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ECSEL DIGITAL REFERENCE – A SEMANTIC WEB FOR SEMICONDUCTOR MANUFACTURING AND SUPPLY CHAINS CONTAINING SEMICONDUCTORS

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ABSTRACT

Within the public-private ECSEL Joint Undertaking, the project Productive4.0 aims for improvements with regard to digitalization for electronic components like semiconductors and systems as key enabling technologies. The semiconductor industry has a high growth potential within the frame of digitalization as manufactured products are intensively used in production and B2B environment. Thus, Supply chains employing and fabricating semiconductors become the core driver and beneficent of digitalization. In order to exploit digitalization potentials, Semantic Web technologies are used to create a digital twin for semiconductor supply chains and supply chains containing semiconductors. Exemplary benefits of this lingua franca which can be understood by humans and machines alike for various applications like simulation, deep learning, security, trust, and automation are shown in this paper.

1 INTRODUCTION

With the transformation of industries and companies towards Industry 4.0 as well as Internet of Things (IoT), electronic components and systems (ECS) serve as a key enabling technology. As the digital transformation is still booming for businesses as well as society, it presents enormous growth potential. Smart devices and machines necessary for the digitalization are used in a wide field of applications, not only in industries but also in private environments e.g. home applications. Hence an extensive usage of this technology is inevitable for successful economies.

With the public–private *Electronic Components and Systems for European Leadership Joint Undertaking* (ECSEL JU), Europe's contribution in the era of the digital economy is achieved by funding research, development and innovation projects in these key enabling technologies within the European industry. This affects small and medium-sized enterprises (SMEs), research and technology organizations together with all 30 ECSEL participating states and the European Union.

Within this joint undertaking, several projects are started in Europe (ECSEL Joint Undertaking 2019). One of them is Productive4.0 with the mission to establish a link between the real and digital world by efficiently designing and integrating both the hardware and software of IoT. The main objective of Productive4.0 is to improve the digitalization of the European industry by creating a user platform across value chains and industries, thus promoting the digital networking of manufacturing companies, production machines and products. The project is structured into ten work packages, as shown in Figure 1, with more than 100 partner institutions involved (Productive4.0 Consortium 2019).

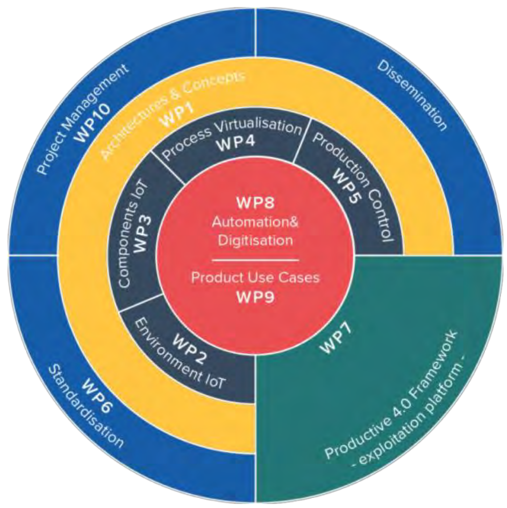

Figure 1: Work packages of Prodcutive4.0.

Especially the semiconductor industry is affected by the digital development as semiconductors build the basis for almost all technologies enabling the digitalization and therefore it has a promising market. Moreover, it is also in need to use the technologies itself for manufacturing semiconductors. Several trends drive the growth of the semiconductor industry, namely energy efficiency, mobility security, IoT and Big Data. In order to seize the opportunities resulting from these trends, the authors participated in developing the Semantic Web based digital twin called Digital Reference within work package seven (WP7). As a business-to-business (B2B) interface, the continuously developed Digital Reference represents the digital twin for semiconductor supply chains as well as the supply chains containing semiconductors. The whole manufacturing of semiconductors is represented between the Deliver and the Source. Other so called lobes - in analogy to a brain - of the Digital Reference include semiconductor products and systems as well as the Cloud for Services.

This paper will take a closer look at the Digital Reference, realized and potential applications with their benefits as well as possible future extensions. In specific, the possibility of improving the attraction of offers towards customers by a semantically enriched online sales and marketing platform, the role of Semantic Web as a *lingua franca* with regard to Artificial Intelligence (AI) and Deep Learning (DL) as well as the benefits of Semantic Web for planning and simulation will be explained.

2 CONTEXT AND REALTED WORK

The Digital Reference developed by the ECSEL consortium is based on Semantic Web technologies. The concept of Semantic Web was introduced by Tim Berners-Lee in 2001 (Berners-Lee et. al. 2001; Shadbolt et al. 2006) with the aim to provide web contents not only in human-readable form as in the traditional World Wide Web but also in machine-readable form. The IT systems should be able to process information from web sites and other data sources in order to recognize relationships as well as dependencies between pieces of data, make implicit knowledge explicit and link data from different data sources effectively (Baumgärtel 2018). For standardization purposes, the World Wide Web Consortium developed the Semantic Web Technology stack, which is displayed in Figure 2. This offers the fundamentals for an extension of the web based on semantic technologies. The Resource Description Framework (RDF), which consists of simple semantics, is the data model for things and their relations. More information about the data is given by the Unified Resource Identifiers (URI), the taxonomies are represented in the RDF Schema (RDFS) and an extension of that is the Web Ontology Language (OWL) describing the ontologies. An explanation of the technologies is given by (Hitzler et al. 2009) and the advantages of the usage are provided by Oracle (2016).

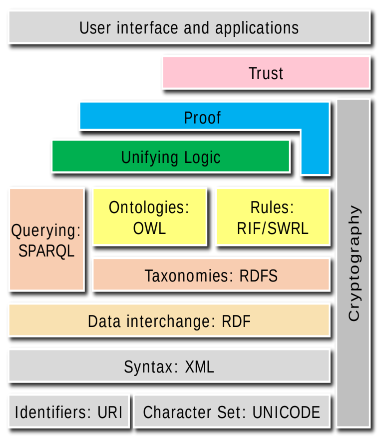

Figure 2: The Semantic Web technology stack (W3C 2012).

With this technology structured and connected knowledge can be saved and reasoning can be applied on it to detect hidden knowledge. Reasoning in Semantic Web is the means to derive facts that are not explicitly stated in the ontology or in the knowledge graph. Inference not only improves the quality of data by analyzing the current data set and enriching it but also allows the discovery of inconsistencies. There are two reasoning approaches: ontology-based and rule-based reasoning.

Furthermore, Abele and McCrae (2017) mention the Linked Open Data (LOD) as a cloud widely used with approximately 10.000 data sources freely accessible and is therefore often seen as synonymous to the Semantic Web. Additionally, we can see the benefit of using Semantic Web especially in the B2C domain. Namely, Semantic Web serves large scaled US/Chinese companies like Google/Baidu, Facebook/WeChat, Amazon/Alibaba. To clarify, e-commerce applications enabled by Semantic Web are for example semantic product descriptions, need-oriented applications, search engines for product characteristics, model-based product recommendation systems and digital, autonomic shopping assistants. Herewith, it will be easier for the customer to find a required product within the whole internet, especially with complex product properties. Moreover, it is easier to compare offers and get the desired information, thus improving the overall user experience and creating a better environment. Not only does Semantic Web in e-commerce has an effect on the customer but also on the business side. It allows more flexibility to analyze and react according to the customer demand. It also unleashes open markets with high competition and opportunities for innovative business models (ECIN 2010).

In contrast to the B2C business, the usage of Semantic Web technologies is relatively rare within the B2B domain and industrial applications. There are already some examples of implementations of Semantic Web in the industry, e.g. the integration of different data sources at a car manufacturer (Taylor 2015) and a company-wide information model for a large German manufacturing company for machine tracking and energy consumption monitoring (Petersen et al. 2017). But as it can be seen at the huge success of Semantic Web in the B2C domain there are many more opportunities for the B2B implementation of these technologies, which offer great chances for full exploitation of the growth potential. The application areas could be most of all in knowledge management as well as electronic business and it could also enable even more Deep Learning as it did in the B2C business. The expandable usage of digital innovations, including Semantic Web technologies, especially within the B2B domain, leads to different projects like the ECSEL JU.

3 THE DIGITAL REFERENCE

As the "traditional supply chain solutions alone no longer fit in the bill in this new age" (Tim Payne, Vice President of Research for Gartner), organizations are seeking to digitize their supply chain planning efforts through the use of a representative supply chain model, or a supply chain digital twin. The Digital Reference ontology, introduced to Productive4.0, is a supply chain-related Semantic Web mirror of the semiconductor industry depicting a combination of different supply chain pillars and semiconductor production concepts e.g. Digital Production, Supply Chain Networks, and Product Lifecycle Management. The Digital Reference organized in topic clusters (lobes) represents all stages of the supply chain and provides a knowledge base readable for humans and computer alike. The Digital Reference contains around 500 classes that describe concepts in different domains. Currently, the Digital Reference is the overarching ontology containing several sub-ontologies that represent hierarchies, processes and taxonomies e.g. product ontology, sensor ontology, organization ontology and process ontology. The scale of the Digital Reference continues to expand with the integration of further relevant ontologies. An overview of the visualized domains of the Digital Reference is presented in Figure 3.

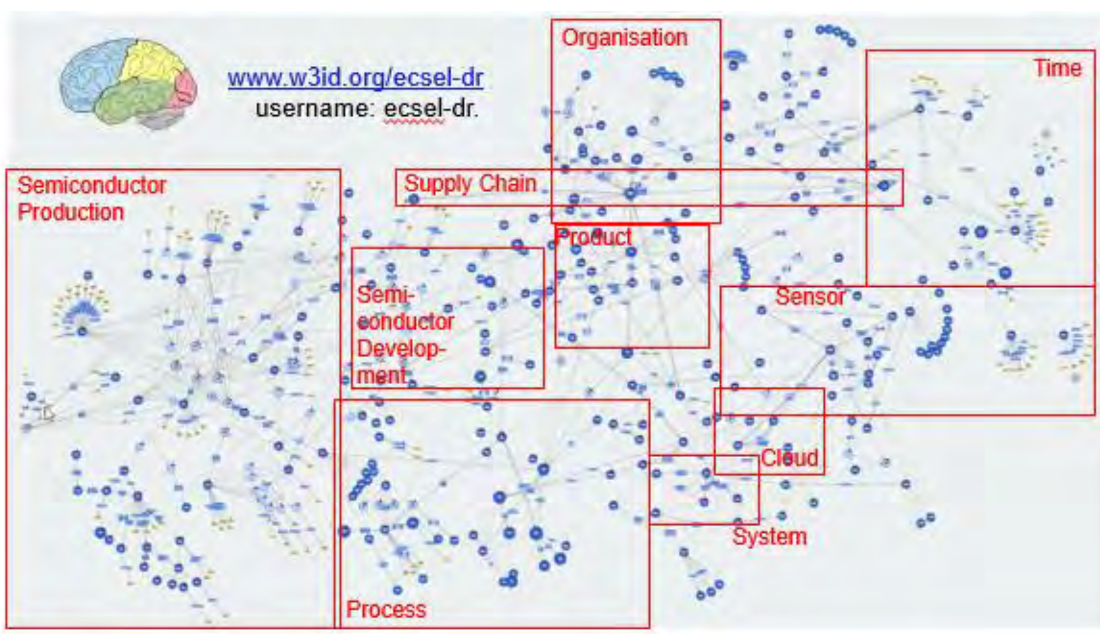

Figure 3: The Digital Reference.

In Figure 4, the “Demand” class is shown as an example of a main concept included in the “Semiconductor Production” lobe as an excerpt of the holistic Digital Reference. It is presented as a triple existing of a class (subject) linked by a property (predicate) to another class or literal (object).

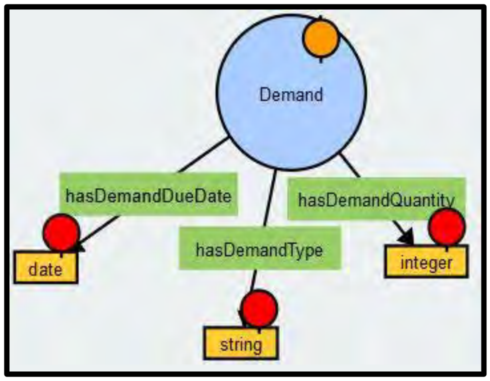

Figure 4: The demand class.

4 REALIZED AND POTENTIAL BENEFITS FROM THE DIGITAL REFERENCE

The Digital Reference is developed within Productive4.0 for the semiconductor manufacturing and supply chains containing semiconductors to facilitate digitization and IoT. There are several already realized and possible benefits resulting from the development and usage of the Semantic Web-based Digital Reference. So far within this paper, the benefits in the fields of sales, planning, simulations, and Deep Learning have been evaluated.

4.1 Benefit for Selling Semiconductors Fitting Best Match to the Need

A semiconductor company can profit from a Semantic Web based Digital Reference by using it for an open online sales and marketing platform which is the communication interface between companies and customers. Semiconductor manufacturers are able to sell their products on a B2B basis to other companies via such a platform. By applying Semantic Web technologies to this sales platform, which includes all relevant products offered by a company, increased sale volumes and customers satisfaction are expected. A Semantic Web-based sales platform enhances the user experience by delivering better search results to the customer. This is due to machine understandability of all data as well as connections of data to earlier supply chain stages. Therefore, providing the right products and their respective information to customers is facilitated, resulting in higher customer satisfaction. Furthermore, Semantic Web underlying the sales and marketing platform enables less time-consuming maintenance of the platform as data can be adjusted and updated automatically. For employees being in charge of maintaining the platform, this implies an increased grade of automation and hence faster data gathering and product placement with regard to the platform. This is particularly important in the semiconductor industry since the product life cycles are relatively short (Ehm et al. 2016). Faster updates and better results offered to the customer can then lead to higher sales numbers and ensure competitive advantages against other semiconductor manufacturers.

4.2 Benefit for Simulation

Semantic Web technologies can not only be used to depict semiconductor operations and supply chains but also to simulate involved functions, included personnel and operational tasks. The division of scope is in accordance with the four standard simulation levels (Fowler et al. 2015). Each level is initially represented by an ontology, merged into an abstract, higher level ontology – the Digital Reference. On level one, the most granular, detailed ontology includes the interaction of products, machines, and operators within a production work center. On level two, the production work center network is represented including the major classes workshop, demand, lot, and route. The broader view of the complex manufacturing site network comprising the internal supply chain (frontend, backend and Distribution Centers) is given in level three. Finally, level four shows the end-to-end supply chain, that includes all the other ontologies from the levels below and therefore represents the Digital Reference ontology described earlier (compare Figure 5). The overall ontology, which can be uploaded and added, is important for information sharing, collaboration and simulation by providing an understandable common structure to the system of the supply chain knowledge. The Digital Reference facilitates the understanding of complex adaptable supply chains and interactions between enterprises and eases the involvement of partner companies within the mutual vocabulary of terms used and functions depictions adopted.

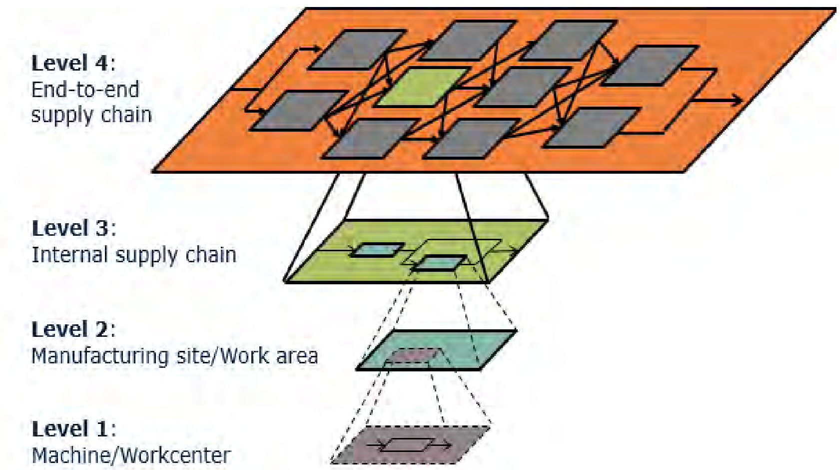

Figure 5: The four levels of semiconductor operations (Fowler et al. 2015).

4.3 Benefit for Setting Up Planning Structures – the Example Tree versus Networks Case Study

Due to various production and market factors, flexibility is required in semiconductor manufacturing supply chains. Complexity concerns that arise from increased flexibility are also rooted in production and market factors. It is not uncommon for a single semiconductor product to be partially manufactured in multiple factories around the world, including the use of subcontractors to complete manufacturing steps (Chien et al. 2008). The typical production processes of semiconductor manufacturing include wafer fab, probe, assembly, and final test. Wafer fab and probe are usually called front-end processes and have long cycle times (up to 20 weeks). Assembly and final test are usually called back-end processes and have shorter cycle times (a few weeks). To effectively cope with and mitigate the factors impacting the supply chain, semiconductor manufacturers employ a variety of strategies concerning the design of the supply chain and its planning structures. An important factor affecting the complexity management of flexible supply chains is the way product identifiers are defined and utilized within supply chain processes and data. Three typical examples of product structures in the semiconductor industry are bamboo (or linear), trees and networks structures (compare Figure 6).

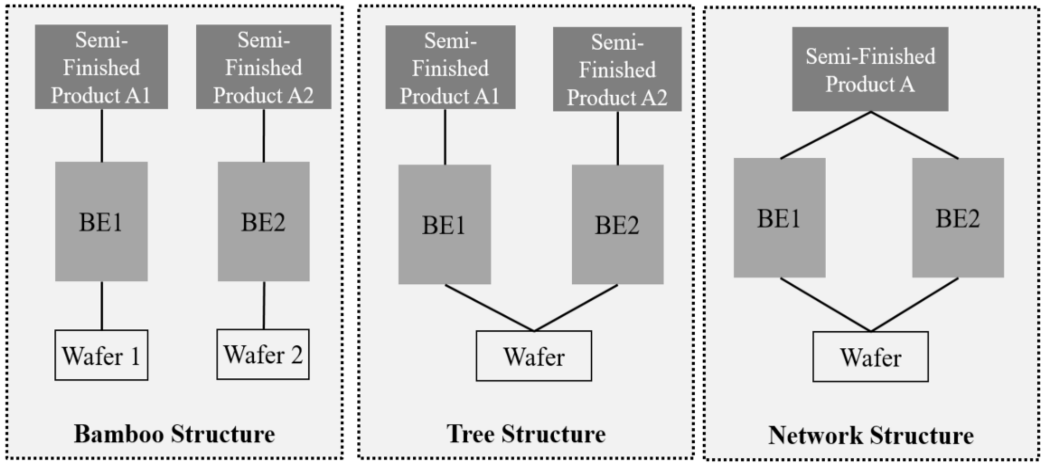

Figure 6: Typical product structures in the semiconductor industry: Bamboo, tree and network (BE stands for back-end manufacturing processes).

In a Tree product structure, the planning product identifier is unique. It is defined by a change in an activity or a component that still corresponds to the same finished product. In a Network product structure, the planning product identifier is not unique. It is defined by all activities or components that correspond to the same finished product. Product structures and the resulting product identifiers have a great impact on supply chain management because they form the basis for supply chain processes and data. Thus choosing one structure over the other in the Supply Chain Planning could have a large impact in all of the company´s processes.

The Digital Reference highlights the relations between planning structures and the demand-supply match algorithms. An ontology linked to simulation will enable to rapidly implement a complex product structure directly into a simulation model. Finally, the Digital Reference could change the Master Data applications of BOMs, resulting in better communication and alignment between customer orders and the Master Planning System, as an universal platform, and could simplify the interaction between the algorithms as well as uniform data types.

4.4 Benefit for Deep Learning

Semantic Web serves as an enabler for Artificial Intelligence and Deep Learning Firstly, Semantic Web is a promising option to overcome data silos and to serve as a *lingua franca* enabling a common abstract structure for data that permits a faster and more successful use of AI and DL, which useful for high knowledge domains like the semiconductor industry. Semantic Web technologies and knowledge representation emphasize the usability and sharing of knowledge in a structured, distributed and machine-readable way, overcoming the problem of unstructured, scattered data that hinder preliminary phases of machine learning approaches. The latter can then be directly applied to analyze distributed data sources (silos) described in Semantic Web format (compare Figure 7). The semiconductor value/supply chain and the value/supply chain containing semiconductors are high knowledge domains, hence, a well-defined and meaningful structure is needed to represent the know-how. This is given by the Digital Reference. Filled with data, it is a powerful structure where different semantic reasoning techniques can be applied to enhance the input for Machine Learning and Deep Learning algorithms and therefore promises better results than classical ML/DL methods. Deep Learning techniques, on the other hand, can be applied for improving Semantic Web functionalities like ontology learning, ontology annotation, relation extraction, and ontology merging. The importance of powerful knowledge domains can be seen in the race between B2B and B2C, where low knowledge domains like Hotel industry already lost their influence to B2C (e.g. Booking.com).

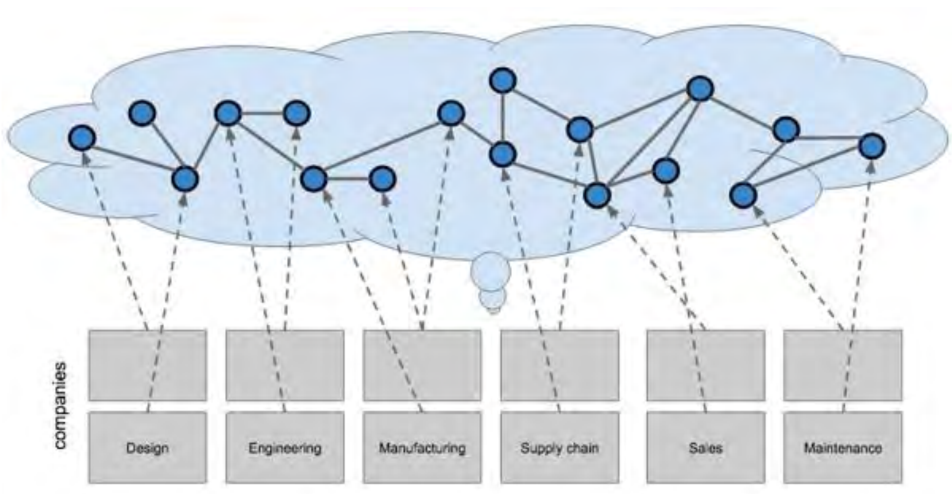

Figure 7: Integration of data silos using Semantic Web (Beyond PLM 2018).

5 OUTLOOK FOR THE DIGITAL REFERENCE

As already mentioned, the Digital Reference representing the semiconductor supply chains and supply chains containing semiconductors is constantly extended with more detailed concepts to larger and better-detailed descriptions. More areas of the supply chain and internal processes will be included by creating more ontologies. This will result in more benefits that can be derived from developing a holistic ontology. A potentially important new application area of the Digital Reference is the area of automation with regard to internal processes as well as interfaces to external partners. A collaboration platform for smart textiles as a use case scenario is intended. Here the idea is that parts used for consumer/end products are matched automatically with electronic suppliers' products that enable smart textiles. Additionally, markets that are currently unknown could be identified by an automated, information-driven, interactive innovation platform concept. Ontologies for these future concepts are developed and evaluated (Baumgärtel, 2018).

Another area which is not included in the ontology so far is the application of Semantic Web to Material Master Data or the Bill of Material (BOM). It is the basis of the communication not only along the supply chain but also between internal stakeholders in order to ensure the production of the customer orders. Representing it as a Semantic Web-based ontology may facilitate the communication between departments because of a common language and will ensure the usage of correct material combinations for according products. In case machines are not only reading the data but also understand it, the automation of the material selection process will be supported. The benefits of including the material master data in the ontology will be further evaluated.

Furthermore, the question of trust is an important general issue in the Semantic Web, i.e. which contributors are trustworthy and which content is reliable. In order to generate a certain level of confidence, the application of blockchain technologies with a respective distributed consensus method is investigated within the further development of the Digital Reference. Distributed consensus methods make it possible to reach a trusted agreement in a decentralized network. This agreement, represented by the last block in the blockchain and immutable stored on a distributed ledger, represents the latest single source of truth, trusted by a majority of the network. Together with other properties of the blockchain technology such as high transparency and traceability, this is a promising and especially fast way to install trust in Semantic Web content, i.e. the Digital Reference. However, as in this case no simple (financial) transactions need to be validated and agreed on but controversial content is considered instead, the validation and consensus-finding requires expert knowledge and new ways to represent this on a blockchain environment.

6 CONCLUSION

Discrete-event and agent-based simulation models serve as a highly spread concept for manufacturing representation and planning during the last decades within the semiconductor industry. Currently and in line with regard to digitalization, Industry 4.0 and the Internet of Things, the initiative on *Electronic Components and Systems for European Leadership* (ECSEL) aims to reach the next level for semiconductor development, manufacturing, and supply chain with its projects, as semiconductors build the fundamental technology. Trends being identified are Big Data, Semantic Web, Artificial Intelligence and Deep Learning. Productive4.0 contributes to this goal with a Digital Reference based on Semantic Web technologies representing semiconductor supply chains and supply chains containing semiconductors as a digital twin.
First benefits from this Digital Reference and the usage of Semantic Web can already be seen. More parts of the internal and external supply chain will be included to fully exploit the potential of the Digital Reference.

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