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ONTOLOGY-BASED MODEL FOR PRODUCTION-CONTROL SYSTEMS INTEROPERABILITY

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ABSTRACT

One of the emerging control problem in manufacturing systems is the “information interoperability (I^2)” problem: information is required to be coherent and congruent with the specific use, particularly in interfacing manufacturing processes, at any stage of the product lifecycle management. Lack of comprehension, misunderstandings as well as redundant activities are typically signs of I^2 problems. Standardisation initiatives, in the frame of ISO and IEC (IEC 62264), try to answer these problems by specifying the information related to products, manufacturing resources and processes. These represent the most assessed corpus of knowledge for business to manufacturing (B2M) applications interoperability, available so far for studying and solving the I^2 issues. This paper tries to trace a path for studying the I^2 problems in production-control systems, by a formalisation procedure to build an ontology-based model, based on the IEC 62264 standard.

KEYWORDS

Enterprise interoperability; Information modelling; Production-control systems integration; Ontological model; IEC 62264; OWL.

1. PROBLEM STATEMENT

Managing distributed and delocalised productions is one of the strongest issues to address in the present era of market globalisation. Information becomes even more a key issue to face the emerging complexity of managing dispersed manufacturing processes.

One of the emerging control problems in manufacturing systems concerns “information interoperability (I²)” problems. The problem of managing heterogeneous information coming from different sources, in order to achieve a unique meaning is typically an interoperability problem.

Interoperability can be defined as the ability of two or more systems or components to exchange information and to use the information that has been exchanged (IEEE, 1990). In more general terms, interoperability can be defined as that intrinsic characteristic of a generic entity (organization, system, process, model, ...) allowing its interaction with other entities - to a different extent of simplicity - to cooperate for achieving a common goal within a definite interval of time, while pursuing its own specific goal. Heterogeneous manufacturing systems, either inside a single enterprise or between networked enterprises, need to share information and to cooperate in pursuing their scopes. This information may be stored, processed and communicated in different ways by different systems, according to the scopes for which these have been collected and they will be used. Each enterprise system, in fact, uses an information repository, which refers to a Reference Information Model (RIM). A RIM specifies the structure and embeds the semantics of the information treated, in relation to the scope of the application to which it is devoted (Dassisti, et al., 2006).

The “Babel tower effect” induced by the heterogeneity of applications and their specific scopes, of users and of domains may cause information understanding problems, leading systems to fail in collecting information from different and heterogeneous sources to effectively ensure their local objective.

In order to manage heterogeneous information, it is appropriate to develop models able to trace all relevant information related to the product lifecycle (design, manufacturing, sales, use and disposal). This information is, in fact, quite often scattered within organizations: it is a matter of the materials adopted, of the applications used to manage technical data (e.g.: Product Data Management systems (PDM)), of the applications that manage business data (e.g.: Enterprise Resource Planning (ERP)) and, finally, of the applications that manage

manufacturing data (e.g.: Manufacturing Execution Systems (MES)).

The information problem born because the information need to be coherent and congruent with the specific use, particularly in interfacing manufacturing processes, at any stage of the product lifecycle management. Coherence addresses completeness and validity of information, meaning that information sets should be complete and reliable enough for the scope of their use in the manufacturing processes, independently of the IT applications adopted to manage them. Congruence addresses the matter of pertinence of information, i.e. usefulness and temporal significance of information. These two are sensible aspects to consider before reasoning about I² problems.

Questions pertinent to information exchange and its support may complicate the I² problem: lack of comprehension, misunderstandings, as well as redundant activities are some examples of loss of efficiency influenced by information exchange tasks. In fact, a problem of misunderstanding when information is exchanged between enterprise applications can occur, due to different view points, for which they have been developed and, consequently, a risk of loss of information semantics may arise when exchanging between heterogeneous systems.

This latter seems to be the most important issue addressed so far, particularly in the IT research domain, even though also the coherence and congruence problems before cited are important as well from a technological point of view.

In a word, I² problem is not only a matter of how information is managed, but also on what kind and meanings of information is needed at different stages of the manufacturing processes during product lifecycle.

Standardisation initiatives (ISO and IEC) witness this problem, trying to solve the emerging problems of merging heterogeneous information, scattered within organizations and their IT applications, by formalising the knowledge related to product and process technical data.

Standardisation initiatives, in the frame of ISO and IEC (IEC 62264), try to answer these problems by structuring the information related to products, manufacturing resources and processes, thus representing the most well assessed corpus of knowledge for business to manufacturing (B2M) applications interoperability available so far for addressing the I² issues. Furthermore, even though prescriptive, this approach represents a widely shared and consensual knowledge useful for

addressing interoperability of manufacturing systems.

In this paper a path for studying the I^2 problems in production-control systems is traced, by proposing a formalisation approach to build an ontology-based model, centred on the IEC 62264 standard. The use of a formalised approach and of an information model is here sustained to be a valuable one to address interoperability issues, either inside a single enterprise or between cooperating networked enterprises. Addressing the heterogeneity of IT applications adopted to control different manufacturing processes is in fact a matter of finding a common ontological meaning. Test cases on the proposed ontology, using Protégé tool and inference engines are presented to demonstrate the feasibility of the approach for production-control systems interoperability.

2. IEC 62264 STANDARD AND B2MML

Information interoperability (I^2) asks for common shared approaches: in fact, interesting standardisation initiatives already exist, such as the IEC 62264 set of standards (IEC 62264, 2002) and the ISO 10303 technical specifications (ISO/TS 10303, 2004). They try to solve the problem of managing heterogeneous information coming from different systems by formalising the knowledge related to products technical data. Both these standards are related to Product Data Management at the business and the manufacturing levels of enterprises (B2M). In this paragraph a short review will be done of these two standards.

The IEC 62264 set of standards specifies a set of reference models extending the ANSI/ISA S95 (ANSI/ISA, 2000) specifications, that defines an information exchange framework to facilitate the integration of business applications and manufacturing control applications, within an enterprise. It is composed by six different parts designed for defining the interfaces between enterprise activities and control activities. Among all its parts, part 1 describes the relevant functions within an enterprise and within the control domain of an enterprise, stating which objects are normally exchanged between these domains (Figure-1) depicts the different levels of a functional hierarchy model: business planning and logistics, manufacturing operations and control, and batch, continuous, or discrete control.

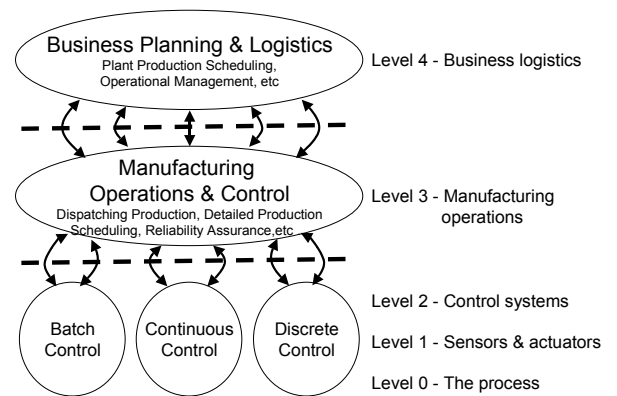


Figure 1 - Functional hierarchy as defined in IEC 62264

The model shows the hierarchical levels at which decisions are made. The interface addressed in the standard is between Level 4 and Level 3 of the hierarchy model. This is generally the interface between plant production scheduling and operation management and plant floor coordination.

Levels 2, 1, and 0 present the cell or line supervision functions, operations functions, and process control functions, not addressed by this standard. Level 0 indicates the process, usually the manufacturing or production process. Level 1 indicates manual sensing, sensors, and actuators used to monitor and manipulate the process. Level 2 indicates the control activities, either manual or automated, that keeps the process stable or under control. There are several different models for the functions at these levels based on the actual production strategy used.

The key aspects for integrating the business applications at Level 4 and the manufacturing operations and control applications at Level 2 (and below) are the information structures and exchanges managed by Level 3 activities, applications, processes, resources, and functions. Examples of Level 3 activities include the management of various manufacturing operations, such as: production, maintenance, product quality testing, and material handling.

Enterprise applications dealing with these exchanges are, at the business levels, ERP (Enterprise Resource Planning) systems, APS (Advanced Planning and Scheduling) systems, and CRM (Customer Relationship Management) systems and, at the manufacturing level, MES (Manufacturing Execution Systems), SCE (Supply Chain Execution) systems. In particular, MES functions relate production monitoring, rescheduling and control including production requests and responses, materials (raw and finished) and resources (equipment and personnel) traceability information.

To take into account the various exchanged information, through the product representation, the

standard defines a set of eight models that specifies all concepts for enterprise-control integration. Each model concerns a particular view of the integration problem. Those models show increasing detail level and are operational models or resource models

The different models from IEC 62264 are linked together in a logical way in order to define a hierarchy of models (Figure - 2). The production information presents what was made and what was used. Its elements correspond to information in production scheduling that listed what to make and what to use. The production scheduling elements correspond to information in the product definition that shows what is specified to make a product. The product definition elements correspond to information in the process segment descriptions that present what can be done with the production resources.

product segments for a product gives the sequence and ordering of segments required to manufacture a product in sufficient detail for production planning and scheduling. The corresponding production rule presents the additional detail required for actual production.

Material Model: the material model defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, and intermediate materials. Material classes are defined to organise materials. A Material definition is a means to describe goods with similar characteristics for purposes of scheduling and planning.

Equipment Model: the equipment model contains the information about specific equipment, the classes of equipment, equipment capability tests, and

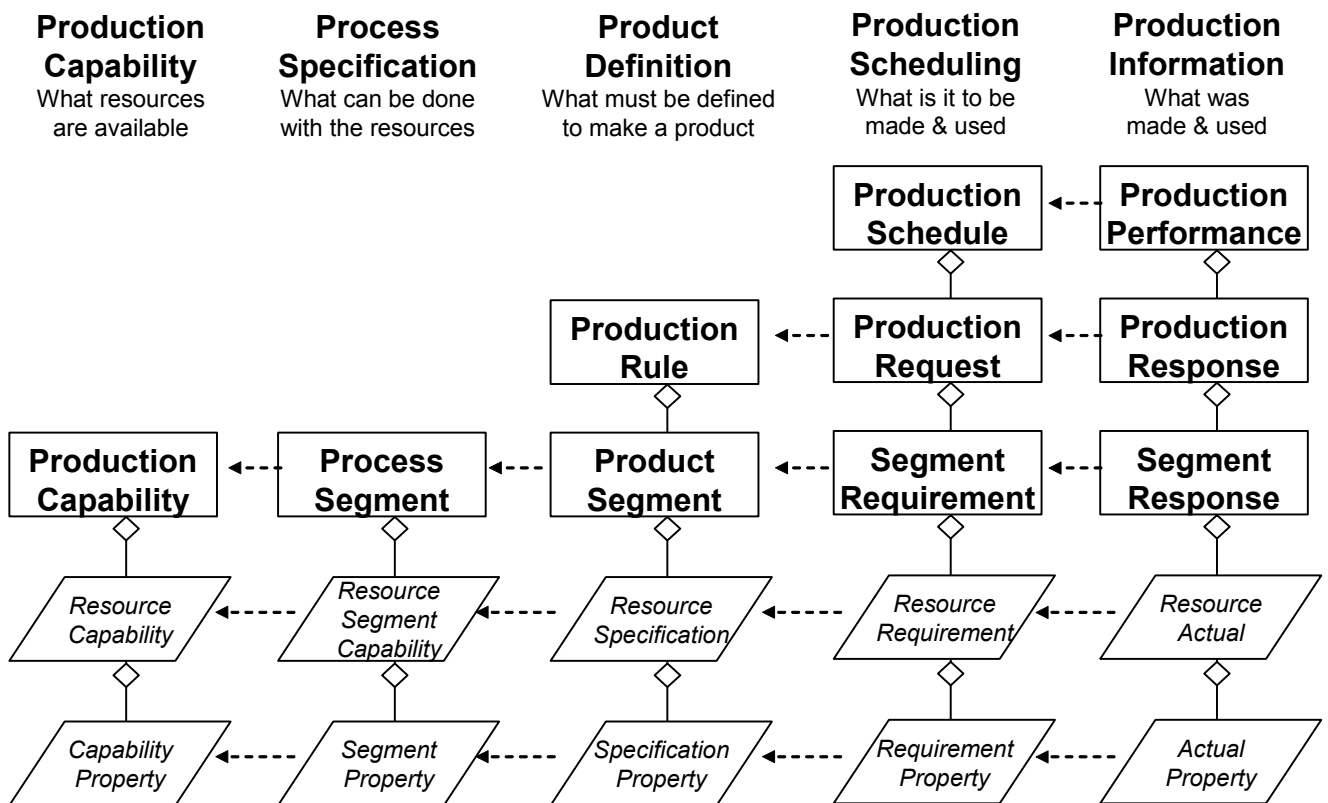


Figure 2 - The IEC 62264 models hierarchy (IEC 62264, 2002)

Product Definition Model (Figure - 4): the product definition model is information shared between production rules, bill of material, and bill of resources. A product definition contains a listing of the exchanged information about a product. The information is used in a set of product segments that are the values needed to quantify a segment for a specific product. A product segment identifies, references, or corresponds to a process segment. It is related to a specific product, while a process segment is product independent. The collection of

maintenance information associated with equipment.

Personnel Model: the personnel model contains the information about specific personnel, classes of personnel, and qualifications of personnel.

Process Segment Model: the process segment model contains process segments that list the classes of personnel, equipment, and material needed, and/or it may present specific resources, such as specific equipment needed. A process segment may list the quantity of the resource needed. A process segment

is related to a product segment that can occur during production, as presented in the product definition model.

Production Schedule Model: a request for production shall be listed as a production schedule. A production schedule shall be made up of one or more production requests. A request for production for a single product identified by a production rule shall be shown as a production request. A production request contains the information required by manufacturing to fulfil scheduled production. This may be a subset of the business production order information, or it may contain additional information not normally used by the business system. A production request may identify or reference the associated production rule. A production request shall contain at least one segment requirement, even if it spans all production of the product.

Production Capability Model: the production capability information is the collection of information about all resources for production for selected times. This is made up of information about equipment, material, personnel, and process segments. It describes the names, terms, statuses, and quantities of which the manufacturing control system has knowledge. The production capability information contains the vocabulary for capacity scheduling and maintenance information.

Production Performance Model: the performance of the requested manufacturing requests shall be listed as production performance. Production performance shall be a collection of production responses. The responses from manufacturing that are associated with a production request shall be used as production responses. There may be one or more production responses for a single production request if the production facility needs to split the production request into smaller elements of work. A production result may include the status of the request, such as the percentage complete, a finished status, or an aborted status.

Even if all models specified in the standard are important for trying to answer the I^2 problem of an enterprise, the paper will focus on analysing one of them: the material model (Figure - 3).

The material model is a resource model that defines the actual materials, material definitions, and information about classes of material definitions. Material information includes the inventory of raw, finished, and intermediate materials. Material classes are defined to organise materials. A material definition is a means to describe goods with similar characteristics for purposes of scheduling and planning.

A material class is a means for defining sets of material definitions. A material class may be further characterised through zero or more material class properties. The material class properties usually define the nominal or standard values for the material. A material definition property does not have to match a material class property. A material lot uniquely identifies a specific amount of material, as defined by its Material Definition. It defines specific instances, where Material Lot Properties have specific values, regarding a particular Material Definition and its Material Definition Properties. Material lots and Material sublots may be used for traceability when they contain unique identification. A material lot may be stored as a separate identifiable quantity. Each separate identifiable quantity of the material is identified in a material subplot object. The semantics attached to these constructs realises a semantic interoperability between business applications (level 4) and manufacturing operations (level 3).

Information described in IEC 62264 is collected into information categories. The categories of information provide the overview for the object model (Brandl 2001, IEC 62264-1 2002).

Information required producing a product: this is 'Product Definition Information' dealing with 'how to make a product'. It answers the question of 'What does it take to make a product?'. This may be a specific product, such as a specific model of a car, or may be a rate of production, such as a production rate of liquid gas, etc.

Information on the capacity to produce a product: this is also called 'Production Capacity Information'. It answers the question 'What is available?'. It defines what the production system is capable of doing: (1) to the level of detail required for planning and scheduling; (2) taking into account maintenance activities; and (3) taking into account committed and available capacity and capacity.

Information about actual production of the product: also called 'Production Information'. This is concerned with 'what to make and results'. In other words, it answers the questions: 'What should be used to make the product?', 'When is it due?' or 'When can it be made?' It also provides production follow-up information and answers the question 'What was made?', i.e. what was actually used to make it, when it was made, how long it took, etc.

Some information in each of these three areas is shared between the production control systems and the other business systems.

These three information categories are used to define formal information models which are detailed sufficiently for actual enterprise-integration projects. In other words, each category of information is detailed further by one or several models.

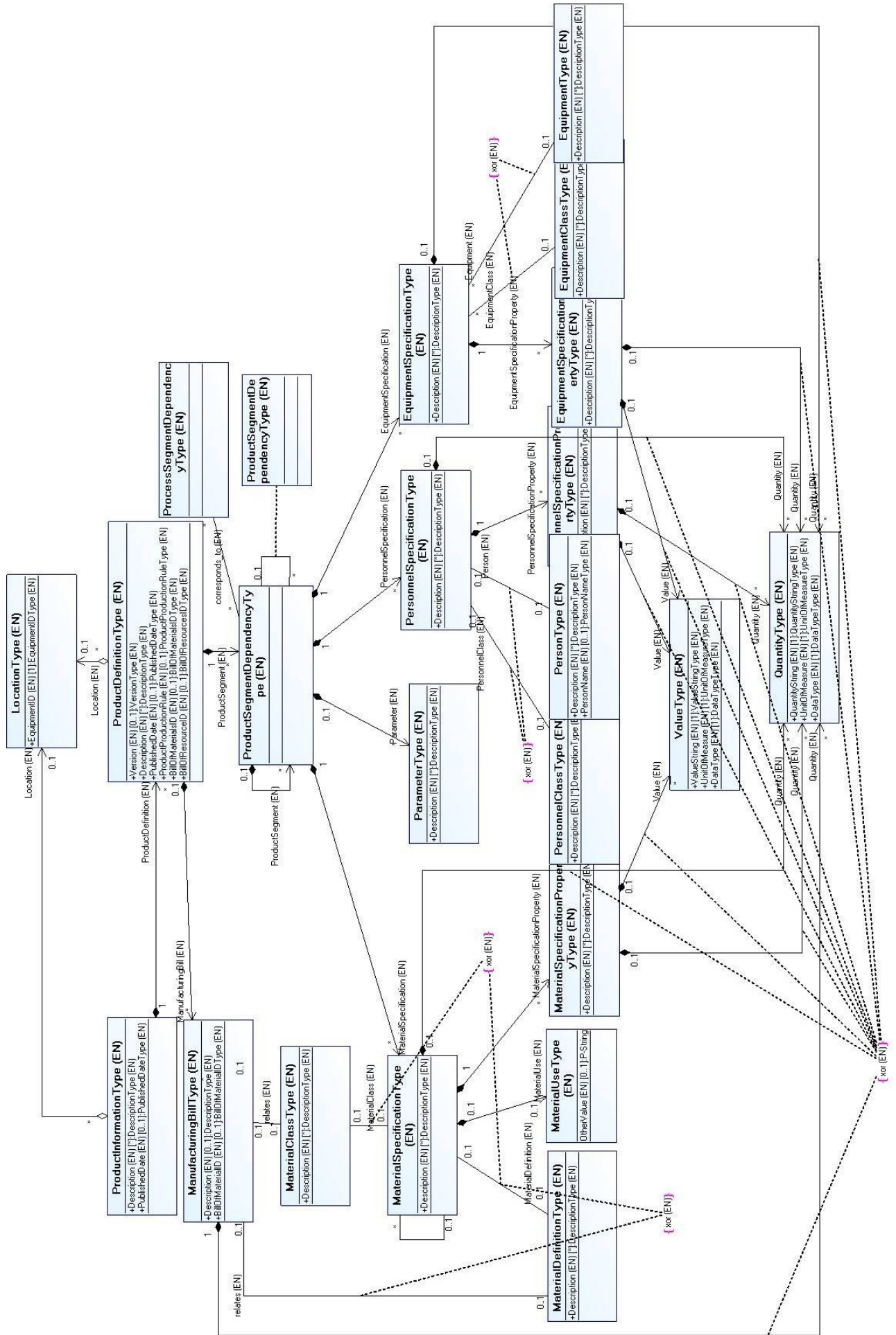


Figure 4 - The conceptualized IEC 62264 Product Definition Model

The eight object models developed in IEC/ISO 62264 aim at: (1) identifying categories of information; and (2) defining formal definitions of shared information. The term ‘formal’ does not have a mathematical sense; instead, it is concerned with the set of necessary data attributes that contribute to better define the semantic of the information (Tursi et al, 2007).

3. FROM THE STANDARD TO THE ONTOLOGY

The IEC 62264 standardisation initiative tries to answer the I² problems by specifying the information related to products, manufacturing resources and processes, thus representing the most assessed corpus of knowledge for business to manufacturing (B2M) applications interoperability, available for studying and solving the I² issues.

This approach is rather prescriptive, but it represents a widely shared and consensual knowledge useful for addressing interoperability of manufacturing systems. In fact, the IEC models represent a common standardised knowledge built by expert of the domain.

The standard’s models can be defined a sort of *ontology*. An ontology, in fact, provides formal definitions of basic concepts in a domain and the relationships among them in a usually logic-based language (Gruninger and Lee, 2002).

In order to overcome questions pertinent to information exchange and its support, such as loss of information, problems of misunderstanding as well as redundant activities, which may complicate the I² problem, it’s necessary to define an ontology-based information model, to support information exchange between IT applications adopted to control different manufacturing processes and systems.

There have been, in many different sectors, some efforts examining the use of ontologies in supporting the semantic integration task (e.g. Gehre et al, 2005; Guo et al., 2003, Katranuschkov et al. 2003; Lima et al. 2005, Patil et al., 2005). Aware of the efforts demonstrating the integration of models using ontologies, the matter of the approach, discussed here, is to trace a path for studying the I² problems in production-control systems environment, by appropriately formalising an ontology-based model, based on the IEC 62264 standard. In this sense, standards efforts can be taken into account, in term of useful bases for the ontology of the domain. To the scope of the present paper, in order to develop the abstraction meaning of the concepts, based on the standard (which is more at a logical level), we have de-normalised and conceptualised its models and then represented

them using the UML class diagram notation. This was done because UML is the most used and known language to model application structure behaviour.

4. THE ONTOLOGY IMPLEMENTATION AND ANALYSIS

This paragraph traced the engineered procedure used to transform the conceptualized IEC 62264 models into a ontology-based model useful to solve the I² problem in production-control systems.

The tool considered for the UML-to-OWL transformation has been realized in the Eclipse platform (<http://www.eclipse.org>) by the SIDo Group from the L3I lab in La Rochelle.

It is freely available from the Eclipse website at the following address:

<http://www.eclipse.org/m2m/atl/atlTransformations/>.

The work is an implementation of the Object Management Group (OMG) Ontology Definition Metamodel (ODM) specification using the Atlas Transformation Language (ATL).

ODM offers a set of meta-models and mappings for bridging the meta-modelling world and the ontologies. The solution supports the UML (Unified Modeling Language) 2.0 meta-model and the OWL (Web Ontology Language) meta-model as defined in ODM. The ODM is a recently adopted standard from the OMG that supports ontology development and conceptual modeling in several standard representation languages. It provides a coherent framework for ontology creation based on MOF (Meta Object Facility) and UML. In this way it played a central role for bridging Model Driven Architecture based standards and Semantic Web technologies.

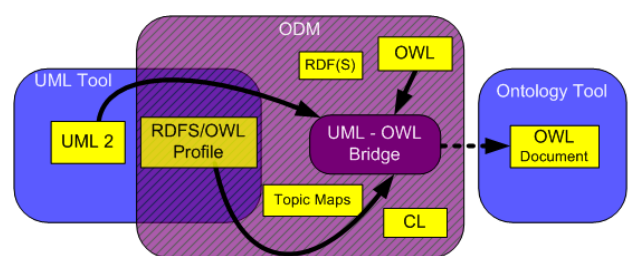


Figure 5 - OWL overview

ODM defines five meta-models (RDFS, OWL, Topic Maps, Common Logic and Description Logic), two UML Profiles (RDFS/OWL Profile, Topic Maps Profile) and a set of QVT mappings from UML to OWL, Topic Maps to OWL and RDFS/OWL to Common Logic.

The considered tool implements two meta-models (RDFS and OWL in KM3) and the UML Profile for RDFS/OWL. It also implements the mapping between UML and OWL by using ATL.

This scenario is composed of 2 ATL transformations: the core transformation UML2OWL takes as input a UML model and produces an ontology conforms to the OWL meta-model (OWL ontology + OWL Individuals from a UML Model + UML Instances). The second transformation is an XML extractor that produces an XML document conforms to the OWL/XML syntax, as defined by the W3C specification.

The core transformation (UML2OWL) includes two distinct parts. The first part is dedicated to the mapping from UML model to ontology, i.e. UML classes are mapped into OWL classes, attributes into datatype property, associations into object property, etc.. The second part of the transformation deals with instances that are defined in the same class diagram as the UML model. Those instances are converted into OWL individuals (OWL term for instances). This method offers the possibility to manage UML instances and populate the ontology with corresponding knowledge.

The UML2OWL transformation can produce an OWL model in *ecore* format or an OWL document conform to the OWL/XML presentation syntax. To obtain this XML file, the tool implements an OWL/XML extractor that transforms a model conforms to the OWL metamodel into an OWL document. This makes it possible to use the obtained OWL files under ontology tools like Protégé, the one available under the UML eclipse project (eclipse.org/uml2).

OWL (Web Ontology language) is the most expressive language for representing and sharing

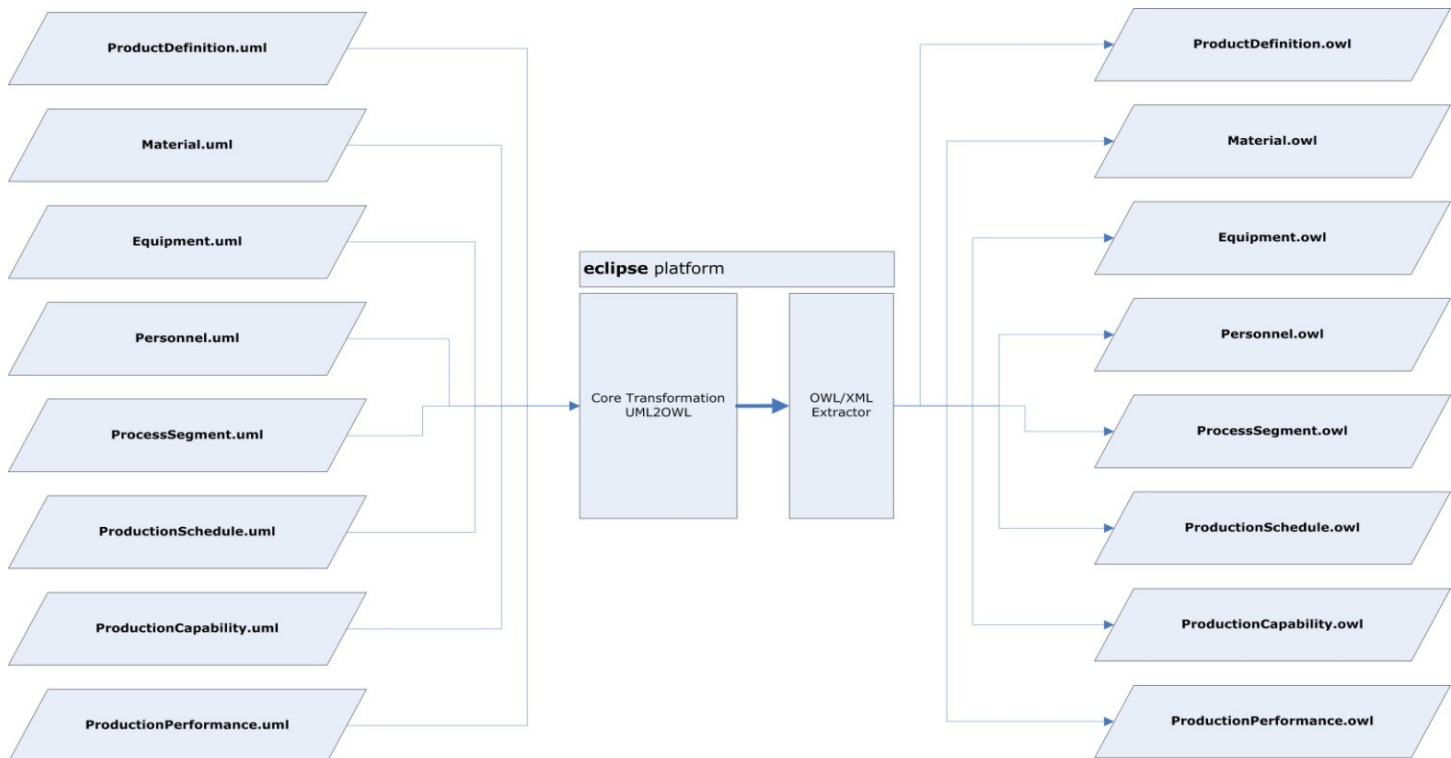


Figure 6 - The engineered system to build the ontological model in OWL

ontologies over the Web. OWL is designed for use by applications that need to process the content of information instead of just presenting information. It facilitates greater machine interoperability of Web content than other description languages like XML, RDF and RDF-S by providing additional vocabulary along with a formal semantics.

The OWL metamodel is implemented in by extending the RDFS metamodel.

This ATL scenario makes possible the conversion of an arbitrary UML model into an OWL ontology, that is, provides a solution for bridging modeling tools based on UML or MOF and tools for the Semantic Web and ontology development. The complete scenario of this transformation is given in figure below.

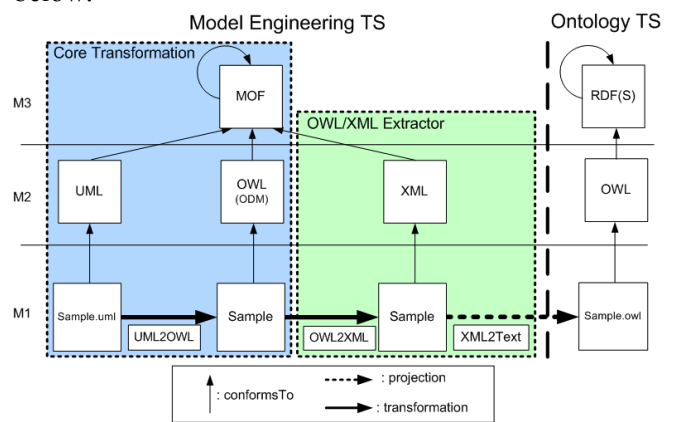


Figure 7 - UML2OWL complete transformation scenario

The Figure - 6 shows the engineered system to build the ontological model in OWL.

4. CONCLUSIONS

The approach proposed to build an ontology-based model tries to face information interoperability problems by using two main concepts: formalisation (using appropriate knowledge management tools) and standardisation (using shared standards). The final result, which is in phase of completion, will be a model with a final aim to address interoperability issues either inside a single enterprise or between cooperating networked enterprises, as well as addressing heterogeneity of IT applications adopted to control different manufacturing processes.

The paper serves to present the idea and trace the technical path to follow for the construction of the ontological model.

Proof are not possible here because test cases of reasoning analysis on the proposed ontology, using Protégé tool and inference engines, need to be performed to demonstrate, in the next future, the efficacy and efficiency of the approach for production-control systems interoperability.

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