Structuring a Lean Engineering Ontology for Managing the Product Lifecycle

Mariangela Lazoi and Manuela Marra

Abstract Many companies refer to PLM considering only the IT side and ignoring the organizational impact. The organizational aspects of PLM can be represented using an ontology providing a support to address issues and actions. Based on these premises an action research was carried out to increase awareness on dimensions and elements characterizing the product lifecycle in the engineering groups. The aim is to easily represent in an ontology the complexity related to the lifecycle of aerospace products, capturing relevant dimensions, relations and impacts for improving manufacturing activities through a reduction of errors, reworks and missed information.

Keywords PLM · Ontology · Processes · IT · Organization

1 Industrial Context: Background and Starting Situation

The context of the research is a large aerospace group made up of several divisions working in different sectors of the aerospace industry. The divisions produce products (such as helicopters, aircraft, aero structures, airborne and space systems) with specific characteristics in terms of IT tools used during design activities and management approaches applied during product development. All divisions are characterized by a very high degree of complexity of both the technology and organizational structure involved. The adoption of PLM is a common practice among all divisions. Some of them manage the lifecycle from only a conceptual point of view while most of the divisions identify PLM with the IT systems supporting the engineering group (PLMS). Complexity in the elements managed and the impact on the processes involved are sometimes underestimated. Problems of the impacts of PLMS arise later when the IT investment has already been made. Furthermore, given the peculiarity of the aerospace supply chain, it often happens that a divi-

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sion has different PLMS for the programmes in which it is involved. Each programme leads, therefore, to a specific way of working in which reviews, IT systems, flows of activities are established by the OEM and by the product type. In this context, however, the company's standard and legacy tools are also used and integrated.

The main aerospace production approach is engineering-to-order (i.e. high technological complexity, high product variety, significant customer participation in product specification, low volume per product, and high involvement of stakeholders) and the product lifecycle is strictly related to the product development programme and customers' orders. Errors, ambiguities or misunderstandings at the design phase can result in substantial costs, which occur during the manufacturing and later stages of the product lifecycle [5].

Consequently, PLM means an integrated management of technological, methodological and strategic issues along the whole product lifecycle. It is important to understand that product data is not created and used only in a specific activity but it is linked to the whole set of data that is created and used during the product lifecycle. Having this awareness, inefficiencies related to waste of time, energy and resources can be avoided. Additionally, the cost of having the right information inside the company is less than the cost of inefficiencies in manufacturing. The understanding of these issues is not immediate. It needs consciousness and knowledge of the impacts and relations among all the elements of the whole product lifecycle.

The need for a harmonized and integrated management of all the PLM managerial issues, that guides this research, emerged in an aerospace group characterized by the simultaneous presence of multiple NPD programmes, the adoption in the different divisions of various PLMS and different PLM practices. This scenario leads to the coexistence of several meanings for the same terms, several different software licences to be managed, as well as difficulties in sharing information between divisions of the same group.

2 The Research Activities

Based on the literature and on the analyzed industrial context, this research activity aims to create a managerial structure that identifies and connects all the functional areas of the engineering groups of the analyzed context to the product lifecycle data, information and processes needed to provide an organization-wide view about product lifecycle management. Consequently, the aim is to represent in an ontology the complexity related to the lifecycle of aerospace products, capturing relevant aspects related to milestones, reviews, organization structure, operative processes and IT resources used. These aspects characterize the managerial landscape of activities, flows of information and tools involved in the product lifecycle. The research activities are addressed through the proposal of an ontology that aims to support managerial activities in order to make "lean" the operations and optimize manufacturing.

The manufacturing phase of a product lifecycle takes in results and practices realized and decided in the early design phases that have important impacts in the manufacturing activities. In the manufacturing phase, the cost of changes is higher than in the preceding phases, this is due to longer time of implementation, shop-floor configuration, involvement of machines, goods and so on. Companies need and ask for product and process design that can produce low (better no) errors and reworks during manufacturing. To reach this result an efficient and effective management of all the complexity of information, steps, systems, structures related to a product lifecycle can have important and positive feedbacks.

Therefore, for attaining the desired results, an action research was carried out through a strict collaboration in an integrated team made up of three University researchers and five company technicians and engineers. The researchers had a management engineering and computer science background that was integrated with the competences of the involved technicians and engineers. The latter were representative of the engineering groups of the company's divisions, they had experience in process management and engineering improvement initiatives.

The team worked to collect, analyze and systematize all the relevant information useful to synthetize and express the managerial aspects of a product lifecycle and to link these with manufacturing impacts that can emerge. The research activities had a duration of 18 months with monthly coordination meetings to share preliminary results and address further actions. Qualitative data were collected using official documents and interviews with product engineers and IT systems leaders. Furthermore, every three months, focus groups with managers and directors were organized. In the focus group, preliminary results were shared and feedbacks were collected about completeness of elements, highlighted linkages and references to be used for expressing the instances for each domain's taxonomy.

Stage by stage an ontology structure was defined with domains, classes and suggestions for taxonomies. The ontology was focalized on lean engineering insights led by process improvements, waste reduction and optimization in all the aspects of product lifecycle management. For these reasons, it was named Lean Engineering Ontology—LEontology. A database containing the complete structures was also built to provide a tool in which all the values of the taxonomy's elements were available, and to better support search of information and relations among concepts.

3 The LEontology Implementation

According to Mostefai and Bouras [10] an ontology acts as a reference and shared vocabulary for a certain application area. According to the authors, it is complex to model, manage and utilize effectively and efficiently all the product knowledge emerging along the lifecycle in an ontology. In this study, this challenge is faced and ontologies are considered as the way to explain a phenomenon and the related context. Considering El Kadiri and Kiritsis [3], ontology is a relative truth of a specific concept and through different entities, attributes and relations, an ontology can be developed to express all the aspects related to the lifecycle management of complex products.

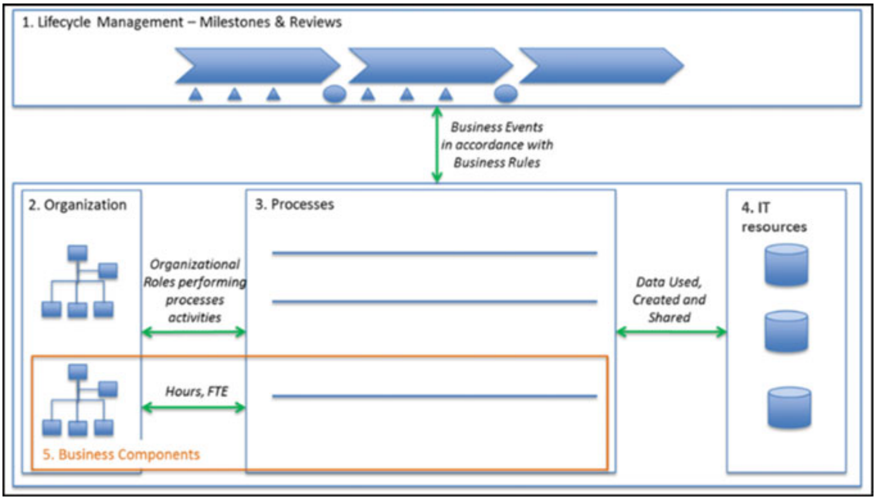

Fig. 1 LEontology's domains and relations

Following the approach suggested by Chungoora and Young [2] to represent product and manufacturing knowledge models, the LEontology is structured in five domains (Fig. 1). These are: (1) "Lifecycle Management" contains information about phases, design reviews and milestones of product programmes; (2) "Organization" is the domain about the organizational roles and related competencies involved during reviews and processes; (3) "Engineering Processes" refers to processes involved for design and manufacturing and to the flow among processes and core activities; (4) "IT resource" has a focus on software solutions used to store, create and share data and information; (5) "Business component" is the last domain with an integrated perspective on organizational and processes aspects enriched by information about costs [i.e. hours, Full Time Equivalent (FTE)].

The proposed domains are linked. The "Lifecycle Management" domain is linked through business events with the "Processes" domain. To allow this relationship, business events need to be in line with defined business rules. Furthermore, the "Organization" domain and the "Processes" domain are related via organizational roles involved in processes and activities. The "IT resources" domain links to the "Processes" domain with the data that can be used, created and shared. Finally, the "Business Components" domain is linked with the "Organization" domain and the "Processes" domain through the use of common information for hours and FTE (Full Time Equivalent) evaluation.

The LEontology is therefore composed by the cited five domains. Each domain has classes and relationships. In each class, there are specific attributes that characterize the domain.

3.1 The Lifecycle Management Domain

The "Lifecycle Management" domain contains information about phases, design reviews and milestones of products in relation to a specific programme. A phase review (PR) is a periodic verification test performed at the end of each phase to attest that the planned objectives/results are satisfied. Actions are established to overcome specific issues and to guarantee the satisfaction of requirements. Milestones (M) are defined moments inside a phase that can report about one or more design reviews carried out in the same time period. Milestones are usually grouped for specific topics (e.g., contract, system, development milestones) and are distributed along the time flow of the lifecycle phases. The Design Reviews (DR) are carried out to verify and validate partial or final results of defined activities on a product. This domain has five classes. "Lifecycle" where information about the programme and related order is available, this class is the link with the product. "Phase" has attributes to identify each phase of a lifecycle. "Phase Review" provides information for the review of a defined phase. "Design Review" is used to collect information on this kind of review and it is directly linked with the last class of this domain. Finally, "Milestone" that highlights the milestone's features.

3.2 The Organization Domain

Each company has its organizational structure and often, in the case of large companies and corporations, each unit has its own specific organization. The organizational structure is usually the result of company/unit history and of experience and managerial preference. In literature, a unique reference standard doesn't exist for organizational structure. In the same way, in the industrial context, several organizational structures are available for different engineering units. Consequently, the first step of the analysis of this domain was the observation of the organizational company's charts and the linked coordination mechanisms for highlighting similarities and differences among the structures. The Organization Domain has, as classes, "Organizational Role" to describe the main roles involved during the lifecycle and "Competency" and "Competency Type" to characterize the competencies required in the roles and activities. Based on Fortunato et al. [4], "Competency Type" can be of three typologies: *Method* represents procedures, company policies, methodological standards, implementing rules and calculation methods applied in an activity; *Technology* is the tool or technological knowledge used for the activity; *Product* refers to the physical characteristics (size, shape, etc.) and the complexity (detail or assembly) of the realized object.

3.3 The Processes Domain

Processes is a large context in which differences in lexicon and in the lower level decomposition are very common. For the Processes Domain, activities are considered as the basis elements that can be combined and re-used in several processes. Furthermore, processes are not disconnected: a set of processes generates input and therefore, one precedes another; a set of processes is launched as a consequence to consume output that has been generated. The network of processes is the neural connections of the company/units working. Understanding them makes it possible to develop knowledge for taking actions in the right place. Activities are also the element of connection between the Processes domain and the Business Component domain.

In the Process Domain there are: "Business Event", "Activity", "Process" and "Relationship Process". The "Business Event" class is the core of the LEontology to enable the shift between the different views, it is the bridge between the Lifecycle Management Domain and the Process Domain. "Activity" is another relevant class, it contains several information about activities and has many linkages with the other classes. "Process" identifies the processes executed and allows to group activities. "Relationship Process" is the class which specifies linkages with the previous and next processes.

3.4 The IT Resources Domain

The IT Resource Domain ontology is a classification of IT systems to support engineering processes through a consolidated management across different organizational units. The ontology is focused on the business activities that a specific IT resource can solve and support. For its development, the IT resources are classified in three areas: knowledge, information and data processed [8]. The data area consists of CAx systems used to create and modify most of the data generated and generated during the lifecycle of the product. The information area consists of the technologies that allow managing both product and processes information (e.g., BOM and Configuration Management, Digital Mockup, Simulation Process Management, Requirement Management, Material Management, Manufacturing Process Management, Content and Document Management, etc.). Finally, the knowledge area (Dashboard and Analytics Systems) consists of technologies that deal with processing the information (knowledge) to have a complete and updated vision of all the systems involved; dashboarding systems and engineering analytics tools make it possible to aggregate data and synthesize information to support strategic decision making.

The IT resource Domain has two main classes: "IT resource" which identifies the software used and "Category IT resource" which classifies the software based on data, information and knowledge management.

3.5 *The Business Components Domain*

The Business Component Domain is based on CBM (Component Business Model), a framework developed by IBM [6] to model and analyse an enterprise through a logical representation or map of business components or 'building blocks'. CBM supports a set of strategic operations which can be accomplished through a pure process-based approach. Each component usually has five dimensions: business purpose, activities, resources, governance and business services. For the aim of this ontology domain, only activities and resources are considered.

This Domain is composed of a single class: "Business Component" where the components are named and linked to activities and roles.

3.6 *LEontology Structure*

In Table 1 and Fig. 2, the whole structure is represented to provide an integrated view of the LEontology. Domains are linked and integrated through direct relationships between classes.

4 The Results: Implication, Benefits and Extension

4.1 *Managerial Implications*

The proposed LEontology provides a clear and integrated way to map all elements related to a company's PLM including the product lifecycle reviews and stages, the organizational roles involved, the processes executed during the lifecycle of a product and the IT systems used. This represents a useful knowledge asset for a company that can be used for several activities: documentation, diffusion of a PLM culture and a shared meaning of PLM related terms, company cross-analysis and re-organizational initiatives, licence costs rationalization, etc.

Documentation is the most immediate use of the LEontology. Allowing sharing structured information in the whole company and with company's stakeholders, it can be used to inform employees about a PLM culture. An employee's task is a small part of a wider set of activities that affect the product lifecycle performance and its impact is usually unknown. Best practices and lacks could be observed in the tasks executed for similar process and in the use of IT systems. The sharing of unambiguous meanings to terms assigned to PLM elements (e.g., design review names) creates a group's PLM awareness, necessary for cross-analysis (inter-/intra-division), for improving IT management and collaboration. Using the ontology, it is possible to have a PLM reference guide shared among different divisions that, at the moment, doesn't exist. Furthermore, creating instances of the LEontology, the

Table 1 LEontology domains, classes and attributes

Domains	Classes	Attributes
Lifecycle	Lifecycle	– Lifecycle name – Lifecycle description – Program reference – Reference order
	Phase	– Phase name – Phase description – Elapsed time – Scope phase
	Phase review	– Phase review name – Phase review description – Deadline phase review
	Design review	– Design review name – Design review description
	Milestone	– Milestone name – Milestone description
Organization	Organizational role	– Organizational role name – Organizational role description – Organizational role type
	Competency	– Competency name – Competency description
	Competency type	– Competency type – Competency type description
Process	Business event	– Business event name – Business event description
	Activity	– Activity name – Activity description – Activity type – Used data – Created data – Resources number
	Process	– Process name – Process description
	Relationship process	This only contains the relationships among the identification numbers of the "process" class (i.e. id_process, id_previous process, id_next process)
IT resource	IT resource	– Software name – Software description – Software version
	Category IT resource	– Category software name – Category software description
Business component	Business component	– Business component name – Business component description

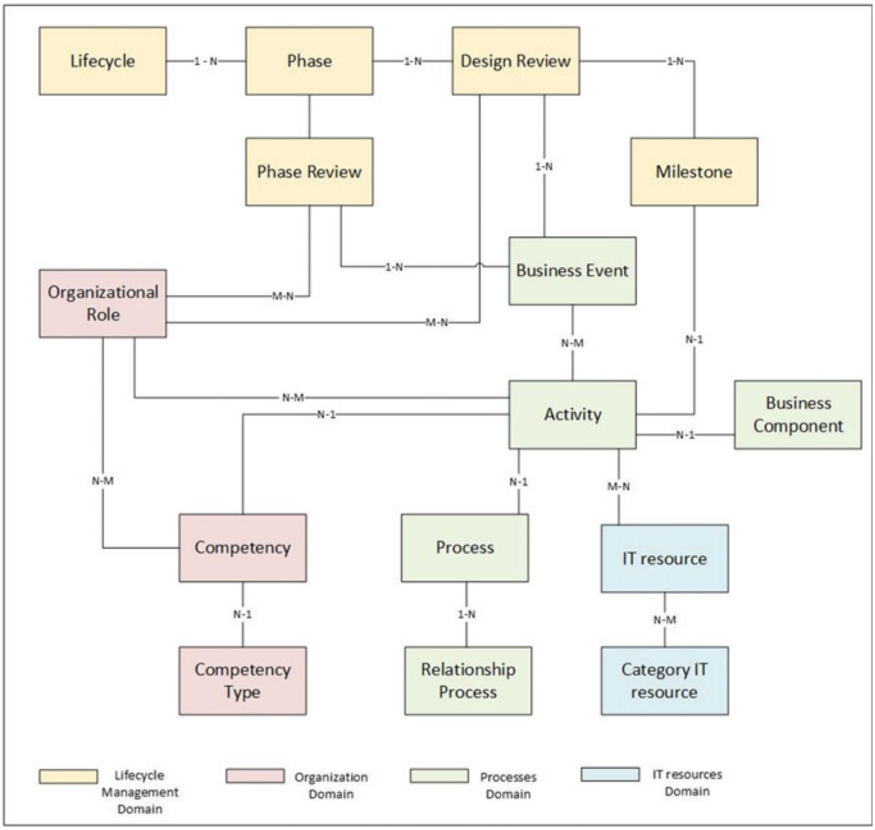

Fig. 2 LEontology structure

aerospace companies could monitor, scout and decide looking to the same reference model in the PLM field. This can be useful in particular during re-organization initiatives or in the proposal of corporate policies.

The LEontology, structuring relevant PLM dimensions and their relations and impacts in the organizations and in the product and processes engineering groups, enables improvement of manufacturing activities through a reduction of errors, reworks and missed information. Aiming to optimize processes and reduce errors offering an integrated view on the engineering processes, the LEontology can enable operative mechanisms to improve the design of products with relevant impacts on manufacturing. A better knowledge of engineering processes, a wide understanding of the different roles involved in an organization, an analysis of the IT systems used to reduce overlap and duplication of information have positive impacts on the product design.

4.2 State of Arts Relations

The ontology presented in this paper is original because it is more focused on managerial issues when compared to the others available in the literature on PLM. It overcomes a lack of completeness [3] since the whole lifecycle related information is covered. A missing contribution and direct linkage with product structure is evident, but it is overlap through the focus on lifecycle phases and activities that makes it possible to also address product issues through a direct reference to programme and order. Phase, Business Event and Activity classes are in common with the work proposed by Matsokis and Kiritsis [9], even if they are used for a different scope (i.e. to integrate data from different systems) and also the linkage in the overall ontology is different. Considering also the ontology proposed by Lee and Shu [7], where a layer of product manufacturing model is available for describing the knowledge of the physical items that are manufactured, this research activity enriches this state of art including organizational aspects. Furthermore, even if the study of Sanya and Shebab [11]) has a different focus of the ontology treated in this paper, in both cases a reference ontology for aerospace engineering activities enables the creation of a knowledge base with a multidisciplinary value.

In addition, based on the role of ontologies suggested by El Kadiri and Kiritsis [3], the LEontology plays three relevant roles for PLM: *trusted source of knowledge* since concepts, properties and relationships are provided; *database* because creation, storage and sharing of the ontology data are enabled by the web tool that supports also instantiation; *knowledge base* from the rules and relationships among classes it is possible to make inferences and have a complete picture about the context.

Finally, as observed also in Borsato et al. [1] and Sanya and Shebab [11], the need of standardization in the meaning of terms used inside a company is an important issue to be addressed. In the LEontology, it is achieved with a top down approach carrying out a first stage of analysis in literature or in the industrial context, based on the domain, of the terminology that is latter discussed and agreed in a focus group.

5 Lessons Learned and Future Research

Based on the needs of an aerospace company in terms of improving engineering activities and harmonizing the information and elements involved, the paper describes the development of a Lean Engineering Ontology for improving the management of product lifecycle issues. Five domains are defined: Lifecycle Management, Organization, Processes, IT resource and Business Component. The domains are composed of classes and links among classes for enabling a complete integration of the whole knowledge managed in the ontology. The LEontology is created by the collaboration among representatives of different divisions of a large aerospace group and academia, guarantying solid fundamentals linked to industrial practice.

The proposed ontology is general and of immediate application. Time and complexity of application depends on the availability of information inside the division and on their collection and analysis. Furthermore, processes involved in the lifecycle are core for the ontology and their representation and systematization could be used also for other activities of documentation or analysis inside the companies.

A main limit of the LEontology is the lack of a direct link with the product structure. This lack is a conscious decision of the authors. It is motivated by the need to strength the role of the product lifecycle related to the programme more than by the physical structure. The LEontology aims to be an ontology supporting managerial activities.

Future research will collect all the instances for each entity using different case studies. In this way the information for each domain will be used for the development of specific instances for a given company context.

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