Digital Twin for Plan and Make Using Semantic Web Technologies – Extending the JESSI/SEMATECH MIMAC Standard to the Digital Reference

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Abstract. This proposed research is concerned with developing an extension of the joint JESSI/SEMATECH standard MIMAC to the Digital Reference. It analyzes the capabilities of a Semantic Web based Digital Twin for the semiconductor supply chain Plan and Make processes. The long-term goal is an accelerated broad-scale digitalization of the entire supply chain. This incorporates benefits for fab simulation, inter-enterprise collaboration, inconsistency identification and knowledge transfer. Industry related use cases show the potential and allow an analysis of current difficulties.

Keywords: SCOR · Supply Chain Management · Manufacturing · Semantic Web · Ontology · Digital Twin · Manufacturing Capacity

1 Motivation

The union of Joint European Submicron Silicon Initiative (JESSI) and the U.S. SEMATECH (derived from Semiconductor Manufacturing Technology) consortium in the early 90s of the last century is considered as the foundation of a strong collaboration within the semiconductor industry. The collaboration aims at identifying the main factors that influence development and manufacturing efficiency to improve the performance on a strategic level. Established for this purpose, the Measurement and Improvement of Manufacturing Capacity (MIMAC) pre-competitive project analyzed coefficients that led to drops in production capacity. The developed data sets, which also include a simulation model of an Infineon facility, are serving as reliable simulation reference models since then, yet the changing semiconductor environment necessitates adjustments of the model to a certain extent (Hassoun and Kalir 2017). Discrete-event and (multi) agent-based simulation approaches are leaving the tool and factory level towards the entire semiconductor supply chain, partially going beyond and covering the domains of value chains employing semiconductors. However, the core remains to cover the operations of manufacturing and development of lots of

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semiconductor products (Fowler and Robinson 1995). With a multitude of processing steps and tool interrelations, the semiconductor manufacturing (Make) section of the supply chain is considered as highly complex. Hence, planning this supply chain is crucial for handling demand or supply volatility and managing global production flexibility.

Introducing Horizon 2020, the European Commission maintains the largest international collaborative research & innovation program. ECSEL, the Initiative on Electronic Components and Systems for European Leadership is the joint strategic approach reusing the JESSI experiences. Projects under the ECSEL umbrella – such as iDev40 and Productive4.0 – contribute to reaching the next level for semiconductor development, manufacturing and supply chain. Main reasons for the highly turbulent environment are shorter product lifecycles, high demand uncertainty and fluctuation, changing manufacturing processes as well as an increasing quantity of fabs involved in the globalized production of a single product (Chien et al. 2008). This includes an enhanced connection of the digital and physical world for smarter, automatable processes that are more flexible, scalable and versatile (Mönch et al. 2018). However, it is still unclear, to what extent the semiconductor industry will be influenced and which players are capable of driving the digital transformation.

Semantic Web technologies are a promising approach in order to ensure that the current B2B actors are staying in the driver seat in their field and are not taken over by B2C competition. Data is unified substantially in consistent ontologies by defining explicit semantics and can be enriched in a later phase. Furthermore, the machine understandable and interpretable structure improves collaboration within and between enterprises as well as on a workcenter layer (Baumgärtel et al. 2018). This paper describes a consistent digital twin approach that accompanies the semiconductor manufacturers with their supplier and customer tiers during the digital transformation by enhancing existing MIMAC standard data sets with Semantic Web technologies.

2 Background

The industrial importance and scientific attention of supply chain management concepts increased in the 1980s as strategic components were added, however, it initially emerged as logistics concept in the 1950s (Oliver and Webber 2012). As one of the most renowned approaches to manage supply chains, the Supply Chain Operations Reference Model (SCOR Model) contains recommendations for planning, controlling and monitoring (Bolstorff et al. 2007). The SCOR Model is endorsed by the Supply Chain Council (SCC) with its vast number of member companies and therefore serves as a harmonized industry standard across sectors. It furthermore allows efficient benchmarking procedures for supplier selection. The basic reference model includes the phases Plan, Source, Make, Deliver and Return, as depicted in Fig. 1. It is developed as a management tool, covering all business activities from the supplier's supplier to the customer's customer with the overarching goal to satisfy the customer's demand. The SCOR model is applied for describing, measuring and analyzing supply chain configurations. Furthermore, supply chain relevant sub processes are harmonized and become visible. Considering details within and between the sub phases, it is of major interest how to design and control the processes for material, information and value flow. The manufacturing (Make) phase is primarily processing material downstream and relevant data in both directions for controlling the production environment. Especially for the semiconductor industry and its various sensitive manufacturing systems, it includes a highly complex task that needs to be aligned effectively. This is achieved by the means of the Plan phase and incorporated processes. Within the Plan phase, major reasons for the high complexity of the semiconductor supply chain are aimed to be controlled, namely short lead times, frequent product innovations or volatile demand and supply behavior.

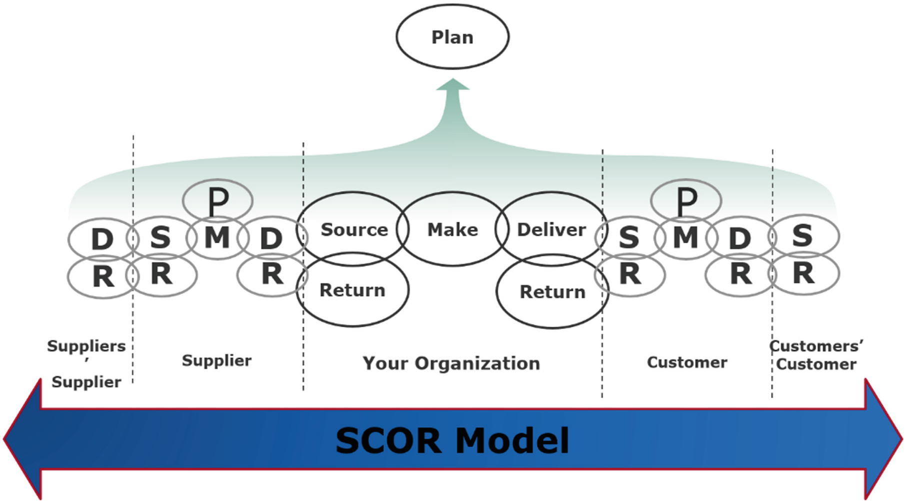

Fig. 1. The SCOR model. Cf. Bolstorff et al. (2007).

Addressing the needs of large and complex manufacturing environments, the joint JESSI/SEMATECH standard MIMAC incorporates the most relevant factors that influence fab capacity in a negative manner. It is based on surveys and interviews of member companies that reveal the importance of cycle-time and on-time delivery for semiconductor manufacturing. Furthermore, literature research and analysis of factory-level effects are conducted. Besides the identification of the most crucial factors, the results include a discrete-event simulation testbed for semiconductor manufacturing, capacity planning process reports and training tools for workshop participants. For the global experiment, after eliminating some variables during simulation, nine factors are consequently identified that have major effect on factory capacity. Namely, this is downtime, setup, yield, batching, operator availability, rework, operator cross-training, dispatch rules and hot lots. It incorporates capacity that is constrained by cycle time at different scenarios and calculated with different data sets. The complex and resource-expensive experiment provides lessons learned for the future in the form of characteristic curves. However, it is pointed out that each factory tends to behave differently due to individual factors that are not part of the experiment. Similar approaches in the area of semiconductor manufacturing scheduling improvement strategies mainly cover simulation- and agent-based control solutions (Mönch 2006), heuristic multi-criteria optimization approaches (Pfund et al. 2008), simulation models and policies (Singh and Mathirajan 2018) as well as rule-based optimization techniques that are based on the work from MIMAC (Mittler and Schoernig 2000).

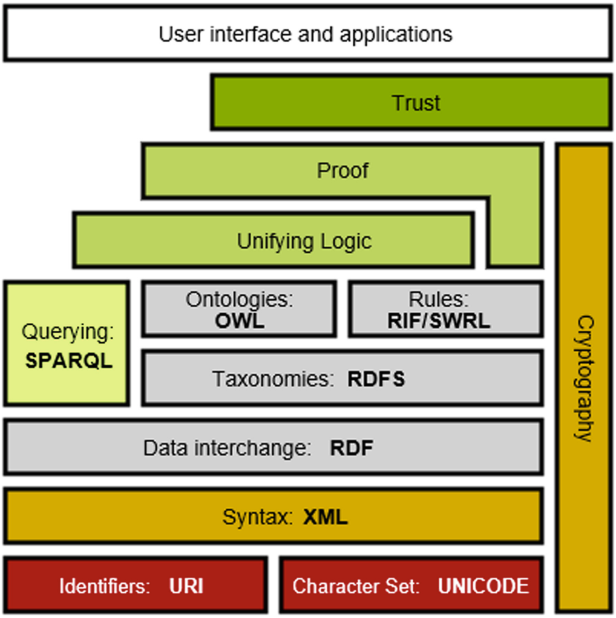

Fig. 2. The Semantic Web stack. Cf. Berners-Lee et al. (2001).

For overcoming the challenges that appear due to an increasing number of generated and processed data points, efficient data management strategies are necessary. Semantic Web Technologies are a promising approach that enable both data integration from heterogeneous sources and interpretability for machines. Semantic Web is an extension of the World Wide Web (WWW) framework that now connects data instead of hyperlinked documents. The building blocks of Semantic Web Technologies are depicted in Fig. 2, showing the Semantic Web Stack. Semantic Web applies the Resource Description Framework (RDF) to represent knowledge taxonomically, thus allowing to model resources with properties and linkages that identify them. Information is defined by the means of triples with each of the triples containing a subject, predicate and an object. The subject is the *thing* of interest, similar to the subject of a statement. The predicate, also referred to as property, links the subject with the object and hence defines their relationship. This relationship is either of type object property or data property. Here, an object property is applied to relate subjects to objects that are resources. In a similar way, a data property connects a subject with data-related information. A unique identifier (URI) is defined for each resource and property, referring to the address where the definition is stored. Ontologies summarize the knowledge about a certain domain and contain of classes – and presumably their subclasses –, individuals and a set of relations. Individuals, also known as instances, are the most individual objects that belong to a class. Resource Description Framework Schema (RDFS) extends RDF and offers a set of property and class vocabularies and hence facilitates the generation of hierarchies. Extending RDF and RDFS and expressing their constructs further, the Web Ontology Language (OWL) enables a variety of more descriptive properties, relationships and class descriptions. OWL is initially developed and now maintained by the World Wide Web Consortium (W3C). It serves as a common language for the Semantic Web community and additionally defines a broad set of standards. (Berners-Lee et al. 2001).

However, OWL adds even more value to the model, since reasoning may be applied. Reasoning is a powerful mechanism that automatically deduces implicit knowledge from the explicit knowledge graph. It is possible to review and trace each step of deduction, hence the knowledge gaining process is not hidden but rather clearly documented. For defining the area in which the inferences may or may not hold, constraints are necessary. Therefore, rule languages like the Semantic Web Rule Language (SWRL) or the Rule Interchange Format (RIF) are applied. The knowledge that is stored in an ontology is retrieved by queries, mainly based on the SPARQL (SPARQL Query Language for RDF). By setting filters, only relevant information will be passed to the user, maintaining a machine interpretable format. A general advantage of ontologies with regards to data management and collaboration of diverse teams is that information retrieval is supported for both humans and machines. This decreases the probability of misconceptions regarding the same bit of information and allows domain experts to readily share their knowledge in a standardized way. Furthermore, ontologies guarantee a certain level of quality in terms of consistency and approval. Automated queries moreover help to detect specific bits of information. By visualizing the graph structure in interactive interfaces, users can benefit from decision support and comprehensive search operations. (DuCharme 2013; Lacy 2006)

3 Approach Description

The semiconductor industry with its strong connection to digitalization approaches has the capacity to lead this disruptive change towards a data-driven smart development and manufacturing environment. In order to manage current issues such as described above, we propose the usage of Semantic Web technologies. This toolset enables the definition and maintenance of a controlled vocabulary of entities, including roles, processes and objects. Incremental improvements by simulation models may be reached by applying the powerful variety of Semantic Web technologies, especially incorporating a well-defined vocabulary of involved entities. Linked and openly available data sets are hence readable and interpretable by both machines and humans, which enables improved collaboration between computers and humans (Hitzler et al. 2009). The Digital Reference is a holistic Semantic Web based ontology that represents entities being relevant for semiconductor manufacturing and manufacturing employing semiconductors, including connections to related objects. Being developed as a digital twin, the Digital Reference accompanies the semiconductor manufacturers with their supplier and customer tiers during the digital transformation. As a digital representation of the physical entities in a semiconductor supply chain, the Digital Reference may support simulation models that are initially built on the MIMAC data set by adding more semantically unique content.

As a first step, the generic data model is depicted as a theoretical UML diagram and further clustered with regards to data content (Laipple et al. 2018). Moreover, solely entities that are related to supply chain simulation are chosen to be modeled as a database schema, including the MIMAC data. In the next step, Semantic Web technologies are applied. The fab data sets are transferred into a model based on the supply chain planning process for semiconductors and engineering integration. Facilitated by appropriate supply chain simulation models, a decision support framework for semiconductor value chains is developed. Similar to the initial MIMAC purpose, the identification of main independent variables is enabled. Increasing the granularity of the Digital Reference reveals four levels, as depicted in Fig. 3. The levels are related to simulation levels, with increasing magnification from top to bottom, the Digital Reference corresponding to the fourth level, accordingly. Each of the other layers contains smaller, partly problem- or domain-specific ontologies that serve as decision support knowledge bases exactly where needed.

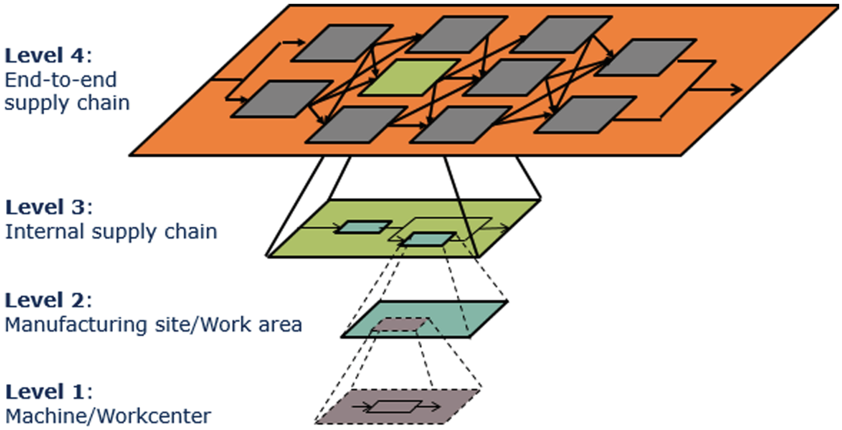

Fig. 3. The four levels of semiconductor operations. Own presentation.

The Digital Reference provides a fundamental understanding of the complex supply chain environment and facilitates inter-company collaboration. It incorporates a set of interrelated data points that is enhanced by reasoning and therefore provides insight into newly discovered implicit knowledge. Moreover, the Digital Reference emphasizes the connection between forecasting algorithms and the planning structure. For planning tasks in the supply chain domain with special focus on the manufacturing processes, overall communication between stakeholders is improved and a clear relation between assumptions in the planning system and the actual outcome may be provided. Depicted as a holistic and general platform, the alignment and interaction between algorithms and processed data is guaranteed.

4 Preliminary Results

By expanding the scope of the MIMAC data set and making it relevant in today's conditions, complexity is reduced and redundancy is eliminated by terms of the new model. Furthermore, the model follows a generic design and is hence flexible for adjustments and upcoming use cases. With the proposed model, high volume of data is being accessed and processed, facilitating knowledge extraction and information sharing. By splitting the holistic model up into smaller ontologies – each for a different scope, respectively – only relevant data is accessible for the respective user that can have several roles such as management, planning or operating. For instance, Fig. 4 shows a Level 3 ontology that represents an internal supply chain of a semiconductor manufacturer. Taking a closer look, one of its nodes is defining the actual demand including its properties due date, quantity and type for instance. Hence, the generic MIMAC model is enriched with detailed relationships and properties. By defining sub-ontologies while still maintaining a holistic top level ontology, the balance between a broad-scale extensibility and a very detailed specification is given. Since cooperation between enterprises within the supply network is increasing, both simulation and Semantic Web Technologies are considered crucial for enabling high volume data processing, real-time access to relevant knowledge and solution generation.

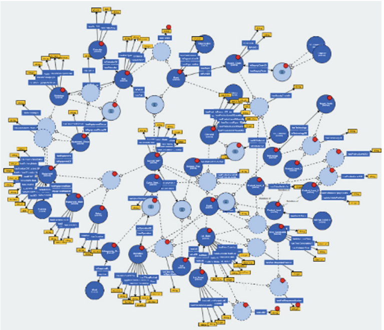

Fig. 4. Semiconductor operations third level ontology: internal supply chain. Own representation.

MIMAC data sets, utilized by agent-based or discrete-event simulation models still serve as a broadly adopted support solution in semiconductor manufacturing domains. Taking into account the digitalization efforts that are funded by large projects in the European Union, the next generation of semiconductor development, manufacturing, supply chain planning and deployment solutions is required to incorporate strategies to overcome Big Data hurdles. It is necessary to guarantee a seamless corporation, allow for automatic decision making processes and let machines and humans reliably interact in real-time. The Semantic Web based Digital Reference serves as a role model for tackling the digitalization challenges of the future. Extending the MIMAC standard in this direction, the semiconductor Plan and Make processes are supported, which hence can lead to a further overall fab capacity increase. This is equivalent to the initial goal of the joint JESSI/SEMATECH standard MIMAC, transferred to future demands.

5 Outlook

Despite the far-reaching advantages of this method, there are still open issues that may be addressed in future research. On the detailed levels of the model, the need for more data properties (such as key performance indicators for simulation) and greater availability of data for import arises. One option to overcome the latter issue is using qualified synthetic data. Yet, specific knowledge that is required for extracting it in favor of decision support needs to be implemented by the respective experts. At higher levels the need for linking projects or business partners arises. Furthermore, specific use cases are necessary to validate the approach and improve it further. Not every level is yet described in a holistic way, which leads to the aim of integrating a semiconductor planning and development ontology in the course of the iDev40 project. Moreover, a critical task is to ensure real-time accessibility of the high volume of data that is generated along the entire product lifecycle. Emerging technologies such as Semantic Web, Artificial Intelligence (AI) or Deep and Machine Learning (DL, ML) approaches will play a crucial role in manufacturing environments of the future.

References

Baumgärtel, H., Ehm, H., Laaouane, S., Gerhardt, J., Kasprzik, A. (eds.): Collaboration in supply chains for development of CPS enabled by semantic web technologies. In: 14th International Conference on Modeling and Analysis of Semiconductor Manufacturing (MASM) at Winter Simulation Conference 2018. Gothenburg, Denmark (2018)

Berners-Lee, T., Hendler, J., Lassila, O.: The semantic web. Sci. Am. Mag. **284**, 34–43 (2001)

Bolstorff, P.A., Rosenbaum, R.G., Poluha, R.G.: Spitzenleistungen im Supply Chain Management. Ein Praxishandbuch zur Optimierung mit SCOR; mit 33 Tabellen. Springer, Berlin (2007)

Chien, C.-F., Dauzere-Peres, S., Ehm, H., Fowler, J.W., Jiang, Z., Krishnaswamy, S., et al.: Modeling and analysis of semiconductor manufacturing in a shrinking world: challenges and successes. In: 2008 Winter Simulation Conference (WSC), Miami, FL, USA, 07–10 December 2008, pp. 2093–2099. IEEE (2008)

DuCharme, B.: Learning SPARQL: Querying and Updating with SPARQL 1.1, 2nd edn. O'Reilly, Cambridge (2013)

Fowler, J., Robinson, J.: Measurement and Improvement of Manufacturing Capacity (MIMAC). Final Report. In Technology Transfer # 95062861A-TR (1995)

Hassoun, M., Kalir, A.: Towards a new simulation testbed for semiconductor manufacturing. In: 2017 Winter Simulation Conference (WSC), Las Vegas, NV, 03–06 December 2017, pp. 3612–3623. IEEE (2017)

Hitzler, P., Kroetzsch, M., Rudolph, S.: Foundations of Semantic Web Technologies. Taylor & Francis Ltd. (Chapman & Hall/CRC Textbooks) (2009)

Lacy, L.W.: Interchanging Discrete Event Simulationprocess Interaction Models Using the Web Ontology Language - OWL. Dissertation. University of Central Florida. College of Engineering and Computer Science (2006)

Laipple, G., Dauzere-Peres, S., Ponsignon, T., Vialletelle, P.: Generic data model for semiconductor manufacturing supply chains. In: 2018 Winter Simulation Conference (WSC), Gothenburg, Sweden, 09–12 December 2018, pp. 3615–3626. IEEE (2018)

Mittler, M., Schoernig, A.K.: Comparison of dispatching rules for reducing the mean and variability of cycle times in semiconductor manufacturing. In: Inderfurth, K. (ed.) Operations Research Proceedings 1999, Selected Papers of the Symposium on Operations Research (SOR 1999), Magdeburg, 1–3 September 1999 pp. 479–485. Springer, Berlin (2000)

Mönch, L.: Agentenbasierte Produktionssteuerung komplexer Produktionssysteme. Deutscher Universitats-Verlag GWV Fachverlage GmbH, Wiesbaden (Wirtschaftsinformatik) (2006)

Mönch, L., Uzsoy, R., Fowler, J.: A survey of semiconductor supply chain models part I. Semiconductor supply chains, strategic network design, and supply chain simulation. Int. J. Prod. Res. **56**(13), 4524–4545 (2018)

Oliver, R.K., Webber, M.D.: Supply-chain management: logistics catches up with strategy. In: Klaus, P., Müller, S., (eds.) The Roots of Logistics, pp. 183–194. Springer, Heidelberg (2012)

Pfund, M.E., Balasubramanian, H., Fowler, J.W., Mason, S.J., Rose, O.: A multi-criteria approach for scheduling semiconductor wafer fabrication facilities. J. Sched. **11**(1), 29–47 (2008). https://doi.org/10.1007/s10951-007-0049-1

Singh, R., Mathirajan, M.: Experimental investigation for performance assessment of scheduling policies in semiconductor wafer fabrication—a simulation approach. Int. J. Adv. Manuf. Technol. **99**(5–8), 1503–1520 (2018). https://doi.org/10.1007/s00170-018-2414-y