Smart Manufacturing at Siemens with metaphactory Knowledge Graph Platform

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EXECUTIVE SUMMARY

Siemens AG is one of the leading providers of factory automation solutions and components as well as Manufacturing Execution Systems and Product Lifecycle Management Software. To support human manufacturing planners and line operators in their daily tasks and increase the autonomy of production machinery, the research group for "Semantics and Reasoning" of Siemens Corporate Technology initiated a Manufacturing Knowledge Graph leveraging metaphactory, an innovative platform for building Knowledge Graph applications.

The goal was to test the feasibility of Smart Manufacturing Planning and Smart Manufacturing Execution concepts utilizing semantic technology. The feasibility studies conducted proved that the number of possible plans and configurations that human planners need to evaluate can in some situations be reduced from approx. 1,400 to as few as 40. Additionally, by enabling machines to act autonomously, low-volume orders can be made possible and become affordable.

THE CUSTOMER

Siemens AG is one of the leading providers of factory automation solutions and components as well as Manufacturing Execution Systems (MES) and Product Lifecycle Management (PLM) Software. This case study focuses on the results achieved in a feasibility study for **Smart Manufacturing Planning** and **Smart Manufacturing Execution** that was conducted by the "Semantics and Reasoning" research group of Siemens Corporate Technology in cooperation with Siemens business units active in the field of manufacturing.

It opens the door for including knowledge-level information integration into future manufacturing solutions as part of the Siemens product portfolio, such as Opcenter[1].

EXECUTIVE OVERVIEW

Industry

- Manufacturing Automation

Use Case

- Manufacturing Planning and Manufacturing Execution.

Goals

- Cost and time savings by supporting human manufacturing planners and line operators.
- Calculation and validation of manufacturing plans.
- Automated, skill-based allocation of machines to production requests.

Challenges

- Integrate engineering data from various sources with domain expert knowledge to support machine allocation decisions.
- Ensure transparency at the knowledge level and avoid representation complexity.

Solution

- Manufacturing Knowledge Graph to capture heterogeneous data sources and expert knowledge.
- AI-based knowledge graph application to automate the allocation of suitable production equipment.

Results

- Reduced number of plans human manufacturing planners need to review from approx. 1,400 to just 40.
- Feasible and affordable realization of low-volume orders.

THE CHALLENGE

Knowledge-level Transparency for Flexible Manufacturing

Industry 4.0 promises to increase the autonomy of machines through smart factories, where cyber-physical systems help bring more flexibility and adaptability into production. The Knowledge Graph experts in the "Semantics and Reasoning" group of Siemens Corporate Technology initiated a Manufacturing Knowledge Graph to support flexible manufacturing in engineering as well as operations. Using the **Manufacturing Knowledge Graph**, machines can be equipped with explicit semantic descriptions about their characteristics and capabilities (aka skills). This allows cyber-physical systems to compare these descriptions to production requests and decide on suitable candidate machines when manufacturing new product orders.

> "MASS PERSONALIZATION IS A NEW NORM IN MANUFACTURING. PRODUCTION RESOURCES CAN LEVERAGE KNOWLEDGE GRAPH SEMANTICS TO DYNAMICALLY MATCH THEIR CAPABILITIES AND AVAILABILITIES TO INDIVIDUAL PRODUCT CONFIGURATIONS."
>
> **Raffaello Lepratti**
> Siemens Manufacturing Operations Management

The **challenge** that many industry players face here is the integration and representation of data required for automating allocation decisions. Information from a variety of sources needs to be connected at the „right" level of granularity. At the same time, expert knowledge about machine capabilities, which is today locked in the engineer's mind, needs to be made machine-interpretable. Moreover, transparency over the decisions autonomously taken by machines needs to be ensured and is critical for human operators to trust the automated decision making process.

Fortunately, the explicit semantics encoded in Knowledge Graphs help to implement automated explanation techniques that inform operators and planners about the reasons why a machine is allocated to a task or not.

To fully reap the benefits of semantic technology and Knowledge Graphs in addressing the challenges described above, Siemens needed to tackle the following three aspects:

- Find the right level of detail for knowledge representation of the manufacturing domain that is sufficient for automating allocation decisions but also manageable by developers and end users.
- Control the knowledge acquisition bottleneck by integrating information from other data sources into the Manufacturing Knowledge Graph, e.g., such as product design information like Bill of Materials and Bill of Process from PLM tools like Teamcenter.
- Provide expressive visualizations and interfaces for end users such as planners and line operators to easily and intuitively access the knowledge structures, configure the matchmaking process, and influence the automated decision making.

[1] *https://www.plm.automation.siemens.com/global/de/products/manufacturing-operations-center/*

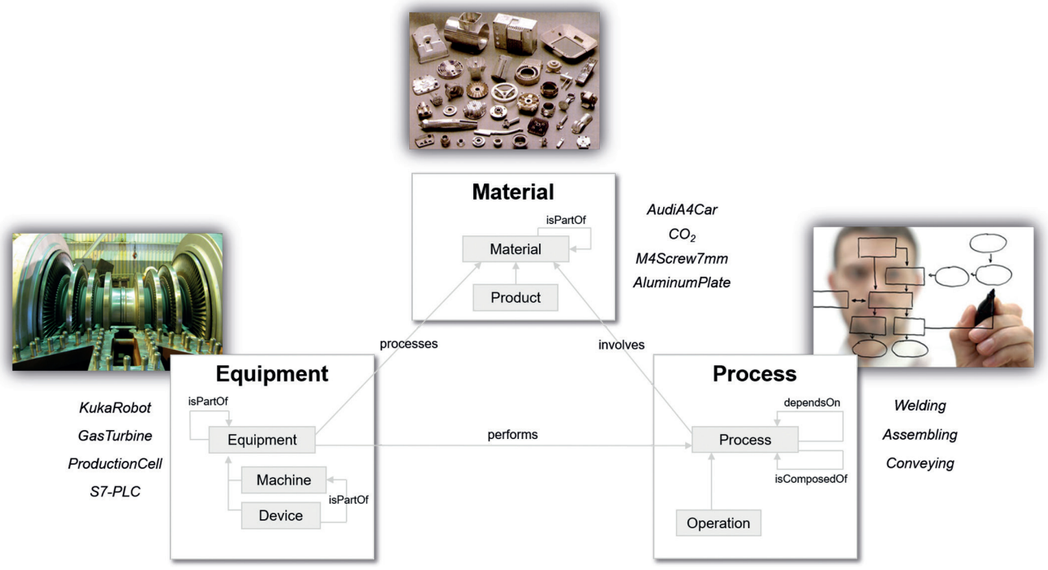


Figure 1
Ontology for Representing Digital Twins of Technical Machinery – Equipment, Material & Processes

THE SOLUTION

metaphactory, the innovative platform for building Knowledge Graph applications, was deployed to manage the Manufacturing Knowledge Graph and help Siemens build an **intuitive application for producibility** checks on top. This resulted in the design of an AI-based solution that utilizes techniques of automated reasoning to decide whether a production step can be allocated to a particular machine based on the semantic descriptions of the machine's capabilities. The overall solution was designed to address two core use cases:

- **Smart Manufacturing Planning:** Support human manufacturing planners during the manufacturing planning process prior to production by providing suggestions for valid production plans.
- **Smart Manufacturing Execution:** Introduce additional functionalities to MES software to fully automate the setup and preparation of machines and route products to suitable machinery. This is particularly relevant to and significantly reduces the cost and effort for realizing low-volume orders.

The different aspects of the solution developed by Siemens Corporate Technology on top of the metaphactory Knowledge Graph platform are described in the following sections.

Supporting Automated Decision Making with Knowledge Graphs

Representing domain knowledge about equipment, products, materials and processes, matching machine skills against required production steps, planning production workflows based on skill knowledge, and the justification of automated decisions are all made possible using the Manufacturing Knowledge Graph. Figure 1 depicts the three pillars in the manufacturing model which need to be accounted for: materials, processes, and equipment. An unprecedented benefit of the Manufacturing Knowledge Graph is that various data sources can be integrated and federated on-demand using metaphactory, and that the schema used can be flexibly and easily expanded to accommodate for these heterogeneous data sources. The Knowledge Graph solution was deployed in an AWS environment using an open-source graph database.

Managing and Querying the Manufacturing Knowledge Graph

For this feasibility study, metaphactory was leveraged as a rapid application development platform, allowing for the flexible integration of the Manufacturing Knowledge Graph with Siemens' PLM and MES software.

Components for workflow planning and skill matching were hosted in a cloud-environment alongside the Knowledge Graph and connected to metaphactory via SPARQL for access to knowledge graph content.

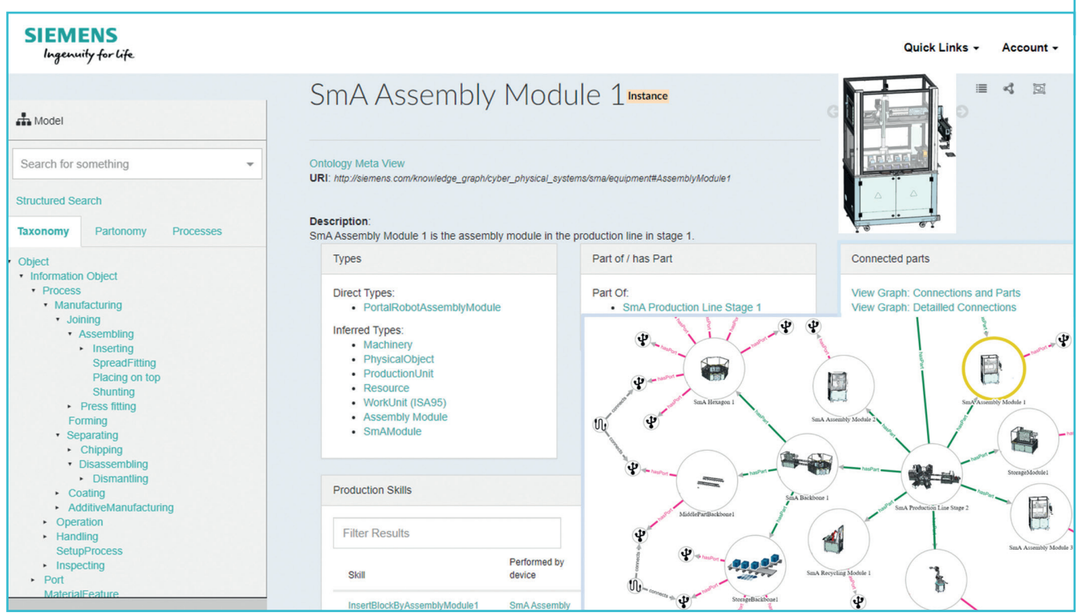
Using its federation engine, metaphactory enables a unified overview of the triple store and external, heterogenous data sources, thus being a highly efficient middleware solution for managing and querying the Manufacturing Knowledge Graph.

Visualizing and Editing the Manufacturing Knowledge Graph

As a frontend solution, metaphactory enables transparency for end users. Utilizing these features, manufacturing planners and line operators have access to knowledge graph content and are provided insights into machine setup and states, connections, skill characteristics, etc., as exemplified in Figure 2.

> "ONE OF THE REASONS WE CHOSE METAPHACTS WAS BECAUSE OF THEIR EXPERTISE WITH CREATING AND MANAGING ENTERPRISE KNOWLEDGE GRAPHS AND BUILDING TAILORED APPLICATIONS ON-TOP."
>
> **Steffen Lamparter**
> Head of Research Group on Semantics and Reasoning, Siemens Corporate Technology

Figure 2
Visualization of manufacturing knowledge in metaphactory for user interaction and transparency over the knowledge graph



> “SEMANTIC TECHNOLOGY IS A SIGNIFICANT ENABLER FOR ADVANCING FUTURE SKILL-BASED ENGINEERING AND MANUFACTURING EXECUTION SCENARIOS AS WE EXPLORE THEM IN OUR RESEARCH LAB AS WELL AS IN PILOT PROJECTS IN OUR SIEMENS FACTORIES.”
>
> **Matthias Loskyll**
> Director Advanced
> AI for Siemens Factory Automation

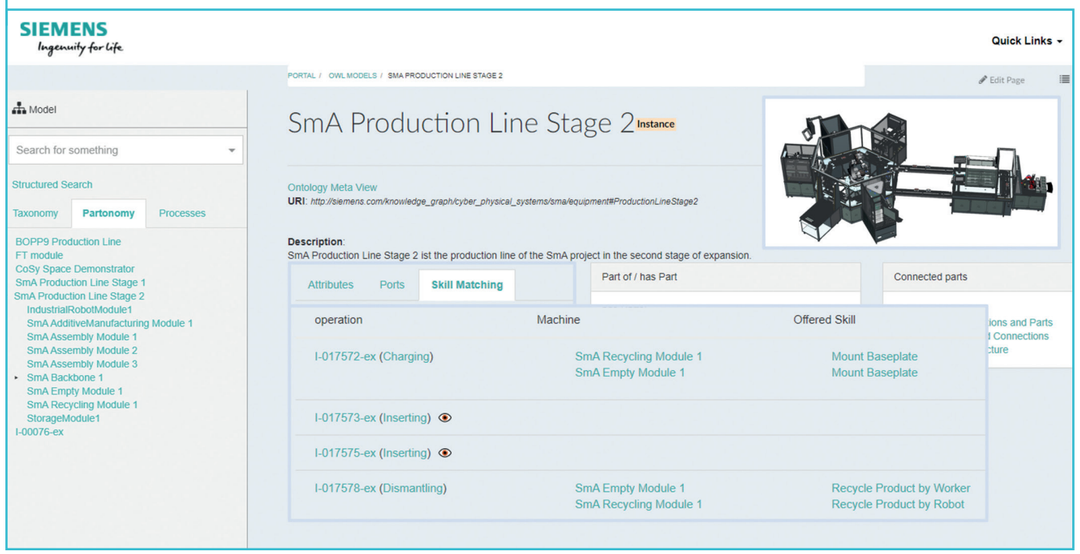
Using simple search interfaces to define specific queries or by navigating through graph structures in the Web browser, end users can obtain answers to a number of production-specific questions, such as:

- Which tasks need to be performed to produce a product?
- Which tasks can be performed utilizing existing equipment?
- Which required tasks can be mapped to existing equipment?
- Can this new product model be produced using the existing equipment?
- Which part goes to which machine?
- In which order should the production steps be performed?

Answers to these questions and more are provided flexibly in various formats, be it interactive and intuitive graph visualizations, tables or charts. Moreover, other Web-based visualization tools for complementary visualizations are also seamlessly integrated via Web-based standards and interfaces like SPARQL and REST.

Figure 3 exemplifies the integration of a REST service for an AI-enabled semantic matchmaking backend component through metaphactory’ federation engine Ephedra. The component applies interactive skill matching to data in the knowledge graph and displays the results on the fly.

Figure 3
Interactive skill matching of production operations against the skills of a production line



THE COOPERATION

The metaphacts team offers unmatched experience and know-how around enterprise knowledge graphs for customers of various sizes and across multiple industries.

“One of the reasons we chose metaphacts was because of their expertise with creating and managing Enterprise Knowledge Graphs and building tailored applications on-top,” comments Steffen Lamparter, Head of Research Group on Semantics and Reasoning at Siemens Corporate Technology. “We have worked with metaphacts in other projects in the past, and the interaction experience was beyond our expectations. Support was always smooth and it was great to see that customer feedback is taken into account and that the team prioritizes customer satisfaction.”

“We’re always delighted to work with customers who truly understand how knowledge graphs can transform an organization,” says Daniel Herzig-Sommer, COO at metaphacts. “The Siemens engineers proved to have very deep expertise and know-how around semantic technology and knowledge graphs, and succeeded in building a flexible solution for smart factories.”

> “THE SIEMENS ENGINEERS PROVED TO HAVE VERY DEEP EXPERTISE AND KNOW-HOW AROUND SEMANTIC TECHNOLOGY AND KNOWLEDGE GRAPHS, AND SUCCEEDED IN BUILDING A FLEXIBLE SOLUTION FOR SMART FACTORIES.”
>
> **Daniel Herzig-Sommer**
> COO, metaphacts

THE RESULTS

„Mass personalization is a new norm in manufacturing. Production resources can leverage Knowledge Graph Semantics to dynamically match their capabilities and availabilities to individual product configurations,” says Raffaello Lepratti within Siemens Manufacturing Operations Management.

This feasibility study demonstrated that significant time and cost savings can be achieved through **Smart Manufacturing Planning**, should this solution be deployed into the production environment. Manufacturing planers went from needing to review approx. 1,400 to just 40 plans for the production of new orders. This reduction could be calculated based on automated machine allocation and material-flow constraints, and promises significant savings in working hours for the planners.

In the **Smart Manufacturing Execution** use case, the complete semantic technology stack could be successfully integrated in a running automation plant seup. Knowledge-based allocation decisions became part of the loop between readily available Siemens PLM and MES software and the underlying Siemens automation hardware.

This setup showcased the future automation scenario of lot-size-one production, where as few as one item is actually produced. Such scenarios become possible and affordable because new product orders described in PLM systems can be issued via knowledge graph structures and run through the producibility check for a fully automated routing of production material to suitable production machines.

“Semantic technology is a significant enabler for advancing future skill-based engineering and manufacturing execution scenarios as we explore them in our research lab as well as in pilot projects in our Siemens factories,” says Matthias Loskyll, Director Advanced AI for Siemens Factory Automation.

Outlook – The Road to Production

The results of the feasibility study described above reinforced Siemens’ confidence in the power of Knowledge Graphs and semantic technology. Siemens will continue to drive the use of these technologies in Manufacturing Planning and Execution solutions as part of the corporate research and innovation agenda. The initial results derived from real-world, in-house and customer-driven use cases are planned to be included into productization roadmaps of the Siemens product portfolio to enrich manufacturing solutions like Opcenter.

Siemens is aiming at tightly involving its customers in the development of new solutions. The value-add of using semantic technology in the manufacturing sector will be sharpened in close collaboration with customers. This will ensure that new technologies and applications are integrated into the product portfolio based on real-world needs.

Lastly, the feasibility study proved that Knowledge Graphs and semantic technology can be applied across a multitude of use cases and business units. Therefore, the utilization of these technologies for handling technical machinery and their processes at a knowledge level is now also being transferred to other Siemens-relevant business, such as Energy Systems, Building Technology or Mobility Solutions.

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Demo

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Get started

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