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Life Cycle Data Management: first steps towards a new PLM standard

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Abstract

Nowadays companies need to focus on efficiency problems, assuring at the same time products to be compliant with quality standards, providing a full product support and managing suppliers and customers relationships. According to these needs, product is reassuming a central role as enterprise value creator. In literature, many authors agree upon that a correct and effective management of the product lifecycle could reduce costs by gaining, meanwhile, a higher customers satisfaction and brand loyalty. This kind of approach needs of an integrated management of all product related information and calls for a wide standardization activity. Today, a data model, capable to collect all the information regarding the product along its lifecycle, is still missing. This paper aims at providing a concrete answer to this urgent industrial need, presenting the steps taken towards the creation of a new Product Lifecycle Management standard, named Life Cycle Data Management. The development of this new standard is an effort to provide an effective and reliable information model to manage all product lifecycle data and information.

Keywords

Lifecycle support, product data and knowledge management, PLM standard

1 Introduction

In the actual competitive world, companies are ever more stressed and subjected to high market requests. Customers pay more and more attention to products quality and related services. The best product, at the lowest price, at the right time and place is the only key factor for success for the modern global enterprise. In order to maintain or gain the needed competitive advantages, modern companies have to manage themselves along two main directions: 1) improve internal and external efficiency, reducing all the not-relevant costs; 2) foster innovation of product, process, and organization (Stark 2006).

According to these needs, enterprises are refocusing on their core competences, while the product is becoming again, after the 90s new economy experiences, the enterprise value creator and the whole production process is reassuming its role. By this way, within the globally scaled scenario, product management is composed by complex overlapped processes. Product development might ever more take into account improved customers' tastes and requests in a shorter time-to-market, while the related engineering activities are consequently stressed and inefficiencies in the production and distribution functions are not tolerated.

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Thus, the “product” management is becoming unavoidably a key-aspect, creating such a “product centric” or “product-driven” approach. This kind of approach needs an integrated management of all the information regarding the product (Garetti and Terzi 2004).

Unfortunately, today a data model, capable to collect and manage in an effective and easily way all product related information along the entire lifecycle, is still missing. Namely, only few existing standards are capable of supporting the whole set of product lifecycle phases and where it is possible their use is fairly complex (Cassina *et al.* 2009).

The purpose of this paper is to provide a concrete answer to this gap, moving the first steps towards the creation of new Product Lifecycle Management (PLM) standard capable to manage all product information along its lifecycle. Paragraph 2 presents the state of the art of product lifecycle modeling, focusing on standards for product data representation. Paragraph 3 focuses on the overall framework and the process used for the creation of the new standard, describing in details the three proposed developing phases.

Then, paragraph 4 provides a deep description of the developed standard, focusing on its aim, scope, and structure. Paragraph 5 presents standard validation, focusing on one of the ten Application Scenarios that has been used in testing the data model. Finally, paragraph 6 concludes the paper, giving also a view of the further developments that can be done.

2 Background

2.1 Mapping of Product Data Standards

This section offers an analysis of the main existing standards for product data modelling. These standards have been classified according to the most common approach used in literature ([Stark 2006](#), [Jun *et al.* 2007](#), [Terzi *et al.* 2008](#), [Sallez *et al.* 2010](#)) that divides the lifecycle of a product into three main parts (Figure 1). The first one is the Beginning of Life (BOL), which is composed of product development and product supply, i.e. the manufacturing process, the logistics etc. Then, the second phase is the Middle of Life (MOL), where the product is used and maintained. Finally, there is the End of Life (EOL) where the product is destroyed or rather dismantled and recycled.

Figure 1. Standards throughout Lifecycle Phases.

Among all, four standards seem to be very interesting, since they reveal to be complementary to each other in the PLM approach (Cassina *et al.* 2006). They are STEP (ISO 10303); MANDATE (ISO 15531); ANSI/ISA-95 (or the new ISO/IEC62264 standard which is derived from it); and PLM@XML. These standards are described below.

STEP - ISO10303

ISO 10303 (TC184/SC4 1994), informally known as STEP, is an industry standard for product data representation. This standard presents a modular architecture composed by four main structural components:

- 1) Description Methods are common mechanisms for specifying the data constructs of STEP. They include the formal data specification language developed for STEP, known as EXPRESS (ISO 10303-11). Other description methods include a graphical form of EXPRESS (EXPRESS-G), a form for instantiating EXPRESS models, and a mapping language for EXPRESS.
- 2) Implementation Methods are standard implementation techniques for the information structures specified by the only STEP data specifications intended for implementation, the so called Application

Protocols (APs). Each STEP implementation method defines the way in which the data constructs specified are mapped to that implementation method, using STEP description methods.

3) Conformance Testing is covered by: 1) conformance testing methodology and framework, that describes how testing of implementations of various STEP parts is accomplished, and 2) abstract test suite, that contains the set of abstract test cases necessary for conformance testing of an implementation of a STEP application protocol.

4) Data Specification: there are two primary types of data specifications: 1) integrated resources and 2) application protocols. The Integrated Resources (IRs) constitute a single, conceptual model for product data. The constructs within the integrated resources are the basic semantic elements used for the description of any product at any stage of the product lifecycle. The Application Protocols (APs) are the implementable data specifications of STEP. APs include an EXPRESS information model that satisfies the specific product data needs of a given application context. APs may be implemented using one or more of the implementation methods. They are the central component of the STEP architecture. Among various APs, particularly interesting result PLCS (ISO 10303-239) and STEP NC (ISO 14649 – ISO 10303-238). PLCS (TC184/SC4, 2005) is an Application Protocol, able to describe products in their whole lifecycle (Design, Production, Use and Dismissing), with particular emphasis on needed support and work required to sustain and maintain the products in operational conditions whereas STEP-NC (Xu *et al.* 2005, Newman *et al.* 2008) is explicitly focused on design and production phase of the product lifecycle, allowing the integration between the activities performed at the backend during the design phase, i.e. the construction of CAD/CAM models, and those directly performed at the shop floor level by the numerically controlled machine tools.

MANDATE – ISO15531

MANDATE (TC184/SC4 2004, Cutting-Decelle *et al.* 2007) is an international standard that provides capabilities for the description and management of product data throughout the portion of the product life concerning its production. The aim is to provide standardized data models for the three types of data – 1) information related to external exchanges (between main plant and suppliers); 2) information related to the management of the resources used during the manufacturing processes; 3) information related to the management of the manufacturing flows – which are usually complex, strongly time-dependent and with close relationships among them. The purpose is to facilitate the integration between numerous industrial applications by means of common, standardized software tools able to represent these three sets of data, that are shared and exchanged during the whole production lifecycle and are in core of the manufacturing process. The standard is divided into three series of parts, strongly related in order to preserve the consistency of the whole standard but published separately, which are:

1) Parts 15531-2x series “Production data for external exchanges”: those parts refer to the representation of production information which has to be exchanged with the external environment. The aim is to model the main production information exchanged between industrial companies, using the EDI protocols. The domain includes all information and functions necessary to support quality, and order management issues, such as planning, executing, controlling and monitoring of product quality, orders and shipments.

2) Parts 15531-3x series “Manufacturing resources usage management data”: those parts refer to the resource usage management, such as resource configuration and capabilities, operation management of manufacturing devices, installation and facilities. They also include quality features, maintenance-features (regarding the availability) and safety-features.

3) Parts 15531-4x series “Manufacturing flow management data”: those parts refer to the material flow control, and are intended to standardize data and elements which support the control and

monitoring of the flow of material in manufacturing or industrial processes. This includes all the elements describing the material flow, including inventory.

All those parts are based on ISO 15531-1 (overview and fundamental principles), which provides a general overview, specifying the functions of the various series of parts of the standard and the relationships among them.

PLM@XML

PLM@XML (Ding *et al.* 2007) (Choi *et al.* 2010) is an open standard developed mainly by EDS and dealing with the product design phase. Its functional objectives are to: orchestrate product structure; geometric representation data and additional product metadata in an open, lightweight and extensible form; proliferate relevant information through the product lifecycle by offering a standardized protocol for data interoperability; and integrate collaborative product lifecycle processes by providing a homogenous flow of data within a heterogeneous application environment.

It is defined by a set of XML schemas that are compliant with the World Wide Web Consortium (W3C) XML schema recommendation and define a generalized data model in a framework focused on product lifecycle data. PLM@XML schemas support different types of data such as: product structure; PLM metadata; geometric representation data; data ownership; visualization properties; etc.

ANSI/ISA-95 – ISO 62264

ANSI/ISA-95, which has been accepted by ISO community and published as ISO 62264, is an international standard for the integration of enterprise and control systems. It consists of models and terminology that can be used to determine which information has to be exchanged between systems for sales, finance and logistics and systems for production, maintenance and quality. This information is structured in UML models, which are the basis for the development of standard interfaces between Enterprise Resource Planning (ERP) and Manufacturing Execution System (MES). The standard consists of five parts. Part 1 (ISA 95.01) (TC184/SC5 2003) provides standard terminology and object models, which can be used to decide which information, should be exchanged. Part 2 (ISA 95.02) (TC184/SC5 2004) consists of attributes for every object that is defined in Part 1. The objects and attributes of Part 2 can be used for the exchange of information between different systems, but these objects and attributes can also be used as the basis for relational databases. Part 3 (ISA 95.03) (TC184/SC5 2007) focuses on the functions and activities at Production / MES layer. It is an excellent guideline for describing and comparing the production levels of different sites in a standardized way. The SP95 committee is yet developing part 4, which is entitled "Object Models and Attributes of Manufacturing Operations Management". This technical specification defines object models that determine which information is exchanged between MES activities (which are defined in ISA-95.03). Also part 5 of ISA-95 is yet in development. This technical specification defines operation between office and production automation systems, which can be used together with the object models of part 1 and part 2. The operations connect and organise the production objects and activities that are defined through earlier parts of the standard. Such operations take place on all levels within a business, but the focus of this technical specification lies on the interface between enterprise and control systems.

As shown in literature review above, today standards for product data modelling exist but each one is focused on a specific area of the product lifecycle. As shown in Figure 1, STEP appears to have the most breadth and depth of coverage for product lifecycle data. Particularly, its Application Protocol ISO 10303-239 (PLCS) is currently the only international standard able to cover the entire lifecycle spectrum.

However, PLCS satisfies the industrial need to exchange and to integrate product support information. It provides a comprehensive capability to describe a set of products needing support and the work required to sustain such products in an operational condition. Therefore, this standard is mainly focused on support solutions rather than on product data management. Therefore, there is still a gap to be filled. This paper describes the first steps to fill this gap.

2.2 The PROMISE project

As said in the previous paragraph, nowadays a standard that permits to manage in effective and efficient way product lifecycle information is required by industries. A first attempt to satisfy this urgent industrial need has been provided by the EU-funded FP6-IST project, named PROMISE: PROduct lifecycle Management and Information tracking using Smart Embedded systems (PROMISE 2008). This project aimed at developing instruments making the closing of the products lifecycle information loop possible, which results in the availability of information to all the actors involved in products life-cycle, (i.e. managers who have to take strategic decisions, service and maintenance operators, end-of-life operators, etc).

To achieve this aim, PROMISE has developed an architecture, consisting of four key components; the one we focus on is the so called Product Data and Knowledge Management (PDKM) system, whose purpose is to manage the data and the knowledge of products during their life-cycle by means of a semantic data model, named PDKM Semantic Object Model (SOM) (Cassina *et al.* 2008).

It is developed in UML language and provides a coherent semantic “dictionary” to the whole architecture. Since this data model has been applied successfully to eleven application scenarios covering a variety of sectors (automotive, railway, heavy load vehicles, EEE, instrumental and white goods), it can be considered as a sound base to develop a new PLM (Product Lifecycle Management) standard.

3 The overall framework and process

As seen in the previous chapter, no standards today are capable to cover the entire lifecycle of product; in particular, none of them is focused on management of product information. The idea presented in this paper is to standardize information objects defined in PROMISE PDKM by means of STEP Integrated Resources (IRs), that are standardized “building blocks” to represent product data. In this way a proposal for new Application Protocol can be defined.

Figure 2. Overall framework of standard development

Figure 2 summarizes the overall framework and the process for the creation of the standard. Three main phases are proposed: 1) translation phase; 2) comparison phase; 3) Application Protocol developing phase.

The following sections clarify the aim of each phase and provide detailed information about results.

3.1 Translation Phase: from UML notation to EXPRESS language

The first step towards the creation of new PLM standard is the translation of information requirements defined in PROMISE data model in EXPRESS language to make possible the future comparison of these requirements with standardized constructs of STEP IRs.

Therefore, each information object or class of the PDKM model has been translated in EXPRESS language (TC184/SC4 1994, TC184/SC4 1997). This formal data specification language uses the term

“entity” to indicate each information object. Furthermore, to model associations between two objects an attribute has been added in one of the entities. This attribute calls the other entity that is part of the considered association.

Figure 3 shows EXPRESS-G graphical representation (TC184/SC4 1994, TC184/SC4 1997) of the resulting model, named Semantic_Object_Model_schema (SOM_schema).

Figure 3. Semantic_Object_Model_Schema in EXPRESS-G graphical language.

The central portion of the model reflects a “product instance-centric” approach to PLM and properly represents the information on each product at the item level.

The PHYSICAL_PRODUCT entity models some basic information on each product item such as: the name of the product type/model/variant (Product_Type); the ID of its production lot (Object_Lot_ID); the date, at which the existence of the product item starts (Birth_Date) and finishes (End_Date); the identification of the set of components/subassemblies belonging to the product item (components); and, if the considered product item is a component/subassembly of another physical product, the date when it is attached and detached to that product (respectively from and to attributes). There are also some attributes useful to model the association of this central entity with other entities of data model that provide product related information (i.e. product_id; group; etc.).

The ID_INFO entity is important to enable the traceability of the product. The identification of the product instance (ID; ID_Type; Alt_Pres) and the information on where it is possible to retrieve other information on the same product instance are enclosed in this entity. There are two types of links to additional information, URI and INFORMATION_PROVIDER objects. Particularly, the URI entity is a pointer to a source for information regarding the respective PHYSICAL_PRODUCT whereas the INFORMATION_PROVIDER entity contains information that can be used to control the request for information from e.g. a traceability system. Each ID_INFO object may be linked to zero or many of these objects (info_uri; info_provider).

The ACCESS_RIGHTS entity aims at realizing and controlling user access control, realizing rights and capabilities associated to user profiles and user roles. These access rights should be managed at different levels and concern, directly or indirectly, many entities of the SOM_schema.

The AS_DESIGNED_PRODUCT entity represents the BOL as-designed structure of the product. Important pieces of information at this level of the model can concern: CAD models of the product type (CAD_model); information on materials necessary to realize the product item (Materials_Information), on the product variants (Variants_Information), on the Bill of Materials (Components; Parent), on the tests a product has to overcome during its life (Test_and_Specification) and so on.

The PROPERTY entity defines the name of the property (property_name attribute), the possible values (valid_values) the property can take, the actual value (property_value), and some other kind of specifications (category), if needed.

The CONDITION entity allows to defining some either atomic or complex kind of condition which must be checked in some product lifecycle scenario. The condition_id attribute univocally identifies the condition, while the group_id attribute is used to define complex conditions, by grouping atomic conditions together. The type_id attribute states if a condition relates to a property of a product type/instance or to some kind of data collected on the field and concerning a specific product item (in this case, the kind of field data must be specified, as well as the interested data source). Finally, the actions to be taken in case the condition is met/not met are specified by Action_When_Met and Action_When_Not_Met attributes respectively.

The PHYSICAL_PRODUCT_GROUP entity allows to group together a set of PHYSICAL_PRODUCT objects on the basis of some commonalities (e.g. concerning their BOL as-designed structure or the field data collected).

The LIFE_CYCLE_PHASE entity together with its SUBTYPE entities (PRODUCT_BOL_SUPPLY, PRODUCT_MOL, PRODUCT_EOL) aim at collecting all data during the life of a physically existing product. Particularly, the LIFE_CYCLE_PHASE class contains the lifecycle information of the product item that is common to all the different lifecycle phases whereas the PRODUCT_BOL_SUPPLY, PRODUCT_MOL, PRODUCT_EOL classes contain respectively the pieces of information, which are specific to the SUPPLY (product production and product delivery phase), MOL (product usage and service/maintenance phase) and EOL (remanufacturing phase, recycling phase, etc.) phase of the product item.

The LIFE_CYCLE_PHASE entity describes some important issues such as the residual life of a product component (residual_life), or the definition of the set of states in which a product item can be at a given moment in time (product-state_set_its_own; product_state_definition_its_own).

The FIELD_DATA entity enables the collecting of data from the field. Field data can be of different types (VALID_FD_TYPE entity), and are collected by means of sources like sensors (FD_SOURCE entity). It might be organized in documents (DOCUMENT entity) with attached physical files (FILE entity). The fd_id attribute univocally identifies each field data record, while the fd_type attribute states the type of field data (e.g. that it is a temperature of a certain sensor). The document_flag attribute states if the field data has an attached document related to it, while the value and accuracy attributes should be self explaining. The who attribute gives information on "who" is responsible for the field data measurement, i.e. which is the source of the field data. The what attribute explains what the field data stands for, i.e. the meaning of the data itself, while the where attribute states the location where the measurement was carried out (if needed). The when attribute then represents the timestamp indicating when the measurement was carried out. Finally, the reference_group_id and the group_id attributes are used when there is the necessity of grouping some records of the same field data type together, e.g. because of the need of clustering in some way the data before analysing it.

EVENT, RESOURCE and ACTIVITY entities allow to describe with a deep level of details everything that happens to the product during each lifecycle phase. Particularly, the EVENT entity models an event that can occur in a specific moment of the product lifecycle, triggered by some conditions, and may cause the shift of the product from "state A" to "state B". It can also be marked with a proper flag if the event is a planned event, or if it is a predicted event, or if the event has already happened, or has been cancelled because it cannot happen anymore (refer to the flag attributes in the EVENT entity). The ACTIVITY entity provides the identification and the description of an activity done towards product item by means of resources and started by an event. Finally, the RESOURCE entity models the resources of a company which are involved in the product lifecycle phases. Particularly a resource can be a person (PERSONNEL_RESOURCE entity), an equipment (EQUIPMENT_RESOURCE entity), a material (MATERIAL_RESOURCE entity) and a document (DOCUMENT_RESOURCE entity).

3.2 Comparison Phase: the SOM_schema versus STEP IRs

After translating PROMISE information requirements in EXPRESS modelling language, it is possible to proceed with the comparison of the SOM_schema objects with the basic semantic elements of STEP Integrated Resources (IRs). The comparison aims at mapping the SOM_schema objects onto constructs of STEP IRs to verify if they fully cover information requirements for the new standard. As show in Table 1, STEP IRs, useful to make comparison, are fundamentally four: ISO 10303-41, ISO 10303-45, ISO 10303-49 and ISO 10303-56.

ISO 10303-41 (Fundamentals of product description and support) (TC184/SC4 1994) specifies the following:

- Generic product description Resources: the resource constructs for the representation of products and properties. It also specifies ISO 10303 IRs for the description of generic aspect of product usage, categorization of products and associations between products.
- Generic management resources: the resource constructs for the structures that are used to associate administrative data with the product data.
- Support resources: the resource constructs for administrative data, physical quantities and their units, and basic data types.

Table 1 shows that entities, defined within the various schemas included in “generic product description resources” and “support resources”, cover most of information needs to manage product related information along its lifecycle.

The `application_context_schema`, the `product_definition_schema`, the `product_property_definition_schema` and the `product_property_representation_schema` make up the generic product description resources and reflect the different kinds of data that may be associated with a product. Particularly, the `application_context_schema` allows for the description of the conditions under which a given instance of the generic product description resource was defined. The `product_definition_schema` supports the description of data that relates to a particular product. The `product_property_definition_schema` supports the description of properties of this product, for example, its shape and material. Finally, the `product_property_representation_schema` specifies the ways in which a property of a product may be represented.

The `action_schema`, the `document_schema` and the `person_organization_schema` are part of support resources. The `action_schema` allows for the definition of an action, requests for action, and the status of actions.

The `document_schema` allows references to documents outside ISO 10303 to be defined. Finally, the `person_organization_schema` provides information object for the definition of people within organizations.

ISO 10303-45 (Materials) (TC184/SC4 1998) specifies the resource constructs for the material properties of a product and for the characterization of a numerical data value as to its uncertainty and reliability. It is composed of two schemes: `material_property_definition_schema` and `qualified_measure_schema`. The subjects of the `material_property_definition_schema` are associations of a product with a material property, descriptions of material composition, and material identification. The `material_property` entity of this STEP schema allows for the definition of material resources involved in the lifecycle of a product and of their properties (see Table 1). The `qualified_measure_schema` specializes the resource constructs to allow quantities to be qualified. As shown in table 1, entities within this STEP schema satisfy information needs related to the definition of field data type (i.e. “measured”, “calculated”, “nominal”, “maximum”, “minimum”, etc.) and the specification of significant figures in the representation of a value (accuracy of field data).

ISO 10303-49 (Process structures and properties) (TC184/SC4 1998) defines the structure for specifying: relationships between processes, the properties of a process, the resource required for the process, the properties of the resource, the representation of the process, the representation of the resource and the relationship of the process to the product. Particularly, the `process_property_schema` defined in this part of the standard permits to define the resources used within an activity or a process by means of the `resource_property` entity. More precisely, it models a characteristic of a resource. The characteristic may be the behaviour, capability, or performance measure that is pertinent to a process or the actions to impact a process for which the resource is used. For example, a resource property for a

milling machine might be: the size of the machine bed, the maximum rotational speed of the tool head, or the accuracy of the machine.

ISO 10303-56 (State) (TC184/SC4 2005) specifies the integrated resource for: definition of state; definition of what is needed for a state to exist; relationship between two or more states; assignment of a state to items; history of state. Major subdivisions of this part of ISO10303 are: *state_type_schema* and *state_observed_schema*. In more details, *state_type_schema* identifies a type of state by specifying the criteria that shall be satisfied for something to be in a state of that type.

Table 1. The correspondence between the information objects of *SOM_schema* and constructs of the IRs of ISO 10303.

The *state_observed_schema* identifies an observed state and the link to things that are in the state. Observed states may correspond to a period in the life of product data when the criteria defining the state type either have been satisfied, are being satisfied, or will be satisfied. States are not limited to products but may apply to activities, people, and organizations. An observed state records that one or more items were in a defined *state_type* for a period of their life. The item to which an observed state applies is determined by using *state_observed_assignment*.

4 AP developing phase: Life Cycle Data Management

The results of the translation phase and the mapping activity, summarized in Table 1, can be seen as the starting point of the development for the new Application Protocol (AP), named Life Cycle Data Management (LCDM). Before entering a detailed description of the LCDM Application Protocol an overview on the scope and industry focus of the new AP is provided. Then, the developing process and the overall structure of the Application Protocol are presented.

4.1 LCDM: scope and focus

LCDM application protocol defines the context and scope for product lifecycle data management. It aims at satisfying an industrial need to integrate and manage data from all the lifecycle phases of products. LCDM Application Protocol does not propose itself as a new standard for the BOL phase but it can be easily harmonized with other STEP APs that allows the management of this phase (such as AP 203) because it uses the same semantic elements of other STEP APs (i.e. constructs of STEP IRs) and so can share data seamlessly.

The industry focus of this Application Protocol is shown by the shaded area in Figure 4.

Figure 4. Market segmentation (from PROMISE project)

As shown in Figure 4, the new AP is developed to represent the data associated with low or medium complex products such as cars, trucks, refrigerators, plastic materials or milling machines, which may exist as a designed product or as realized products.

The following are within the scope of this AP: information for defining a complex product; information required to maintain a complex product (mainly a maintenance manual); the representation of product assemblies; the representation of a product through life; the management of field data; the representation of the events that occurred to the product; the management of the knowledge derived from field data; the representation of working limits and conditions of the product; the specification and planning of activities and processes for a product; the representation of the activity history of a product; the representation of the product history.

4.2 AP developing process

Typically the process for developing a new application protocol consists of three major steps (Mitchell 1991) :

- 1) definition of information requirements and the corresponding Application Reference Model (ARM);
- 2) mapping table, that describes how each information requirement is represented with STEP Integrated Resource constructs;
- 3) Application Interpreted Model (AIM) that specifies the use of the Integrated Resource (IR) constructs to represent the application information.

The SOM_schema (Figure 3) can be seen as an important step for the development of the ARM of the new AP. In fact, it contains all the information requirements for lifecycle data modelling defined in PROMISE data model. These information needs are identified after a careful analysis of eleven application scenarios. So the information domain of the new AP can be considered partly defined in the SOM_schema.

The mapping of its information objects onto STEP IRs constructs has highlighted that STEP standard includes the necessary standardized semantic elements (entities) for satisfying the information requirements defined in SOM_schema (see Table 1). Furthermore, the careful analysis of IRs has permitted also to identify some new information objects capable to model important data related to lifecycle but not included in SOM_schema, such as information related to process and shape aspects. The mapping activity and its results are the first step towards the development of the mapping table and AIM of new AP.

4.3 The overall structure of the new model

The structure of the LCDM Application Protocol is modular, being composed by different application modules (AMs). For each application module (AM), scope, information requirements (ARM), mapping table and AIM have been defined. Each AM ARM is defined at two different levels. The first level is a "Schema level" focusing on the relationships with other required AMs (see Figure 5). The second level is an "Entity level" and focuses on entities and entity types as building blocks for the AM definition (see Figure 6).

Figure 5. ARM schema level EXPRESS-G of Product AM.

Figure 6. ARM entity level EXPRESS-G of Product AM.

Particularly, the detailed information requirements of LCDM AP are defined in LCDM AP module. This application module acts as the root of other related modules in an abstract module hierarchy. LCDM AP module specifies the information requirements for product lifecycle data management and the integrated resources necessary to satisfy those requirements. Figure 7 shows the module hierarchy implemented by this module.

Figure 7. Abstraction of module hierarchy

As shown in Figure 7, the LCDM AM defines the full information model for LCDM Application Protocol by providing a single root for all of the modules used, briefly presented in the following.

The Product AM specifies an application module for the representation of: the data that identify an existing or potential future product and the categories of products to which it belongs to; the data that designate a version of a product; the relationships between versions of products; the characterization views of a product version; the context-dependent relationships between definitions of product versions. Figure 5 and Figure 6 show the ARM of this AM in EXPRESS-G language.

The Activity AM identifies an application module for: the definition of an activity and the relationship between two activities; the identification and the description of an activity method; the relationship between an activity and the product or activity data that it affects or uses; the definition and the quantification of work output and the association of a work output with the source that produces or delivers the output.

The Condition AM provides an application module for the definition and the assignment of a condition and the recording of parameter values evaluated and the logical result of the evaluation.

The Date AM defines an application module for the representation of a date that is defined as a day in a month of a year.

The Document and file AM offers an application module for the representation of: the data that identify a document; the data that designate a version of a document in a digital or physical format; the files stored on an electronic storage device or non-digital device; the assignments of documentation to product or activity data; the data that identify a formal standard or external document.

The Event AM specifies an application module for the characterization of an event that occurs in a particular moment of the product lifecycle and the relationship between the item involved by the event and the event itself.

The Information AM identifies an application module for the representation of the information concerning the coding schema of product ID and information on where it is possible to retrieve other kinds of information on the same product item; the user rights concerning the access and use of information.

The Material AM provides an application module for the representation of: the data that identify a material; the data that designate a version of a material; the association of a material constituent with a product or its parts.

The Measure AM defines an application module for the representation of units and of quantities.

The Measurement qualification AM makes available an application module for the specification of the type of a measure; the definition of the number of significant figures in the representation of a measure; the specification of the quantitative and/or qualitative uncertainty of a measure.

The Person and organization AM is an application module for the representation of the data that define and describe persons, organizations and persons who are involved in an organization; the data that identify and describe a program of work.

The Property AM identifies an application module for the representation of a property that is assigned to product data and the identification of its representations; a property of an activity or a resource and the identification of its representations; the shape of an object and portions of that shape; the properties of a shape or shape portion; an activity that defines or is part of the definition of a product and the identification of its properties.

The Representation Application Module outlines an application module for the definition of: a representation; a context of representation; an element of representation; a shape representation.

The Resource AM defines an application module for the representation of: the entities defined elsewhere that may act as a resource; the resources used or consumed by an activity; the resource management capabilities; the quantity of resource availability; the relationships between resource event and the corresponding resource usage or consumption; the resources required to achieve a specified objective, such as materials, persons with known skills and technical documentation.

Finally, the Source AM specifies an application module for the identification of the source of a given data type; the identification of information about the source and of the data provided by the source.

5 Validation of the Standard: an application case

The new Application Protocol has been tested in eight companies (Application Scenarios), as shown in Figure 8, belonging to five different industries: 1) automotive sector; 2) manufacturing machines; 3) electrical and electronic equipment; 4) telecommunication; 5) rail equipment.

Figure 8. Application Scenarios

In the following FIAT-MOL Scenario is deeply presented.

5.1 FIAT-MOL Scenario: information management for trucks predictive maintenance

The main focus of this Application Scenario is the Middle Of Life (in particular distribution, use, service and maintenance) of a truck, which can be a Stralis (big truck), a Ducato (small van) or an Iveco Daily (small van).

The main objective of this Demonstrator is to prove that the developed model contains all necessary information for:

- supporting maintenance of a fleet of trucks;
- optimizing maintenance plan and increasing the overall availability of the trucks;
- providing complete and real time feedback to the company.

Although this Application Scenario is focused on the Middle of Life, the MOL data can be used also to improve the BOL phase, such as design and production. For example, the analysis of the statistics summarising the mission profile of the vehicle/component will be used for improvement of the product design and new business model are able to provide useful MOL information (mission profile, maintenance, history data, etc.) to production department for improving production.

But these MOL data of vehicle and component can be used also in the improvement of EOL operations like reuse and dismantling. For instance, a new PLM model should provide useful MOL information to second hand vehicle owners and EOL applications for the last vehicle owner.

The target component is the engine, and in particular the oil, air filters and the brakes (Figure 9).

Figure 9. Physical Product

In this example the IVECO_truck: physical_product is considered, with its component IVECO_engine. The latter consists of three components: brakes, air filter and oil filter (Figure 10).

The IVECO_truck: TRUCK Birth_Date corresponds to the day in which the machine is ready to use, and its End_Date shows the medium time of analysis of the truck.

The engine is bought by third parties, in date 2005-01-08, and lasts in media five years, without maintenance. It's installed in the Truck in 2005-12-02 ("from" attribute) and it's considered its component until the Truck "dies" ("To" attribute coincides with IVECO_truck: TRUCK, end_date).

Also the Engine components have Birth and End_Date referring respectively to the purchasing date and to the estimated end of life. Their Birth_Date are all the same, because it has been hypothesized that they have been bought from the same supplier at the same time.

Figure 10. IVECO_truck

In Figure 11 five properties are detailed for the AIR_FILTER (all these properties are also defined for the other Physical Products, but in this paper they have been detailed only for one component):

- “IV_Vendor: VENDOR”: shows the seller of the Air Filter;
- “Series_Numb: SERIAL_NUMBER”: gives a unique identification code to the product;
- “IV_Prod_Batch: PRODUCTION_BATCH”: defines the batch of production of the filter, which can assume only the integer values between 101 and 150;
- “IV_Material: MATERIAL”: explains the material which the filter is made of. This property must be limited between the values allowed for the filter in analysis, here among 1B to 27B;
- “IV_Cost: COST”: labels the monetary value of the product.

Figure 11. Air_Filter Properties

Considering that the main purpose of this demonstrator is the predictive maintenance for trucks, different mission profile data should be gathered and used.

Field Data can be grouped in three groups, depending on the engine component they refer to. Dynamic data have been collected by different kind of sensors (in the LCDM Application Protocol it means that the type_flag attribute of source entity in Source AM assumes the following values: Air_Sensor, Oil_Sensor and Brakes_Sensor) and refer to three kinds of reports too (document entities in Document and File AM: Air_Data, Oil_Data, Brakes_Data).

Air_Filter Field Data are shown in Figure 13. The Mileage: field_data could be replaced by the RPM (Round Per Minute) data. Delta_Air_Pressure: field_data stands for the difference of air pressure between the inlet and outlet side of the filter.

Figure 12. Air_Filter Field Data

Oil_Filter Field Data specify data regarding the Consume (Fuel_Consumption), the Trip (Trip_Duration), the Engine Starts (N_Engine_StartUp), the Temperatures (Oil_Temperature, Water_Temperature), the Working Time (Engine_Work_Hours), the Age (Engine_Age), the Load Map (RPM) and the Pressure (Boost_Pressure).

Brakes Field Data describe the number of braking action (N_Braking_Actions) and how much energy the Brakes consume (Energy_Consumption).

In Figure 13 a snapshot of data model behind the LCDM AP related to the IVECO Air Filter Middle Of Life phase is shown.

The event here described is the Maintenance_Start, which is triggered by the Humidity: CONDITION (if the Air_Filter Humidity is greater than 78%, then a maintenance action is needed), and triggers the Replacement: ACTIVITY itself. The latter involves different kind of resources, which are all explicitly defined in the LCDM AP data model.

Figure 13. Event: Maintenance_Start

In this section we have proved that data model of the LCDM AP is capable to describe the principal characteristics of the Physical Product in analysis, considering first of all the Main Target Product, and then explaining the Product Structure, detailing the components, their relations, and their roles in the Demonstrator.

6 Conclusion

This paper has presented the first steps taken towards the creation of a new PLM standard: Life Cycle Data Management Application Protocol, capable to follow the product along its entire life.

Firstly, it has provided a detailed comparison between objects of data model developed within PROMISE project and semantic constructs of the IRs of ISO 10303, that are standardized building blocks for representation of product lifecycle data.

Then it focuses on the development of data structures, that are a fundamental part of the new Application Protocol, aiming at collecting all information needed for the various actors involved in different product lifecycle stages.

This standardization effort can be seen as a concrete starting point towards a widespread standardization activity, aiming at fully developing the proposed Application Protocol.

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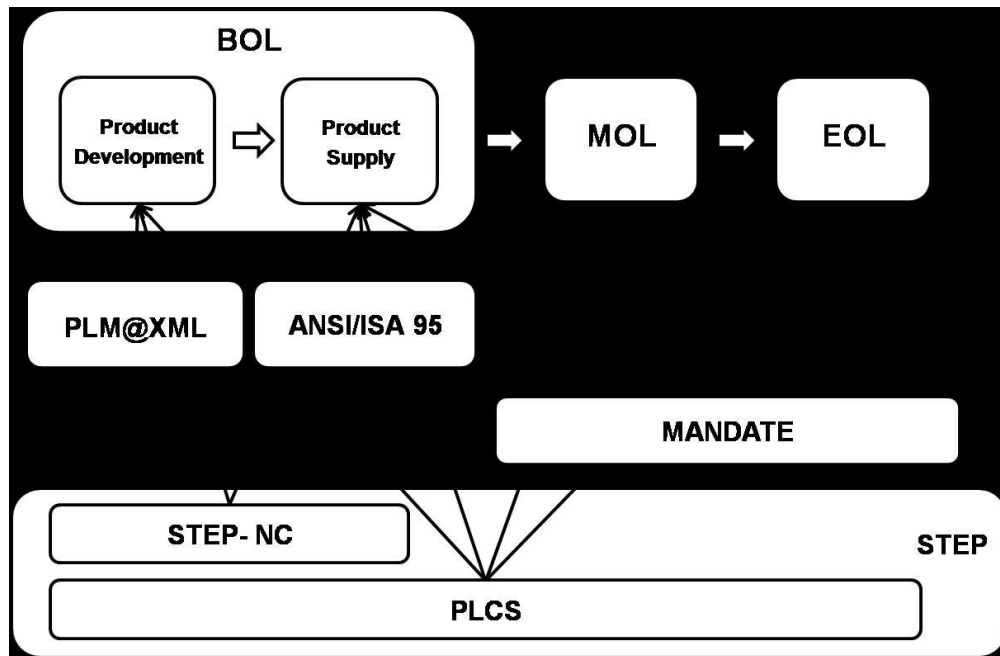
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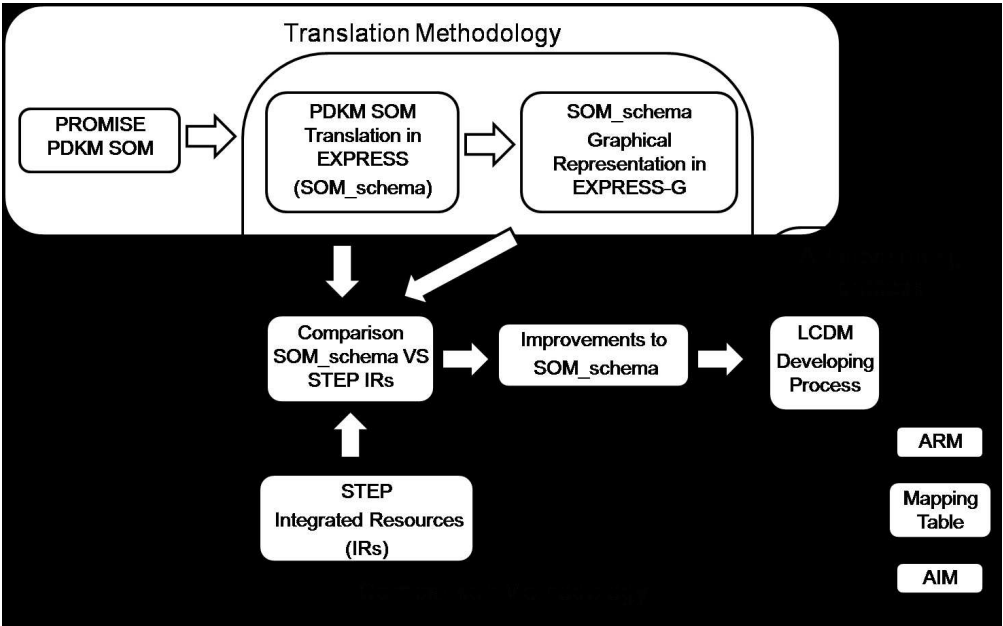
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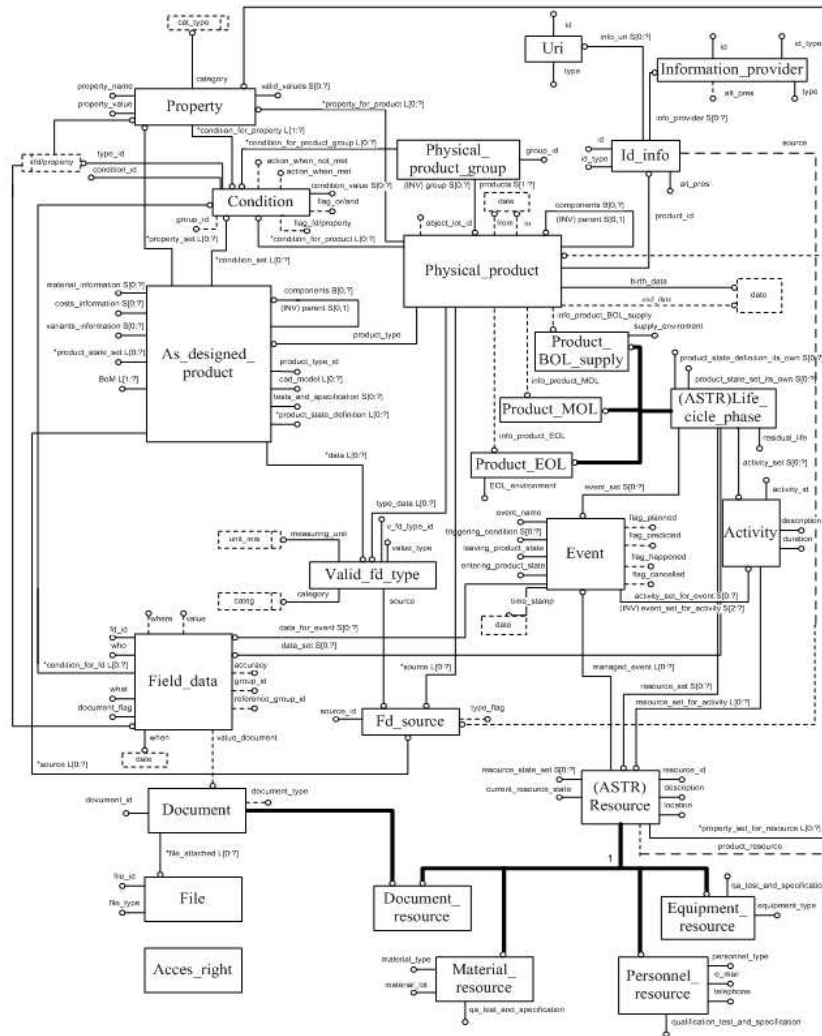
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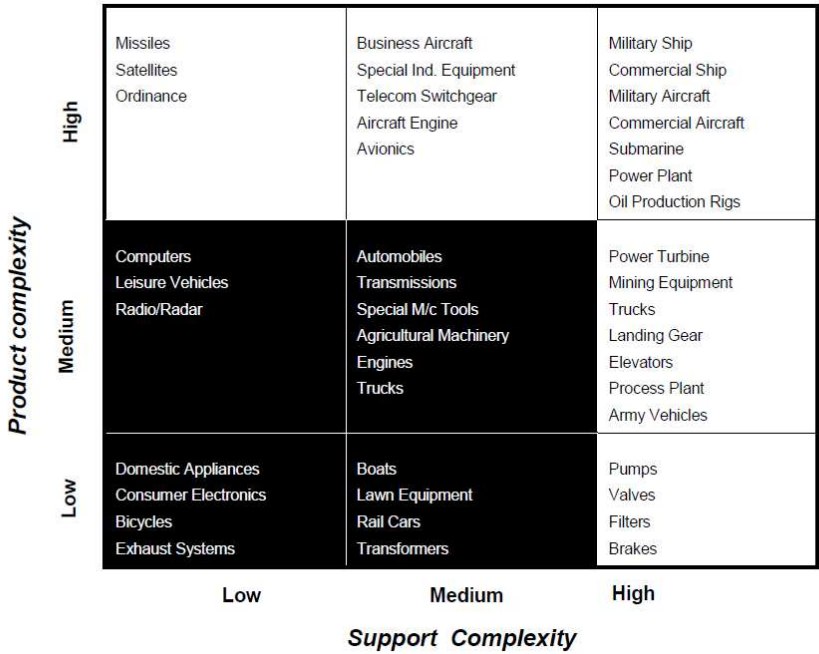
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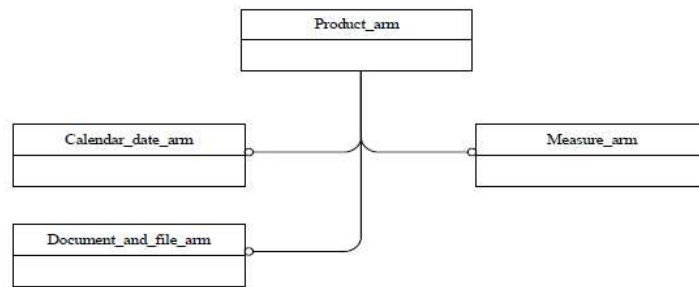
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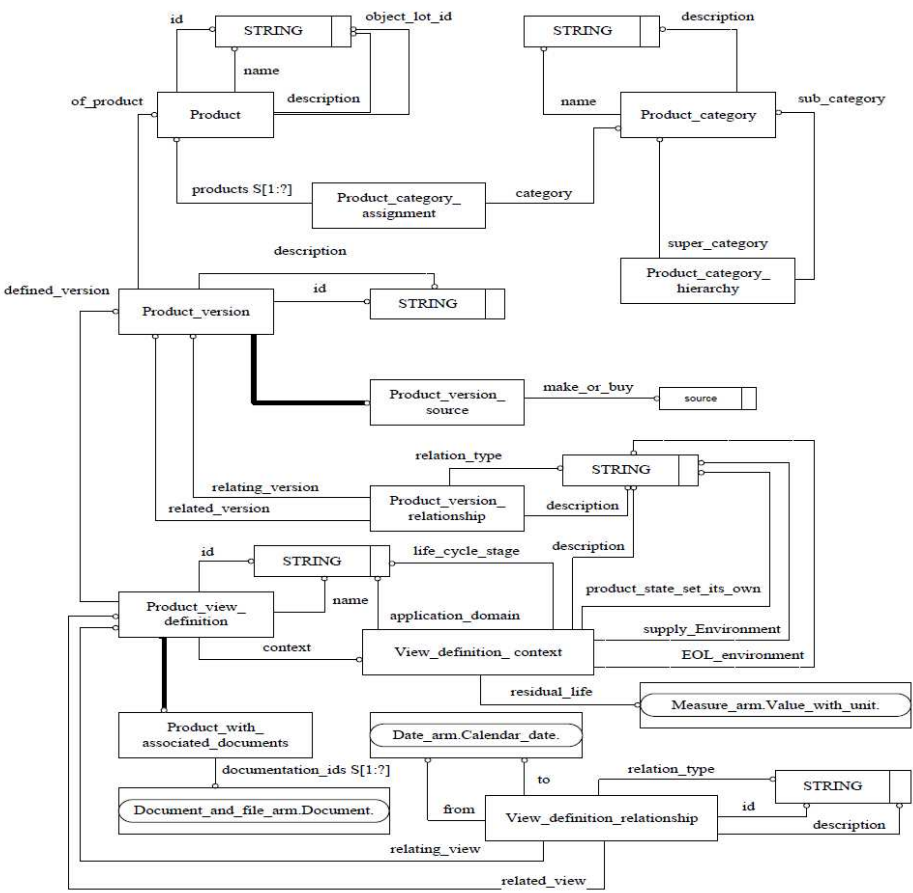
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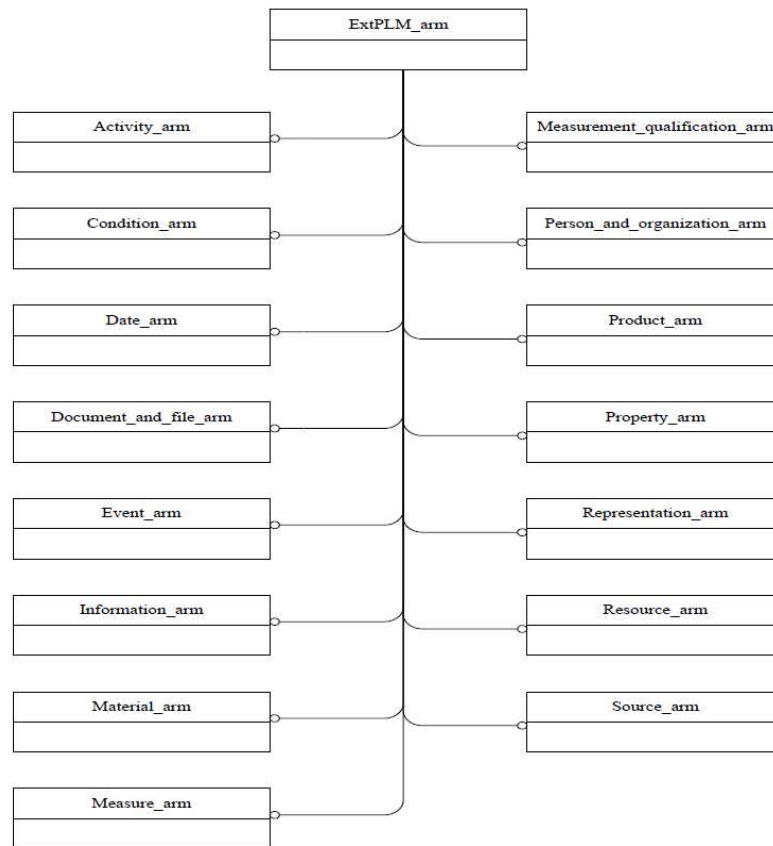


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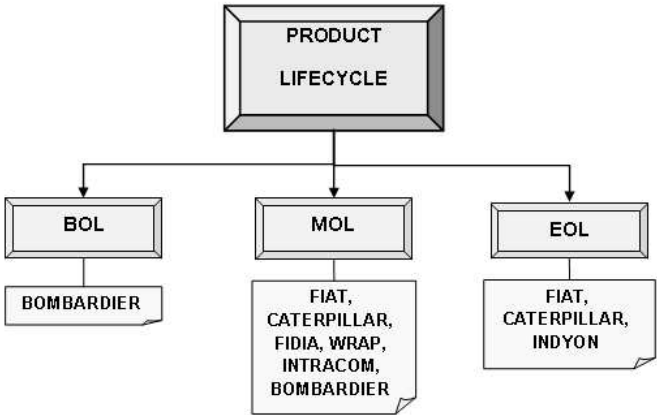


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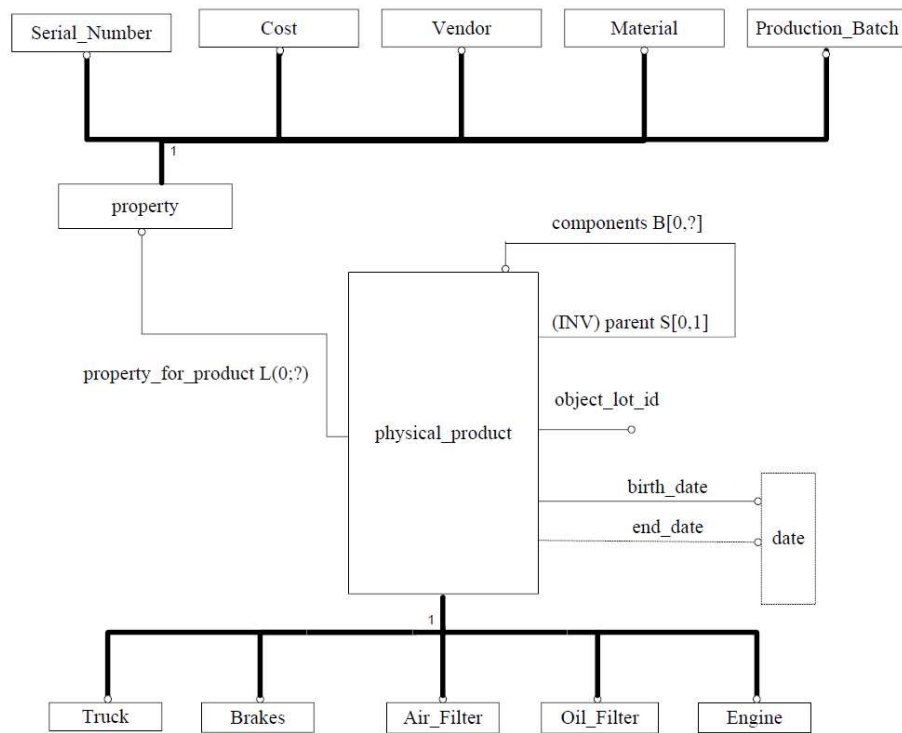
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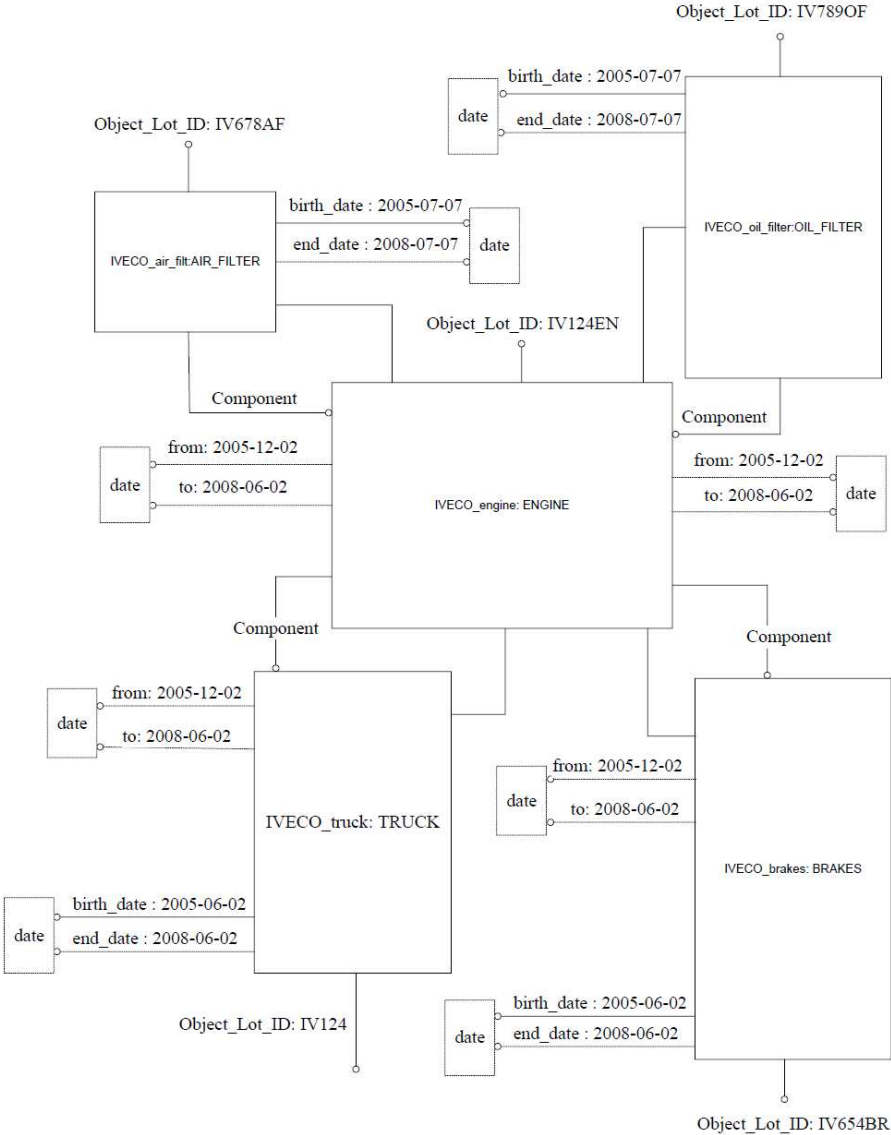
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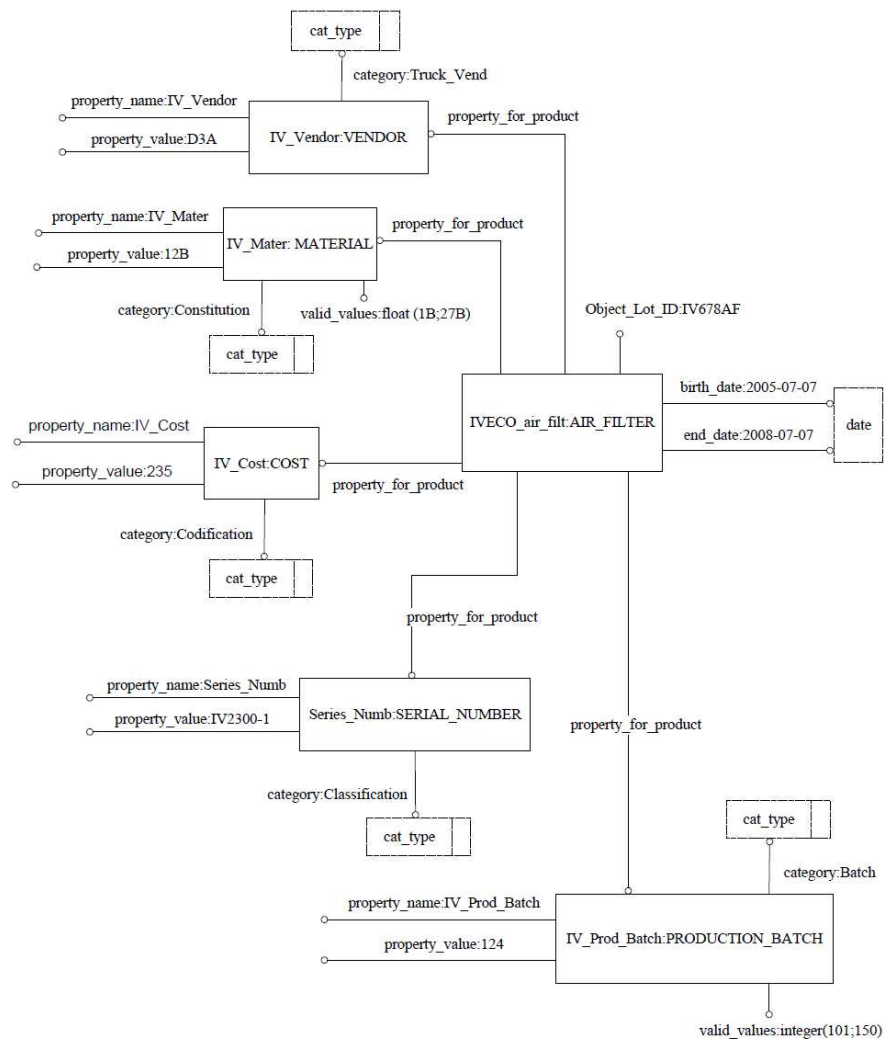
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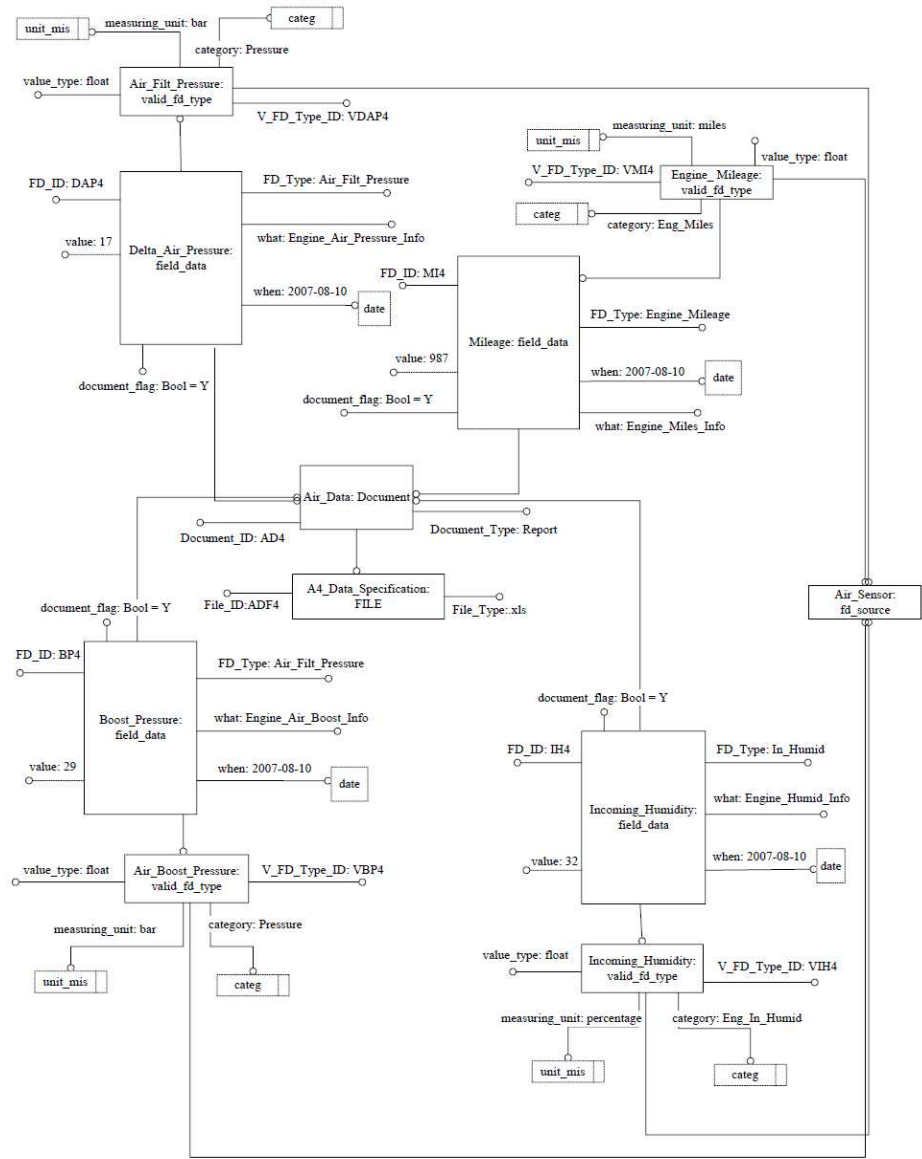


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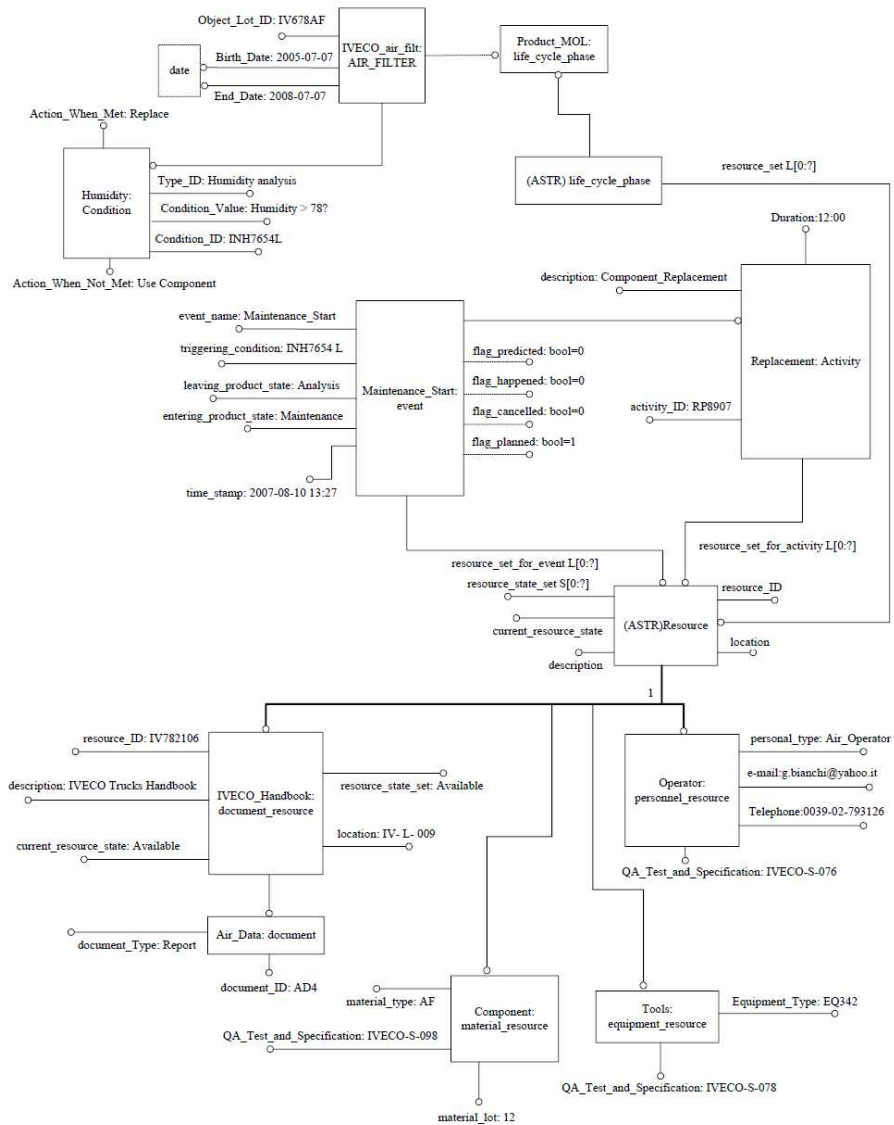


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261x331mm (96 x 96 DPI)



285x342mm (96 x 96 DPI)

STEP IRs entity	STEP schema	SOM_schema entity
product_definition_context	application_context_schema (ISO 10303-41)	life_cycle_phase product_BOL-supply product_MOL product_EOL
product	product_definition_schema (ISO 10303-41)	physical_product as_designed_product
product_category product_related_product_ category	product_definition_schema (ISO 10303-41)	physical_product_group
product_definition_formation	product_definition_schema (ISO 10303-41)	as_designed_product
product_definition	product_definition_schema (ISO 10303-41)	physical_product
product_definition_with_ associated_document	product_definition_schema (ISO 10303-41)	document
product_definition_ relationship	product_definition_schema (ISO 10303-41)	physical_product as_designed_product
property_definition	product_property_definition_ schema (ISO 10303-41)	property
product_definition_shape shape_aspect	product_property_definition_ schema (ISO 10303-41)	as_designed_product
shape_representation	product_property_ representation_schema (ISO 10303-41)	as_designed_product
action excuted_action action_status action_method	action_schema (ISO 10303-41)	activity
action_resource	action_schema (ISO 10303-41)	activity resource
action_resource_type	action_schema (ISO 10303-41)	personnel_resource equipment_resource material_resource document_resource
document document_type	document_schema (ISO 10303-41)	document document_resource
person person_and_organization_role	person_organization_schema (ISO 10303-41)	personnel_resource
material_property	material_property_definition_ schema (ISO 10303-45)	material_resource resource property
type_qualifier precision_qualifier	qualified_measure_schema (ISO 10303-45)	field_data valid_fd_type
resource_property	process_property_schema (ISO 10303-49)	resource property
state_type_assignment state_observed_assignment	state_schema (ISO 10303-56)	condition
event	management_resources_schema (ISO 10303-41)	event

Table 1. The correspondence between the information objects of SOM_schema and constructs of the IRs of ISO 10303.

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