Interoperability Between ERP and PLM Systems Using Ontologies - a Case Study

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Interoperability Between ERP and PLM Systems using Ontologies - A Case Study

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Abstract.
Modern manufacturing has been undergoing significant transformation into the digital era. Advances such as additive manufacturing, biomanufacturing, digital twin, and digital manufacturing bring benefits to manufacturers, but also pose the challenge of transforming planning data using several software tools to accomplish real-time feedback and adjustment for optimal production control and monitoring. Software tools such as CAD, and CAM. PLM, Simulations, ERP, and MOM usually store data in their data models without regard for the semantic meaning of such data. To address interoperability issues researchers have developed ontologies to capture the semantics of data, for example, Industrial Ontology Foundry (IOF) is leading efforts to develop reference ontologies for semantic data integration. This paper reports the results of applying those reference ontologies for data interoperability between CAPP and ERP systems. We have extended reference ontologies to include terms from a domain of plastics manufacturing, particularly process and production planning applications. Domain ontologies are integrated with some domain data of process plans plastic parts from a CAPP systems, and Odoo, an ERP system. We have demonstrated semantic equivalency of those data, though they carry different data model labels. The knowledge graph of ontology and data has been visualized using knowledge graph tool GraphDB. The demonstration serves as a pathway and method for software systems interoperability in industry.

Keywords: Ontology, ERP and PLM System, IOF, Industry 4.0

1 Introduction

Interoperability is the ability to exchange information, and resources across different domains and software tools seamlessly. The correct transfer of information and data resources leads to improved system efficiency and better outcomes. Ontology plays an important role in maintaining interoperability, by formally representing the knowledge within a domain. Ontologies organize and represent domain-specific knowledge, such as in manufacturing or healthcare, in a structured, hierarchical manner. This organization facilitates a clearer understanding and straightforward navigation of the information, making it more accessible and interpretable for users.

The ERP (Enterprise Resource Planning) is a software that helps companies manage all their operations across various departments such as planning, manufacturing, finance, supply chain, and procurement under one domain. It helps companies in achieving efficiency by automating business processes and providing integrated support throughout the company [1]. However, ERP systems suffer semantics inconsistencies, and the use of ontologies can address this issue.

The CAPP (Computer Aided Process Planning) is a bridge between CAD and CAM where the design of an order is fed as input into the system and output is the production process plan to manufacture the order from the system [2]. However, CAPP also suffers from the issue of interoperability when working across different platforms. The issue of interoperability in the CAPP can also be addressed using ontologies. The ontologies provide a structured framework representing knowledge in a hierarchical format.

This research is important in two ways: a) The research creates the semantics for the ERP and the CAPP system using ontologies to address the issue of interoperability, thus making sure that the system is working effectively by seamless transformation of information across multiple platforms; b) The use of ontologies would provide more meaning to the information stored in ERP and CAPP by identifying the instances and providing the relationships between different instances which is not present in the CAPP and ERP systems.

The paper is divided into five sections: section 2 discusses the literature review followed by methodology in section 3. Section 4 presents the case study and section 5 presents the conclusion.

2 Literature Review

The objective of ontology in manufacturing is to provide a standard platform to store information so that there are fewer ambiguities in communication related to product manufacturing thus, reducing the potential for errors. This section discusses the previous research done on ontology in manufacturing and the research on semantic interoperability issues in PLM and ERP systems.

The ontology-based framework streamlines the design process in aircraft manufacturing by using domain knowledge for automation and thus, improving collaboration and decision-making in the aircraft manufacturing process [3] [4]. The aircraft industry faces the challenge of digital discontinuity and the ontology-based system reduces development time, and cost and enhances design quality[5]. The standardization helps in the integration and sharing of knowledge thereby enhancing the application [6] [7].

Ontology can significantly improve manufacturing planning and execution, providing a deeper understanding of the process and optimizing operations in the context of Industry 4.0 in computer-aided process planning [8]. The model for representing the capabilities of machine tools and processes in cloud manufacturing is preseted in [9] .

The key manufacturing constraints of variety, time, and aggregation are addressed by the use of SIMPM (Semantically Integrated Manufacturing Planning Model) [10]. The use of SIMPM enhances the interoperability and reasoning in distributed manufacturing systems by providing a common semantic structure for communication among multiple agents [10].

Ontologies in some industries such as digital manufacturing still face the challenge of semantic interoperability due to their development based on local needs and lack of broader integration. To do this a methodological development of ontologies needs to be developed. The IOF (Industrial Ontology Foundry) could play a crucial role in promoting a methodological development process of ontologies[12]. The present research uses IOF to create ontologies for the two case studies presented in this paper.

From the literature on ontology in manufacturing, it is evident that the use of ontology enhances knowledge transfer and interoperability. The application of ontology in manufacturing offers substantial benefits for Industry 4.0, facilitating seamless knowledge exchange across various platforms and contributing to more efficient and integrated processes.

2.1 Semantic Interoperability in ERP and PLM Systems

The ERP and PLM systems are an essential part of the digital and cloud manufacturing aims of Industry 4.0 for its management of data[13], [14]. In modern industry managers, engineers, and operators engage with multiple software tools such as Product Lifecycle Management (PLM), Enterprise Resource Planning (ERP), and Manufacturing Execution Systems (MES). Data flows bidirectionally among these systems, as illustrated in **Figure 1**. [13]. However, they face the issue of semantic interoperability, and due to this, they face the challenge of the smooth delivery of data, and data exchange and thus, hindering the overall performance of the system.

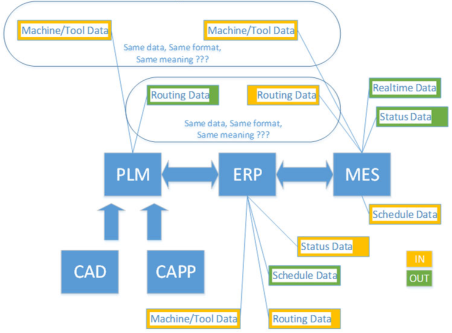

Figure 1: Data exchange between software systems

A fact-oriented modeling approach and an algorithm for constructing semantics to enhance understanding and improve interoperability was created by *[14]*. Interoperability is rapidly changing the evolution of ERP systems, making them from traditional information system integrators to completely interoperable environments that are more accustomed to the change. The use of ontology can improve the issue of semantic interoperability in ERP and PLM systems. The ontology-based model that maps various stages of a product's life cycle, built upon the BFO (basic formal ontology) as part of the IOF project was created by [13]. A fact-oriented modeling approach and an algorithm for constructing semantics to enhance understanding and improve interoperability was created by [14].

The ontology model built on semantic web technology to ensure ERP interoperability was built by [16] . The authors show the use of semantic web ontology for business domain example systems. The OWL- DL- based ontology was used for a Closed-Loop PLM model in the automotive industry, improving interoperability and data integration[18]. It can be concluded from the literature review on ontologies and in PLM and ERP systems that ontologies significantly enhance interoperability and data integration by providing semantic capabilities. Although existing studies highlight its application, the topic needs more exploration to deepen our understanding and to identify additional opportunities for leveraging ontology in these systems.

3 Methodology

This section outlines the process used to establish the semantic of data interoperability between the CAPP system and Odoo (ERP system) by comblining the use of appropriate extended ontologies, a database system, and a mapping tool to generate an ontology based unified knowledge graph, see **Figure 2**. The methodology comprises several steps: 1) routing data generation, 2) selecting and extending reference ontologies, 3) using the mapping tool, and 4) knowledge model validation and application. This systematic approach ensures seamless exchange of information between the systems, and, therefore, improves production planning and process control.

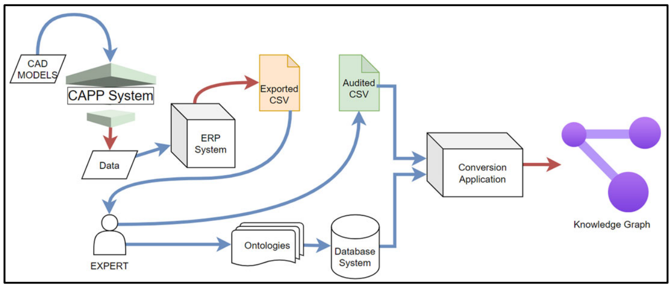

Figure 2: The proposed steps for the methodology

3.1 Routing Data Generation

In this step, CAD models can be imported into CAPP system [19], which processes the models to generate routing data specific to machining the loaded part. This routing data could provide detailed information about production sequences and associated resources required for manufacturing, for example:

- *Part Feature Names:* Descriptions and identifier details of the various features on the part to be manufactured.
- *Process Name:* The specific manufacturing process required for each feature (e.g., drilling turning, and drilling).
- *Machine:* Identification or name of the machine to be used for processing the part feature.
- *Tool Requirements:* The specific tool requires for the manufacturing process, ensuring compatibility with the machine and the material of the part.
- *Processing Time:* The established time required to complete each process step, aiding in production planning.

This routing data is pivotal in establishing semantic interoperability between a CAPP system and an ERP system. The detailed and structured routing data is first exported from the CAPP system as an Excel file, which is then imported into an ERP system, such as Odoo. Once in Odoo, data related to product manufacturing is again exported as an Excel file. This file undergoes further auditing and mapping to prepare all the information for effective ontology mapping and integration into the knowledge graph.

3.2 Selecting a Reference Ontologies

The second step involves selecting suitable reference ontologies from existing domain ontologies. In this case, the Industrial Ontology Foundry (IOF)[1] provides a standardized reference ontology with a hierarchical structure that aligns with key manufacturing concepts. Ontology and manufacturing experts analyze the data from the ERP system to pinpoint key domain-specific terms and relationships pertinent to process and production planning. After thorough analysis, the IOF reference ontologies are extended to incorporate new terms (classes and object properties) that are specific to the manufacturing domain. This extension process involves organizing and adding terms hierarchically to ensure the ontology accurately represents all necessary manufacturing terms.

3.3 Using the Mapping Tool

Following the generation and auditing of exported routing data from the ERP system, the data is imported into OntoRefine for mapping into knowledge graph. The data, exported as an Excel file, is carefully audited to maintain semantic consistency with the extended IOF-Core ontology. Experts then guide the mapping of data attributes in the Excel files to the appropriate terms in the extended IOF-Core ontology using OntoRefine. This mapping process guarantees semantic consistency and precise representation of the data. The mapped data is subsequently exported from OntoRefine in the Turtle file format (.ttl), forming what is known as A-Box or knowledge graph.

3.4 Knowledge Model Validation and Application

The extended IOF-Core ontology and the resulting data file from the mapping tool are imported to generate the final knowledge graph. Validating this model using a reasoner or through competency questions is essential to ensure its completeness, consistency, and accuracy. This final knowledge representation model serves as a dynamic tool that enhances the semantic interoperability between different manufacturing systems.

4 Case Study

This case study illustrates the practical applications of the ontology-based data interoperability framework, specifically tailored for the CAPP system and Odoo (ERP system), within a plastic manufacturing context. This section details the deployment of established methodologies—routing data generation, ontology extension, and data mapping—to enhance a specific manufacturing process, thereby demonstrating the system's effectiveness across various stages of data handling and integration.

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[1] https://oagi.org/pages/industrial-ontologies

Figure 3: A CAD model of Plastic Container with Lid

A Computer-Aided Design (CAD) model (see **Figure 3**) of a plastic container includes two primary components: the container body and its corresponding lid. A plastic manufacturing expert, who then identifies and generates detailed routing data critical for manufacturing this product. This data encompasses several key elements: Process Name, Manufacturing Type, Input Materials, Work Center (Machine), tool requirements, and estimated processing times. Once processed, the routing data was then subsequently imported into an ERP system (Odoo), facilitating the scheduling and management of manufacturing orders.

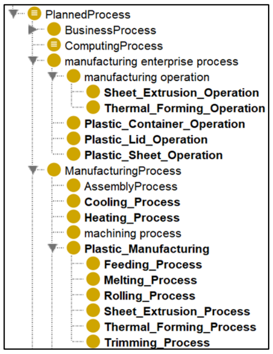
As illustrated in **Figure 4**, the ERP system (Odoo) generated detailed steps for the production of Extruded Sheets—input materials essential for the manufacturing of both the plastic lid and container. This data was then exported from Odoo to an Excel file for further analysis and refinement.

Product Extruded Sheets

Operation	Work Center	Duration Computation	Duration (minutes)
Pellet heating	Heater	Set duration manually	60:00
Melting	Extruder	Set duration manually	10:00
Sheet extrusion	Extruder	Set duration manually	60:00
Cooling	Extruder	Set duration manually	10:00
Sheet Rolling	Extruder	Set duration manually	10:00

Figure 4: ERP system's interface showing the operation steps of the Plastic Extruded Sheets

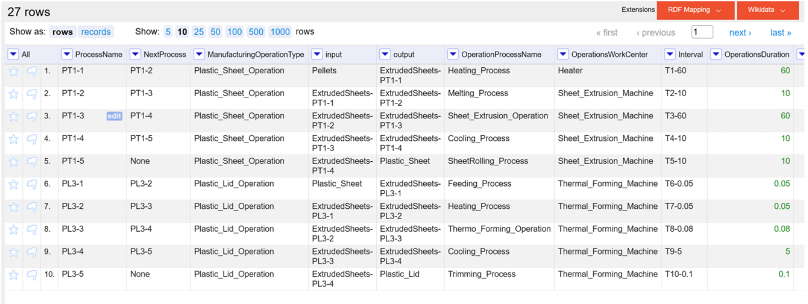
Experts reviewed the exported file from Odoo, applying necessary adjustments to enhance data compatibility with the targeted plastic manufacturing industry. This involved extending the domain ontology, specifically the IOF-Core, to incorporate new classes better suited to the industry's specific needs. As illustrated in **Figure 5**, these new subclasses (bolded) were integrated into the domain ontology under the "Planned Process" a class from IOF-core. Following this extension, we created an augmented data file for importing onto OntoRefine, a mapping tool, to initiate the data mapping process import (see **Figure 6**).



- PlannedProcess
  - BusinessProcess
  - ComputingProcess
  - manufacturing enterprise process
    - manufacturing operation
      - **Sheet_Extrusion_Operation**
      - **Thermal_Forming_Operation**
    - **Plastic_Container_Operation**
    - **Plastic_Lid_Operation**
    - **Plastic_Sheet_Operation**
  - ManufacturingProcess
    - AssemblyProcess
    - **Cooling_Process**
    - **Heating_Process**
    - machining process
    - **Plastic_Manufacturing**
      - **Feeding_Process**
      - **Melting_Process**
      - **Rolling_Process**
      - **Sheet_Extrusion_Process**
      - **Thermal_Forming_Process**
      - **Trimming_Process**

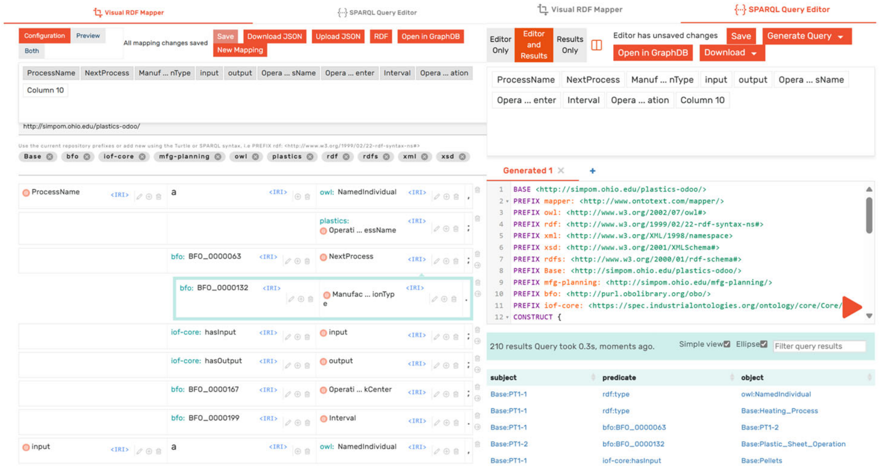
Figure 5: Extended version of IOF-Core for this plastic case study

Data mapping was conducted using two primary methods, as depicted in the **Figure 7**: the Visual RDF Mapper (main editor) and the SPARQL Query Editor (for detailed connections).



All			ProcessName	NextProcess	ManufacturingOperationType	input	output	OperationProcessName	OperationsWorkCenter	Interval	OperationsDuration
☆		1.	PT1-1	PT1-2	Plastic_Sheet_Operation	Pellets	ExtrudedSheets-PT1-1	Heating_Process	Heater	T1-60	60
☆		2.	PT1-2	PT1-3	Plastic_Sheet_Operation	ExtrudedSheets-PT1-1	ExtrudedSheets-PT1-2	Melting_Process	Sheet_Extrusion_Machine	T2-10	10
☆		3.	PT1-3 edit	PT1-4	Plastic_Sheet_Operation	ExtrudedSheets-PT1-2	ExtrudedSheets-PT1-3	Sheet_Extrusion_Operation	Sheet_Extrusion_Machine	T3-60	60
☆		4.	PT1-4	PT1-5	Plastic_Sheet_Operation	ExtrudedSheets-PT1-3	ExtrudedSheets-PT1-4	Cooling_Process	Sheet_Extrusion_Machine	T4-10	10
☆		5.	PT1-5	None	Plastic_Sheet_Operation	ExtrudedSheets-PT1-4	Plastic_Sheet	SheetRolling_Process	Sheet_Extrusion_Machine	T5-10	10
☆		6.	PL3-1	PL3-2	Plastic_Lid_Operation	Plastic_Sheet	ExtrudedSheets-PL3-1	Feeding_Process	Thermal_Forming_Machine	T6-0.05	0.05
☆		7.	PL3-2	PL3-3	Plastic_Lid_Operation	ExtrudedSheets-PL3-1	ExtrudedSheets-PL3-2	Heating_Process	Thermal_Forming_Machine	T7-0.05	0.05
☆		8.	PL3-3	PL3-4	Plastic_Lid_Operation	ExtrudedSheets-PL3-2	ExtrudedSheets-PL3-3	Thermo_Forming_Operation	Thermal_Forming_Machine	T8-0.08	0.08
☆		9.	PL3-4	PL3-5	Plastic_Lid_Operation	ExtrudedSheets-PL3-3	ExtrudedSheets-PL3-4	Cooling_Process	Thermal_Forming_Machine	T9-5	5
☆		10.	PL3-5	None	Plastic_Lid_Operation	ExtrudedSheets-PL3-4	Plastic_Lid	Trimming_Process	Thermal_Forming_Machine	T10-0.1	0.1

Figure 6: Data Sheet for mapping process



```
BASE <http://simpom.ohio.edu/plastics-odoo/>
PREFIX mapper: <http://www.ontotext.com/mapper/>
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX xml: <http://www.w3.org/XML/1998/namespace>
PREFIX xsd: <http://www.w3.org/2001/XMLSchema#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX Base: <http://simpom.ohio.edu/plastics-odoo/>
PREFIX mfg-planning: <http://simpom.ohio.edu/mfg-planning/>
PREFIX bfo: <http://purl.obolibrary.org/obo/>
PREFIX iof-core: <https://spec.industrialontologies.org/ontology/core/Core/
CONSTRUCT {
```

210 results Query took 0.3s, moments ago. Simple view☑ Ellipse☑

subject	predicate	object
Base:PT1-1	rdf:type	owl:NamedIndividual
Base:PT1-1	rdf:type	Base:Heating_Process
Base:PT1-1	bfo:BFO_0000063	Base:PT1-2
Base:PT1-2	bfo:BFO_0000132	Base:Plastic_Sheet_Operation
Base:PT1-1	iof-core:hasInput	Base:Pellets

Figure 7: Mapping interfaces: Visual RDF Mapper (left) and SPARQL Query Editer (right)

The final result after the mapping is demonstrated in **Figure 8**. The result of this mapping process is shown in the GraphDB figure, where the automatically generated graph (nodes and arcs) illustrates the interconnected data relationships. This integration between the mapping application and the knowledge graphing tool not only simplifies the visualization of results but also ensures thorough verification of the outcomes.

Key notations in the final knowledge representation model described in **Figure 8**, include:

1) Sub-processes of producing plastic sheets are "occurrent parts of" the Plastic_Sheet_Operation, shown in light green rectangles. The "precedes" property outlines the sequential order of operations, for instance, indicating that process PT1-4 precedes PT1-5.

2) The "type" relation specifies the type of processes of each process step.

3) An object property named "has participant at all times" is designated to identify the specific machine involved in each process.
4) The representation clarifies the input and output of each process, illustrating the continuous flow and another type of interconnection of manufacturing processes.
5) Processing times for each step are shown in orange rectangles, linked by the "occupies temporal region" relation, indicating the duration of each process.

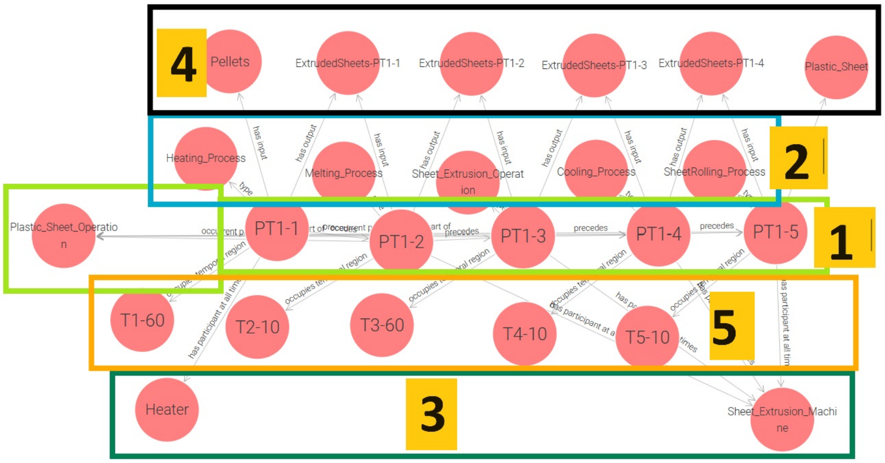


Figure 8: Result's knowledge graph of the proposed application

This semantic connections between ERP and PLM underscores the transformative potential of ontology-based frameworks in streamlining manufacturing processes through enhanced data interoperability and operational insights.

5 Conclusion

This paper has detailed the implementation of an ontology-based data interoperability framework within a plastic manufacturing context, utilizing the capabilities of a CAPP system and ERP systems(Odoo). Our approach hinged on the meticulous routing data generation from CAD models, the extension of IOF-Core ontologies to encompass manufacturing-specific terms, and the rigorous mapping of these terms using OntoRefine. These steps facilitated not only the streamlining of production processes but also enhanced semantic interoperability across manufacturing systems.

The deployment of this framework demonstrated significant advancements in production planning and control, as evidenced by the creation of detailed knowledge graphs that visualize the interactions and dependencies of manufacturing data. These visualizations have proven crucial for understanding complex manufacturing workflows and for making informed decisions that optimize operational efficiencies.

Through these initiatives, we anticipate not only refining the ontology-based data interoperability framework but also contributing to the broader field of manufacturing by providing robust tools for seamless data integration and management.

This endeavor will ultimately pave the way for smarter, more efficient manufacturing processes that are well-equipped to meet the challenges of the digital era.

We plan to extend this ontology-based framework to other sectors within manufacturing, exploring automated systems that minimize human intervention and maximize real-time processing capabilities. Future work will focus on developing a broader range of case studies to test the framework's applicability across different manufacturing conditions and systems. This expansion will likely include more complex case studies and the integration of automated data processing tools to further reduce manual oversight and enhance the system's adaptability to dynamic manufacturing environments.

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