PR = (\{N_i\})_{i \in [1,n]} = \{(d, \sigma, \delta, \beta, \alpha, \Omega)\} \neq \phi$, Set P containing process descriptors.
Output/Postcondition: *procDesc*, descriptor of the chosen selected process.

procedure STRATEGYSELECT(P, PR) ▷ P and PR are the input data
  $maxWeight \leftarrow 0$
  for all $id \in P_g \wedge \exists N_i \mid id = N_i.d$ **do** ▷ Process Selection Step
    if $N_i.\Omega_W \geq maxWeight$ **then**
      $maxWeight \leftarrow N_i.\Omega_W$ ▷ Change Maximum Weight
      $proDesc \leftarrow N_i$ ▷ Assign Process Descriptor

3.3. Context-sensitive Manufacturing Processes

As per Sungur at al. [SBLW15], if we integrate CES with a standard manufacturing process, the latter will becomes *Context-sensitive Adaptive Manufacturing Process*. One of the important activity of BPM life-cycle is process identification. After the identification and analysis of production processes the variable parts of any production process can be defined as CES along with its input data, Main-intention etc. Realization processes are added to a central repository so that CES can look for these process in it and deploy one of the available processes satisfying the Context Definition [SBLW15].

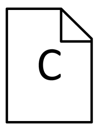

Figure 3.3.: Icon for a CES Construct

As we have chosen BPMN as our implementation and modeling standard, we need to describe a CES construct graphically using standard BPMN notation not violating the OMG standard. Moody [Moo09] suggests the importance of an icons that quickens cognizance and improve comprehensibility of diagrams to both naive and novice users. Unlike most Software Engineering notations that are visually one-dimensional and less appealing, we wanted to realize more than one of the eight available visual communication channels defined by Moody [Moo09]. Furthermore, we need an icon that will be easy to draw by hand while drawing a BPMN task shown in Figure 3.4 over non-digital medium. Hence, we came up with the icon shown in Figure 3.3 which is a *Data Object* with "C" written inside that signifies reception of Contexts from IoT devices. Our icon can be categorized as *Hybrid Symbol* by Moody [Moo09] where the text inside the object expands the meaning and such an amalgamation of textual and graphical representations makes the CES icon more appealing.

Sungur et al. [SBLW15] have proposed a very rudimentary abstract architecture to realize the concept of CES too in their research work which will be adapted by us again in the Chapter 6 while realizing the concepts in our implementation.

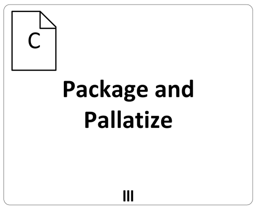

Figure 3.4.: A BPMN Task with a CES Construct

3.4. Summary

In this chapter, we have provided introduced the concepts of CES along with its various components to the reader. The operational semantics of a CES is also discussed briefly in the form of a diagram and formal algorithm. Later we defined the title of our research work *Context-sensitive Manufacturing Process* and designed the fancy pictorial representation of a BPMN task with a CES construct.

- **CES** are similar to BPMN task structures that are activated when the incoming flows are activated upon some conditions. Primarily a CES task contains a Main-Intention, Context Definition, Sub-Intentions, Process Defintions (Main and Complementary), Optimization Strategy and Selection Strategy. Additionally it can contain its own explicit input data and output variable to hold its generated output [SBLW15].
- **Main-Intention** contains the prime goal of the process [SBLW15].
- **Sub-Intentions** are the sub-goals that will be associated with a Main-intention to refine its comprehension [SBLW15].
- **Context Definition** specifies the required Contexts and related Context Conditions that will validate an underlying process definition in a certain scenario and thus makes CES adaptive [SBLW15].
- **Process Definitions** are the main realization processes to achieve all defined intentions [SBLW15].
- **Complementary Realization Processes** are the processes that are emphasized to run during the realization of main process definition for better business value and quality [SBLW15].
- **Selection Strategy** is used for choosing between multiple processes with same goals and Context Definitions [SBLW15].
- **Optimization Strategy** provides means of an automated optimization of the process to be run before execution [SBLW15].

4. Motivating Scenario

4.1. Process Alternatives and Considerations

4.1.1. Main Realization Process Model

4.1.2. Complementary Realization Process Model

4.1.3. Optimizing Process Model

4.2. Process Related Considerations and Assumptions

4.3. Summary

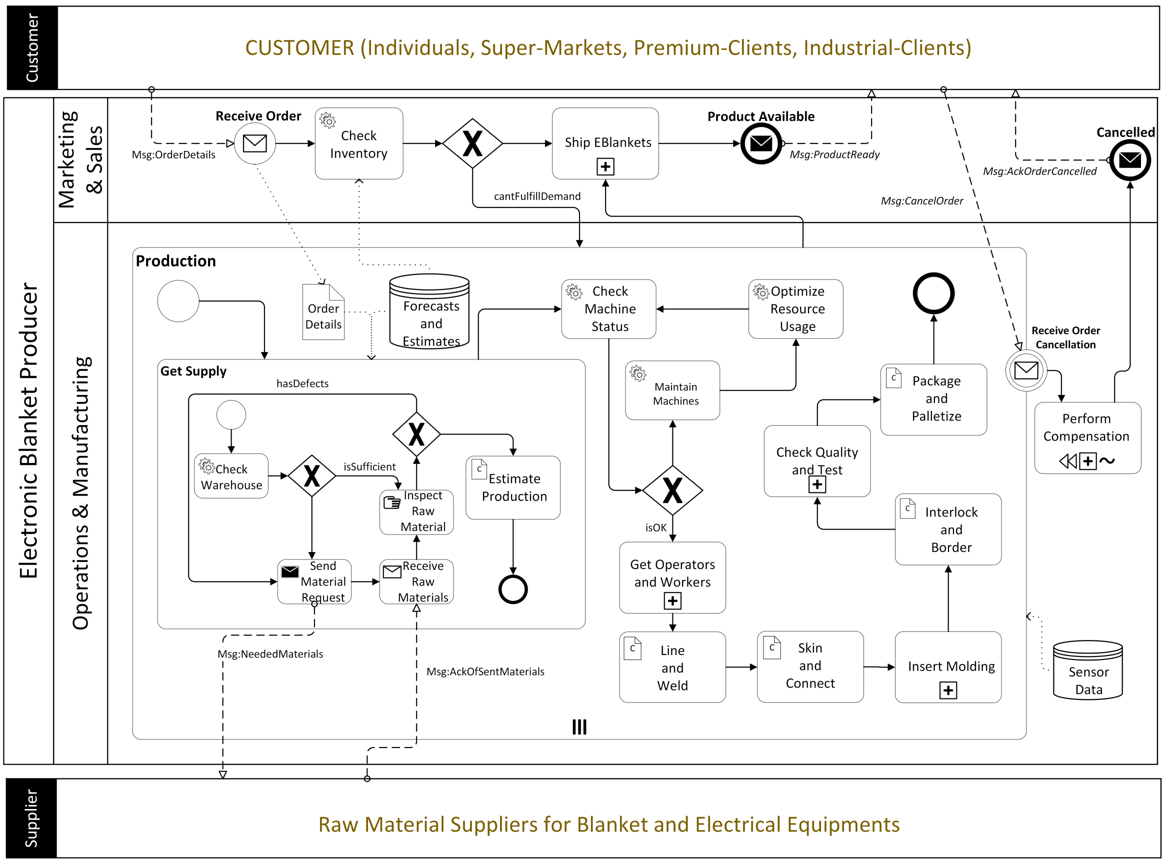

Figure 4.1.: Overall Production Process in BPMN

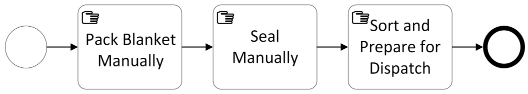

Figure 4.2.: Manual Packaging and Pallatization of Blankets in BPMN

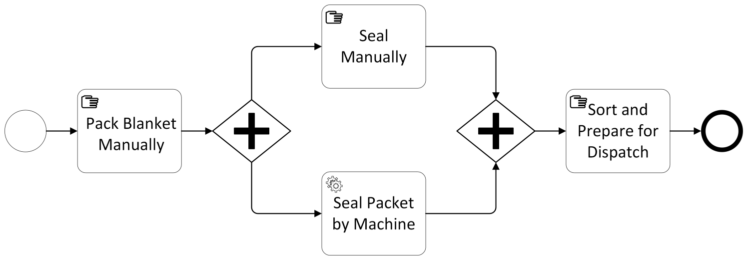

Figure 4.3.: Semi-manual Packaging and Pallatization of Blankets in BPMN

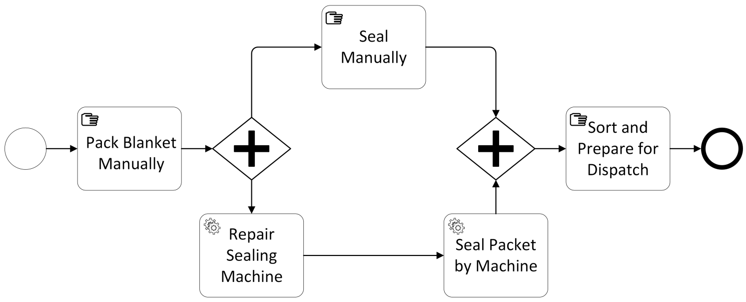

Figure 4.4.: Packaging and Pallatization of Blankets in BPMN with Repair Activity

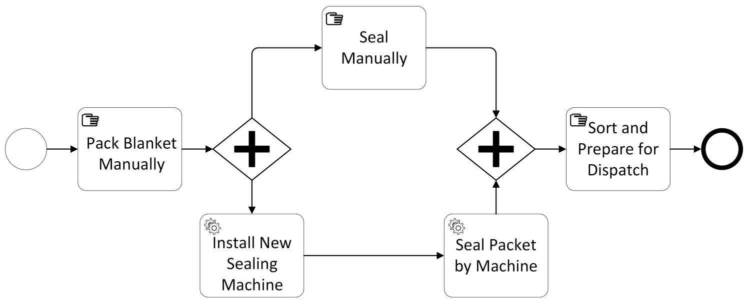

Figure 4.5.: Packaging and Pallatization of Blankets in BPMN with Reinstallation Activity

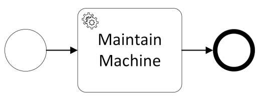

Figure 4.6.: Complementary Realization Process of Maintenance in BPMN

Figure 4.7.: A Naive Optimization of Resources in BPMN

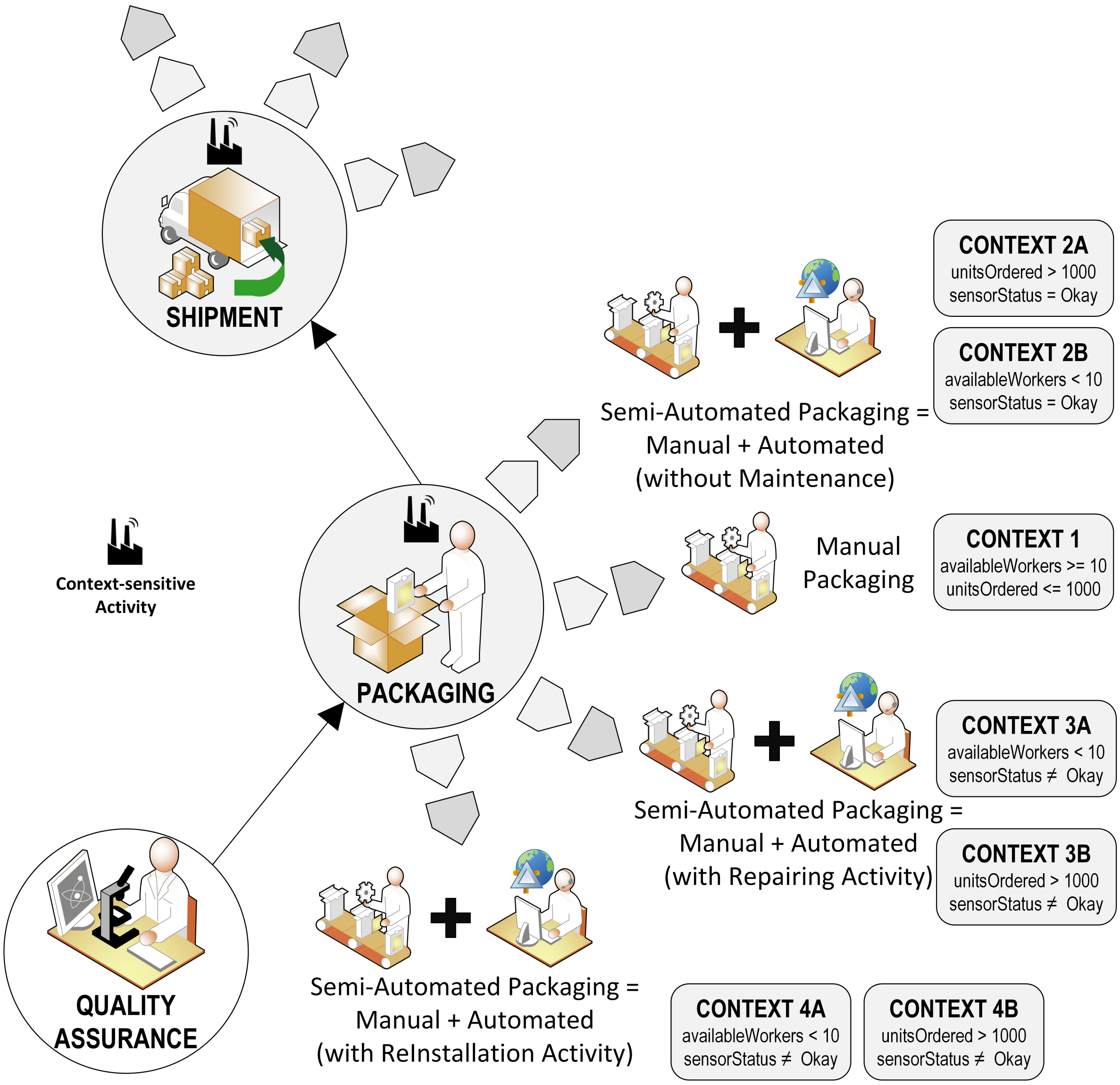

Figure 4.8.: Comprehensive Visual Graph of Motivating Scenario

5. Requirements Analysis

5.1. Properties of CES Construct

5.2. Requirements of CES Construct

5.3. Summary

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 2. Step 2 normal case 3. ...
Special Cases	1a. Step 1a special case a) ... 2a. Step 2a special case a) ... 2b. Step 2b special case a) ...

Table 5.1.: Demo Table

6. Architecture and Implementation

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].

Listing 6.1: Java Demo Example

```java
/* HelloWorld.java*/
public class HelloWorld
{
	public static void main(String[] args) {
		System.out.println("Hello World!");
	}
}
```

Listing 6.2: XML Demo Example

```xml
<complexType name="tContent">
	<sequence>
		<element name="OrderID" type="string" maxOccurs="1" minOccurs="0"></element>
		<element name="SenseValue" type="string" maxOccurs="1" minOccurs="0"></element>
		<element name="DeliveryDate" type="dateTime" maxOccurs="1"
		    minOccurs="0"></element>
		<element name="Location" type="cmp:tLocationType" maxOccurs="1"
		    minOccurs="0"></element>
		<element name="Timestamp" type="string" maxOccurs="1" minOccurs="0"></element>
		<element name="Expression" type="string" maxOccurs="1" minOccurs="0"></element>
		<element name="Resource" type="anyURI" maxOccurs="1" minOccurs="0"></element>
	</sequence>
</complexType>
```

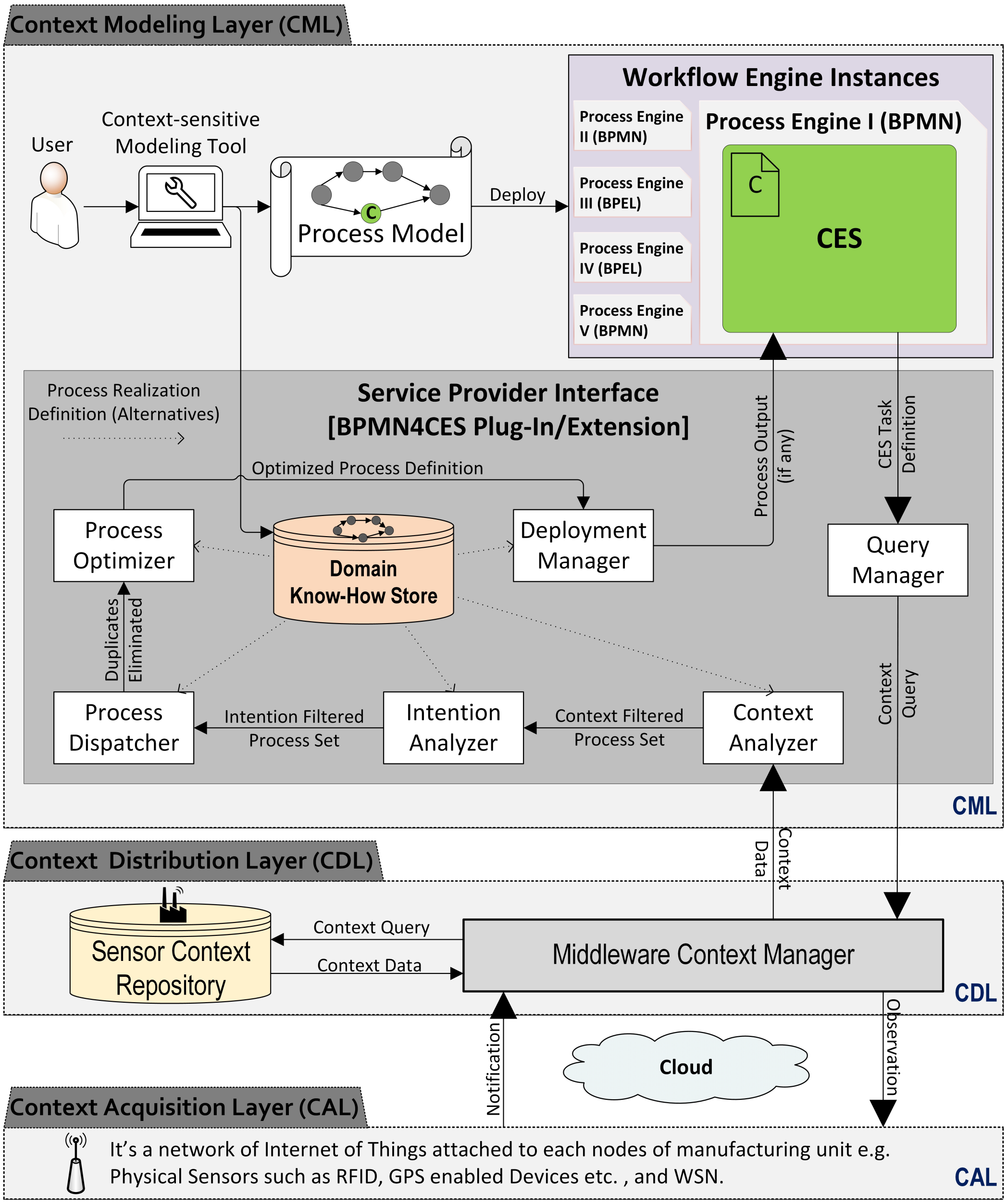

Figure 6.1.: Architecture

7. Related Works

7.1. Discussion

7.2. Summary

8. Conclusion and Outlook

Appendix A.

List of Acronyms

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

AI Artificial Intelligence

BPEL Business Process Execution Language

BPM Business Process Management

BPMI Business Process Management Initiative

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

EU European Union

GPS Global Positioning System

HP Hewlett-Packard

IaaS Infrastructure as a Service

ICT Information and Communication Technology

IFS Innovative Factory Systems

IoS Internet of Services

IoT Internet of Things

IP Internet Protocol

IPv6 Internet Protocol version 6

IT Information Technology

LTE Long-Term Evolution

NIST National Institute of Standards and Technology

OASIS Organization for the Advancement of Structured Information Standards

OMG Object Management Group

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

Ubicomp Ubiquitous Computing

UML Unified Modeling Language

UMTS Universal Mobile Telecommunications System

URI Uniform Resource Identifier

WFMS Workflow Management System

WSN Wireless Sensor Network

XML Extended Markup Language

XPath XML Path Language

XPDL XML Process Definition Language

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All links were last followed on January 19, 2016

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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, January 19, 2016 ____________________________

(Signature)