Progress on IOF's Process and Production Planning Reference Ontology

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Abstract

Modern manufacturing enterprises are characterized by applications of information and automation at all levels in product life cycle (design, manufacturing, usage, recycling). Seamless flow of the data between various stake holders in such supply chain is expected to deliver concepts such as Industry 4.0 and IIoT. However, in order to achieve such semantic integration it is necessary to capture and share knowledge from various product development stages. This paper reports on efforts to develop a reference ontology for Process and Production Planning (PPS) and current progress of the corresponding working group within Industrial Ontology Foundry (IOF). The development process is described together with the current draft of the PPS ontology. Discussion at the end also addresses remaining challenges.

Keywords 1

Ontology, Process Planning, Production Planning, Scheduling

1. Introduction

Modern industry is characterized by a widespread use of information technology and software tools in most design, planning and execution activities, and globalization of markets and resources. However, the ever growing generation, storage, and exchange of design and manufacturing data ask for a proper knowledge representation in formats that will enable easy sharing between various software products, as well as workforce and resources in different cultures and countries. While there has been some success in providing data integration among software tools, it is our opinion that only semantic analysis of the data and development of ontologies for product design and manufacturing planning tasks will enable smart manufacturing applications (e.g. cloud manufacturing, AI-based manufacturing, Industrial IOT, Industry 4.0) [1].

Currently, manufacturing engineering processes see the involvement of various managers, engineers, and operators interacting with several software tools, namely Product Life-cycle Management (PLM), Enterprise Resource Planning (ERP), and Manufacturing Execution Systems (MES) with data flowing in both directions (see Figure 1). For example, all those systems need to have static and/or dynamic data about resources and their availabilities; all those systems need to compare planned activities and real-time deviations or disturbances. Manufacturing enterprises make operational decision based on comparing planned processes from PLM and ERP systems with real-time status from MES systems, and quality of those decisions depend on understanding data and their meaning (semantic) in those systems. There have been some results in adopting or developing ontologies for portions of this business process flow [2] but there has not been overall approach to address semantic data integration on larger scale.

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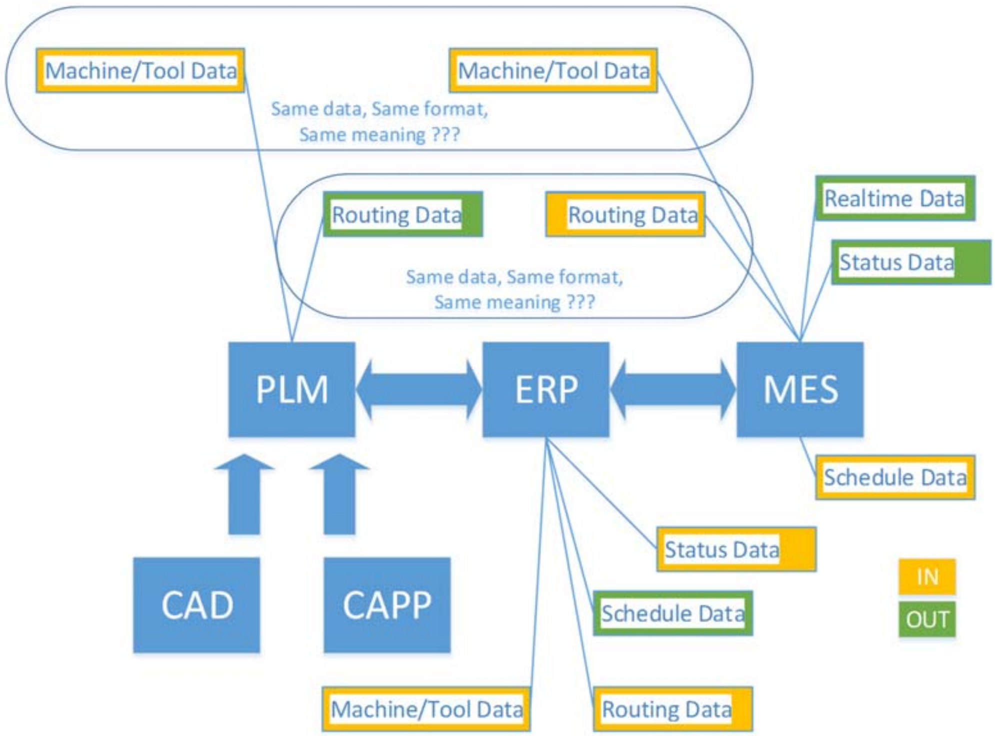

Figure 1. Manufacturing enterprise process data flow

In this scope, the goal of Production Planning and Scheduling workgroup (PPS WG) within IOF activities[2] has been to develop modular ontologies for process planning, manufacturing system design, and scheduling activities thus supporting data sharing among different ICT systems in the manufacturing enterprise. The development of the PPS ontologies stems from the definition of key use cases and competency questions that will be used for the validation as well (Section 2). The proposed PPS ontologies will include relevant terms (Section 3) and will be linked to the IOF top level ontology (Section 4).

2. Use Cases

The PPS WG has collected few use cases from members of the IOF community in order to better define scope and goals of the WG before developing the r reference ontologies: process planning, production system design, and scheduling optimization.

The process planning use case starts with a part design provided as a drawing or a CAD model (which has nominal geometry and tolerance specification) and the goal is to develop one or more process plans that will completely produce a part with given design, considering available production technologies, machines, tools and other resources. Those plans also need to include a sequence of processing steps that will guarantee achievement of prescribed tolerances. Currently in industry various levels of database search are performed (mostly for tools) in CAM tools in order to generate plans with using planners' experience for capabilities and sequencing, while research prototypes apply rule-based reasoning combined with a search within limited data sources (e.g. [3]. Adopting an ontology would provide semantic data integration with tool/machine databases, intelligent matching between design specifications and process capabilities, and manufacturing process model that can be integrated with production system design and scheduling.

The production system design use case takes place after process planning has been completed and consists in the definition of production system configurations that are able to reach the production goals while specifying the required production resources, process/resource assignments, layout design, etc.

[2] https://www.industrialontologies.org

Candidate system configurations may be assessed thanks to performance evaluation methods and tools while iterating the system design loop. Currently, system design employs heterogeneous software tools that are spread among several departments. For example, dynamic performance evaluation (e.g. via discrete event simulation) relies on product and resource data, but simulation software tools do not provide integration paths with PLM/ERP systems. Developing an ontology of products, resources and performance measures, would definitely enable smooth data integration from PLM and design tools to simulation modeling tools.

The scheduling optimization use case is a further step towards the operational control of production processes. In addition to process and resource data, scheduling also needs data from customers, i.e. orders and their due dates, suppliers and supplied components/materials lead times, etc. Currently optimization models are executed on separate optimization software, and it is really challenging to integrate their output into ERP and MES systems. The dynamic nature of production scheduling requires repeated execution of optimization algorithms, and only ontology of the related terms can provide proper semantic links between those tools.

Numerous competency questions should be answered with help of the PPS ontologies under a unified top level framework. The following list shows a few key examples:

- How could a planner identify and allocate suitable manufacturing processes, machines, and tools for a given set of product specifications?
- How could a planner identify alternative manufacturing resources for a particular set of process specifications?
- Which are the production resources (machine tool, buffers, transporters, etc.) composing a production system configuration?
- Which production systems (or resources) are available during the execution of the production plan? Which are their properties and states?
- Which are the scheduled/simulated/monitored KPIs (e.g. throughput, average inventory, and cycle times) of the production system? What is the risk that expected KPI targets will not be achieved?

3. Relevant Terms

More detailed descriptions for above mentioned use cases were provided for the process of WG discussion and identification of most important terms. With the focus being on the process planning use case, the working group has identified ~20 most relevant terms to formalize for a reference ontology for process planning. The list of these terms is shown in Table 1in alphabetical order. Afterwards that, the group members collected definitions for those terms from subject matter experts (SME) in the group and beyond (other IOF members, literature, standards, textbooks) in order to start formalization for the ontology.

Table 1.
Production Planning and Scheduling top-25 terms.

Component	Hole Making	Quality Specification
Dimension Specification	Machine	Quality Representation
Drilling Tool	Process Capability	Tolerance Representation
End Milling	Machining Process	Tolerance Specification
Feature	Manufacturing Process Function	Tool Capability
Feature Specification	Material Removal Function	Twist Drilling
Fixture	Milling	Work Holder
Form Feature	Pocket Making Function	
Hole Improving	Production Machine	

After the definitions were collected, the work involved alignment of the definitions with top-level ontology, and the draft IOF core ontology in order to provide formalization and formal logical definitions for those terms. In the rest of this section we illustrate this process for a few terms from Table 1.

Term: Form Feature

SME Definition: A set of geometric entities (surfaces, edges, and vertices) together with specifications of the bounding relationship between them and which have engineering function and/or provide assembly aid [4].

IOF Formal Definition: A Fiat Object Part that is a proper part of an Artifact and bounded by some fiat boundaries, some of which must share a portion with the bona-fide boundary of the artifact.

Term: Design Document

IOF Formal Definition: An Information Bearing Artifact that is designed to bear some Design Specification either in a form of an annotated drawing (sketch), ideal for visualizing the design of an artifact, or in a form of markup file (electronic), which can be parsed by a suitable computer application (e.g. CAD) for displaying the design in 3D/2D graphics.

Term: Artifact Capability

IOF Formal Definition: An Artifact Capability 'c' is a disposition which inheres in an artifact 'a', such that

a) demarcates the extent by which some function 'f', inhering in artifact 'a', is realized in some process 'p', a participates in, and

b) predicts some change of state for 'a' or some other object 'a'', which also participate in process 'p'.

Term: Machining Function

IOF Formal Definition: A Machining Function is an Artifact Function that is borne by a Production Machine in virtue of its internal structure, which is composed of mechanical or electrical components or both, intentionally arranged to gain mechanical advantage, when connected to a source of power.

4. Process and Production Planning OWL Ontology

Process and Production Planning ontology has been built by extending the terms definitions based on the upper level ontology (BFO) [5], a few midlevel ontologies (IAO, CCO)[3] , and an IOF reference ontology from industrial applications (IOF core) [6].

Therefore, the draft PPS ontology (Figure 2) includes only terms that extend classes and terms from upper level ontologies. The figure shows relevant classes from BFO (on the top, in orange), a few necessary terms from the CCO ontology (on the left, in yellow), several IOF classes (underneath BFO classes, in light orange). The current development of classes for PPP ontologies shows terms divided into two groups, i.e. design related terms (prefixed with DSGN), and process planning terms (prefixed with MFG). The figure shows only is-a relationships among defined classes.

The relationships between design terms and process planning terms are shown in Figure 3 (the detailed explanation of this example is given in [7]). This figure shows detailed relations between product/part representation and specification on one side with manufacturing process functions, and resources capabilities on the other. The execution of the corresponding rule is triggered by filter specification which corresponds to finding dimension within a given range.

[3] https://github.com/CommonCoreOntology/CommonCoreOntologies

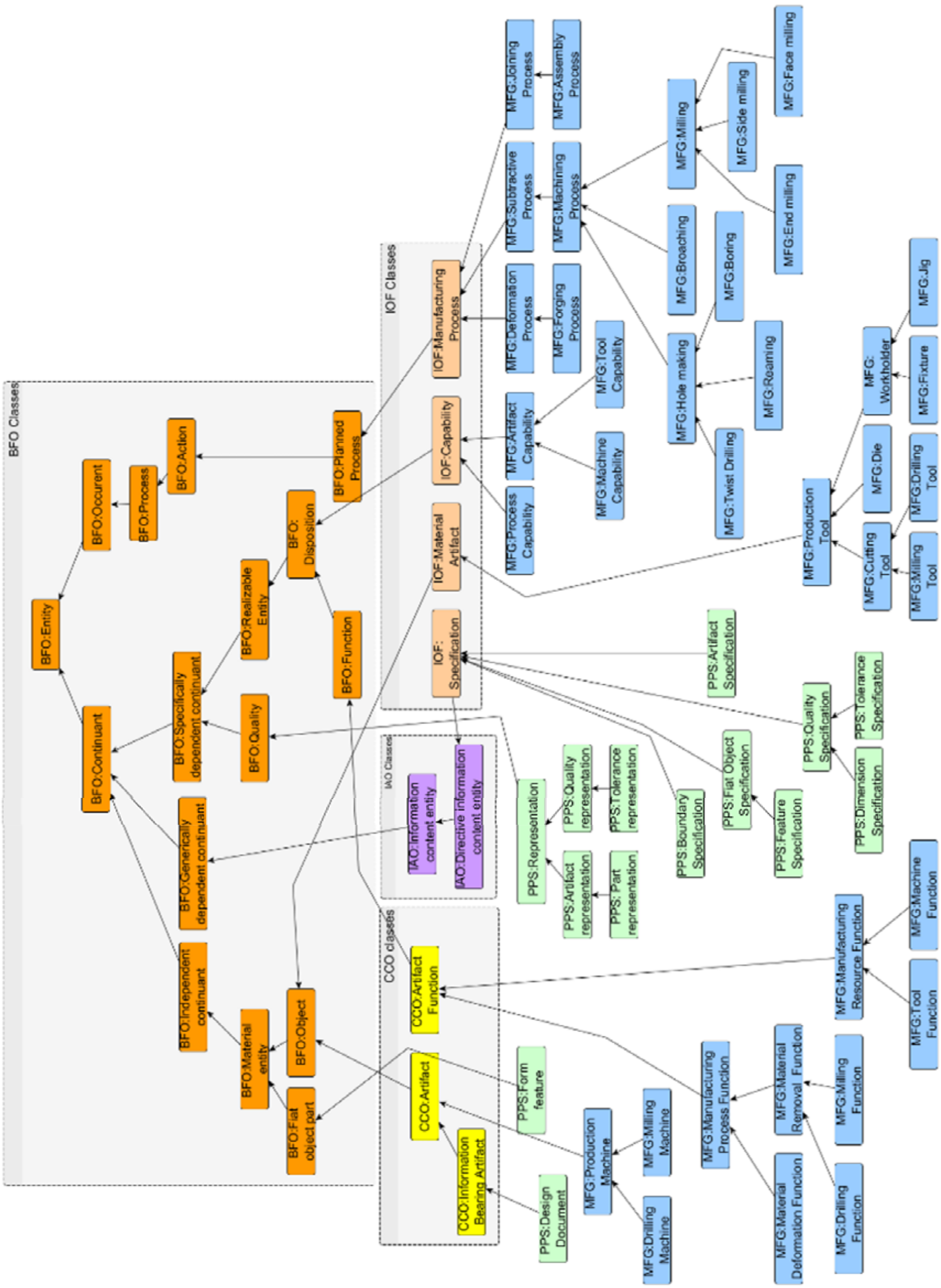

Figure 2. Inheritance hierarchy of PPS ontology terms

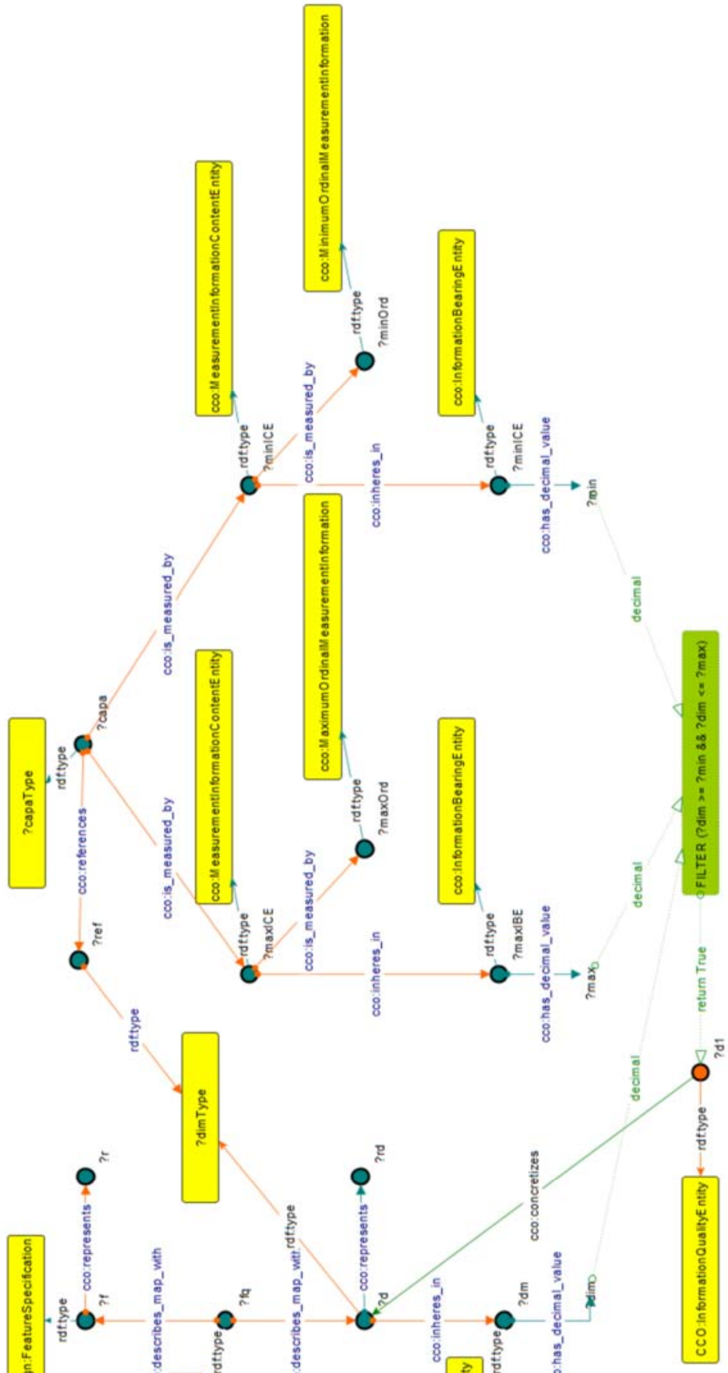

Figure 3. Relations corresponding to matching of design specifications with process functions and resource capabilities (from [7])

5. Discussion

The draft reference PPS ontology presented in this paper is the result of group work of several researchers. Results accomplished so far include design specification, process and resource capability, and resource function. This approach was recently tested in applying this ontology to machining process planning application. However, there is much more work until its completion and a few items still need to be discussed and verified. Further developments to be addressed in next period include:

- Demarcation between functions and capabilities in order to represent how various resources contribute to the part quality (from specification) during manufacturing processes (e.g. what is function of a machine and what is function of a tool)
- Discussion about form feature and manufacturing feature concepts, as they are fundamental elements in some common design and manufacturing activities.
- Levels of granularity in representing manufacturing processes for different planning and scheduling tasks, for example process planning is concerned with many details of each manufacturing operation on a single product, while scheduling deals with higher level operations on several products.
- Formalization of manufacturing resources in different phases of product and manufacturing system design, planning and execution.
- Formalization of scheduling optimization related terms for representing abstract types of entities, such as equation, sequence, problem, constraints, objectives, and performance measurements.

Furthermore, a number of manufacturing operation specific terms, such as capability, job, batch, lot, and cell, require coordination with other IOF working groups, as they are commonly used in the manufacturing, supply chain and maintenance operations.

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