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Technology responsible for sustainable manufacturing

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Abstract. The emergence of the Product Lifecycle Management (PLM) concept, the development and consolidation of its methodological bases, reflects the company's concern to ensure the quality of environmental factors, as well as the obligations of governmental institutions to control the industrial pollution phenomenon. The "loop closure" of the product life cycle through recycling and reuse, with both environmental and economic benefits defines the model of a circular economy. The paper presents the opportunity to implement a PLM system, addressing the R & D activities of processes/products/technologies that take place within an RDI entity.

Key words: PLM (Product Life Cycle Management), Circular Economy, R & D / Innovation, Life Cycle

1. Introduction

PLM is a process of managing the entire life cycle of a product, starting from generating an idea, concept description, economic-financial analysis of the business, product design / solution architecture / technical implementation, successful entry into the market, up to service, withdrawal and recycling [1]. PLM integrates people, data, processes and business systems and represents the digital backbone of process / product / technology data for that entity, Fig. 1 [2].

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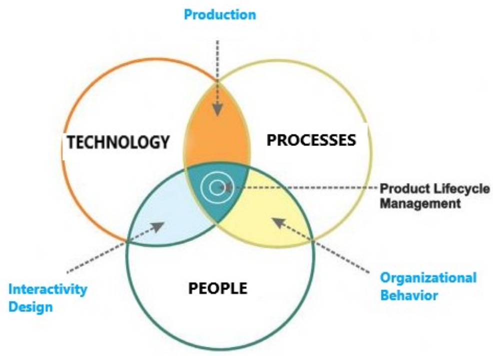

Fig. 1. Fundamental elements of PLM.

Sustainable attitude towards the world, oriented towards people even from the concept phase, PLM management is important for ICPE-CA because here creativity and life cycle are combined in all activities. Especially, as national research-development-innovation institute, we have obligations to contribute to the sustainable development of the Romanian society, thus contributing to the completion of the circular economy.

The circular economy is restorative and eliminates waste by designing more performant materials, products and design systems, activated by innovative business models [3]. In this way, the product life cycle is extended. The circular economy can be defined as an economic system with closed loop materials [4], which aims to maintain at all times the greatest utility and value of products, components and materials.

A closed-loop PLM system will allow all actors who play a role throughout the life cycle of a product (managers, designers, service and maintenance operators, recyclers, etc.) to track, manage and control product information in any phase of their life cycle (design, manufacture, use, repair, maintenance, recycling, disposal) at any time and in any place in the world [5].

In a circular economy, the value of products and materials is kept as long as possible, waste and resource use are kept to a minimum, and resources do not leave the economic flow once they reach the end of their life, but are reused and continue to create value [3].

Applying PLM on respects the new ISO 2015 standards that adopts "high-level structure". In this regard, ISO 14001: 2015 adds the concept of "life cycle perspective", which requires the organization to establish controls to ensure that environmental requirements are taken into account in the design process for: development, delivery, use and treatment its products and services at the end of its life, but also to communicate relevant environmental requirements relating to suppliers and contractors, as well as to provide information on the potential impact on the environment during the use and treatment of the product at the end of its life. In general, PLM is associated with the manufacture of products, but the management structure can also be used for software development and service provision.

2. PLM implementation in a RDI entity

The implementation of a PLM system greatly influences the activities, and a RDI entity, like any other, needs a lot of firmness and openness towards changes. For relatively simple activities there are solutions that can be implemented quickly, but there are also extremely complex projects that extend over a long period of time, three or four years. In such a project, many aspects cannot be anticipated from the beginning, but as it unfolds, new elements appear, from raw materials and technologies, to maintenance and costs. PLM solutions can allow continuous optimization of the entity's internal processes.

Every system has a life cycle that takes place between the moment of appearance and the moment of disappearance of the system. By system we define products / processes / technologies that are subject to the same rules, activities specific to a research institute. The life cycle of a product / process / technology means all aspects related to the product / process / technology, i.e.: research, design, development, production, distribution, use, remanufacturing, recycling, all being simultaneously considered [6]. Thus, for example, PLM solutions manage the entire life cycle of a product, from conception - the moment of generating the idea of a new product in the mind of the researcher - through design and manufacturing, to service and commercial decline, when the product is no longer required by market and ending with recycling. This cycle can be likened to the increase of human physical and intellectual power, going through a succession of phases.

In general, the life cycle looks like it is shown in Fig 2 [7]:

where: A – Launch, B – Growth, C – Maturity, D – Saturation, E - Decline

1 – research and selection of products, ideas, 2 – technical solution and development, 3 – zero series manufacturing (in pilot station), 4 – marketing activity

The four groups of activities (1, 2, 3, 4) make up the dynamic process of the innovation cycle and comprise seven divisions in a logical sequence, Fig. 3 [7].

In practice, it is very difficult to delimit these divisions, which largely intertwine and influence each other positively or negatively.

Pure or fundamental research is found less, in the national R&D institutes oriented mostly towards applied research, but the institutions of the Romanian Academy are dealing with this type of research.

Applied research consists in materializing the products of ideas into real goods that economically satisfy a need.

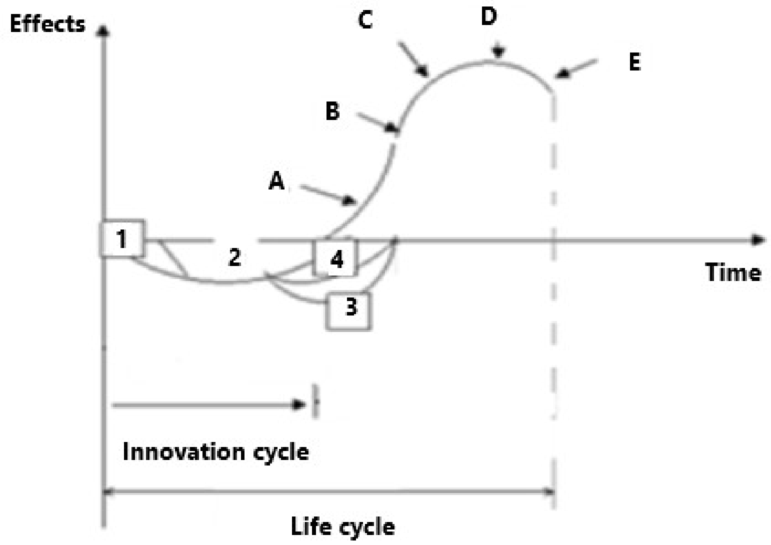

Fig. 2. Product life cycle.

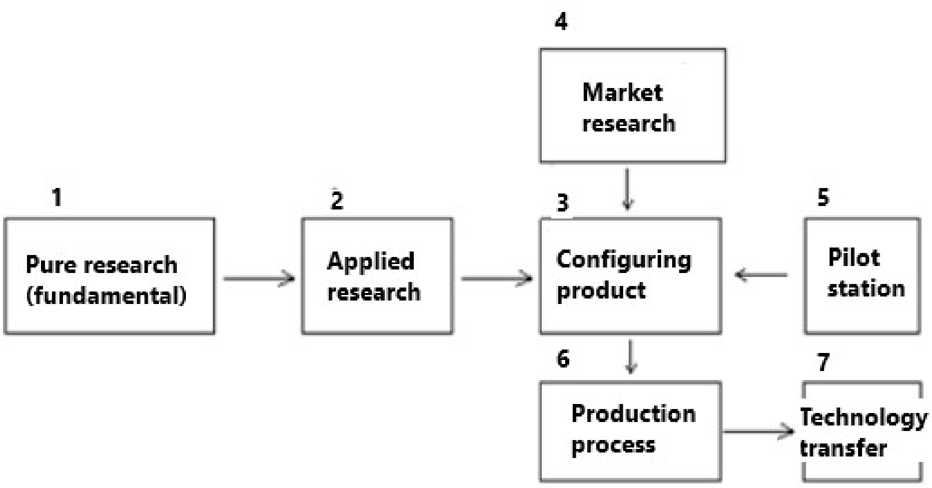

Fig. 3. Innovation cycle.

The configuration of the product immediately resulting from the applied research, determines the appearance of a physical model that comes to prove that the basic ideas of the product are practical. At the beginning, a prototype is made that incorporates its technology and that helps to visualize the operating characteristics proposed for the product. In this way many technical improvements are brought, so that sometimes the product on the market differs a lot from the initial prototype.

Market research on price, demanded quantity, market expansion participates in the realization of the prototype and its finalization.

In *the pilot station* they are technically and economically tested in order to discover some deficiencies or insufficiencies. Defects can come from the production itself or from the manufacturing process.

After certification, the products enter in *the production process*, but the research activity is not finished, requiring a continuous collaboration between research and production.

It is also possible to carry out *technology transfer* through which, for example, a technology, usually protected by one or more intellectual property rights, can be sold to several users who can then further develop and exploit the technology in new products, processes, applications, materials or services.

The final stage of execution takes into account the manufacturing, marketing, pricing, communication, distribution and marketing strategies. All stages achieve, on the basis of analysis, a critical feedback link for the interests of production and product performance. This analysis prevents the risks of damages to the environment taking preventive measures which leading to an optimization of the product based on environmental criteria [6].

We try to exemplify the steps presented in Fig. 3 through an ICPE-CA product, developed since the 1980s. Fundamental research in the field of NdFeB permanent magnets was carried out until 1984-1985 by studying the magnetic properties of binary compounds of 3d transition elements (TM) with rare earths 4f (PR) and ternary compounds $PR_2TM_{14}B$. Stage 2 of applied research and technological development occupied the years until 1988-1990 and extended to both sintered and agglomerated permanent magnets from the NdFeB system. The market study (stage 4) for bonded permanent magnets showed that there is a demand for such products in low power synchronous electric motors, which led to the definition of the product (stage 3), pilot production in the pilot station of the team to establish manufacturing technology and transfer in production (stage 7) to the company "Electromagneticas" during the years 1990-1991. At the end of the life cycle of the permanent magnet in a product, it could be recycled through a developed and experienced process of reuse of raw materials as attested by the patent 115996 C1, granted by OSIM in 1998; this patent is, if not the first in Europe, then at least among the first patents in Europe to deal with the recycling of NdFeB permanent magnets.

PLM is a solution for efficient technology transfer, the research results structured by PLM being directly transferable to any economic agent, the technology transfer can be done from any phase.

The life cycle engineering of a product or process has the role of optimizing the stages of the life cycle aiming to balance the gains and losses related to the energetic aspects, of the materials, of the packaging, of the waste processing. In this sense, seven main directions of eco-efficiency are highlighted in the literature, namely: reducing the consumption of materials, energy, toxic materials, increasing the recyclability of materials, the sustainability of products and services and the development of renewable resources. An indicated approach is to boost innovation, in order to relaunch products that are approaching decline or to revitalize the product by making substantial changes [6].

In the practice several teams are involved in a relatively complex project, and the translation of the concept generated by the research / design team involves a very good coordination of these teams and, therefore, a lot of collaborative work. Thus, concurrent or simultaneous engineering is practiced that promotes the values of team cooperation, trust and sharing in such a way that the decision-making process is by consensus, involving the consideration, in parallel, of all perspectives from the beginning of the product life cycle. Each component part made separately must have the possibility to be perfectly integrated in the final assembly. Moreover, the virtual model, on the way to the final product, undergoes a series of changes required by production technologies, justification of costs or marketing requirements. The collaborative capabilities of a PLM system allow information to flow quickly and consistently in the system, and engineering changes do not cause malfunctions or delays in product launch, which without the support of this system would be common. In addition, elements characteristic of fractals [8] are highlighted due to the fact that different levels of the entity resemble each other. In other words, a whole can be fragmented, its fragments resembling the whole.

The method of analysis is based on the properties of fractals, namely [9]:

- fragmentation to infinity (an infinity of component elements);
- self-similarity which is defined in fractal theory as the property of an object to have any detail of the whole or similar to it at any scale;
- invariance in translations - represents the property of a fractal object, to find a detail of it, by superimposing it over another area of the fractal after translating in a certain direction;
- fractional dimension or “fractal dimension” or “self-similarity dimension”.

Extrapolating, we can think that the process / product / technology is decomposed into subassemblies which, in turn, consist of components and the components are made up of parts. Basically PLM for a process / product / technology is made up of other PLMs specific to each component.

However, reducing the time to market of a process / product / technology, improving quality, reducing costs for prototypes, reusing data, eliminating losses or integrating production flows are all too obvious advantages to be neglected. Managers need to understand that the PLM way of working applies to any process / product / technology, where market and consumer pressure impose process / product / technology innovation and that they can differentiate themselves in the market only by efficiently following the life cycle.

It is proposed to assess and reduce the environmental impact and risks associated with the manufacture of products, manufacturing technologies or specific activities, identify critical areas in which to act to minimize adverse effects, identify and select the most efficient solutions from an economic and ecological point of view. Inventory analysis is a process of collecting data to quantify the inputs and outputs of the studied system. The consumption of raw materials, energy, machinery and equipment, consumables, etc., the emissions to air, in water, in soil together with the solid waste resulting from the studied system are inventoried and are divided into subsystems and unitary processes. The resulting data are grouped into different categories of the life cycle inventory. Life cycle assessment as a fixed structure method must be in accordance with the ISO 14040 standard. This type of study can be used in product development (ecodesign), in their improvement, for strategic planning and decision making, in policy development and regulations, in marketing, for obtaining the green label, etc.

The life cycle is necessarily linked to risk management decisions with major implications for environmental impact. These decisions were intuitive and are based on a lot of experience. At present, there are major concerns for conducting systematic analyses on risk exposure and developing a risk management program with a precise target, efficient in terms of actions and costs. Each entity has the obligation to systematically analyse the risks related to the development of its activities and to develop appropriate plans to limit their possible consequences, risk management managing them throughout the life cycle of processes / products / technologies.

The link between the provisions of product standards and the impact on the environment during the entire life cycle of products is an issue addressed and pursued. Thus, the main European directives and regulations on eco-design and energy efficiency require that throughout the life cycle, the resulting products be in continuous interaction with the environment, or to take from the environment the material resources and energy needed to manufacture the products, or to discharge them into the environment. The main stages of the life cycle, including of electrical and electronic products, are: acquisition of materials, execution of products, packaging and distribution, installation, use, maintenance and development, reuse of products, recycling and recovery of materials or energy, final processes, etc.

An important role is played by the main changes brought by ISO 9001: 2015 and ISO 14001: 2015 ("ISO/IEC Directives, Part Consolidated ISO Supplement - Procedures specific to ISO, 2012), especially Annex SL, which also became known as "High-level structure". ISO has developed Annex SL which represents a framework for a generic management system and it is planned that all revised standards will follow this framework. This includes the behaviour of all staff in relation to management systems and, in particular, of those who form the top management. The change can be very difficult and, especially for this reason, it is considered that the new editions of the standards represent a significant revision.

The new standards adopt the "high-level structure" and terminology in Annex SL. Annex SL has been developed to ensure that all future ISO standards for management systems will have a common format regardless of the specific discipline they refer to, an identical basic structure and text, as well as common terms and definitions.

In ISO 14001: 2015 is added the concept of "life cycle perspective", which requires the manufacturer to establish controls to ensure that the environmental requirements are taken into account in the design process for: development, delivery, use and treatment of products and end-of-life services, but also to communicate relevant environmental requirements relating to suppliers and contractors, as well as to provide information on the potential environmental impact during the delivery of products or services during the use and treatment of the product at the end of its life.

The implementation of software solutions for product life cycle management is based on the decision to strategically address a set of key needs by an entity in order to optimize resources, increase efficiency and profitability. The implementation of a software solution comes from a higher level of thinking of the entity, where there is the vision, the ability to anticipate and look at the producer in a global, dynamic context, in which competition determines the increase of quality and performance, where the need to continuous innovation is imposed by the growing expectations of the beneficiaries. Also, configuring the software solution in a perspective that supports the efficiency of the solution along with a set of complementary services, is an absolutely essential condition. Thus, as steps that ensure the successful implementation of PLM solutions [10], the following are necessary:

- PLM concept; analysis of the organization from the perspective of specific needs and their management with the help of PLM solutions; identifying development objectives and potential;
- elements of fractal theory applied in RDI activities and customization for ICPE-CA;
- tools and standards for PLM systems;
- strategic configuration, management and life cycle models; value analysis;
- life cycle assessment methodology; procedures; applicable ICPE-CA case studies;
- possibilities to introduce software tools for PLM management applicable in the institute;
- simulation, testing and validation of the effects of PLM solutions.

The fundamental elements of PLM are: people, processes / practices and technology (CAD, CAM, CAE, PDM). An entity cannot simply buy PLM as a software application, although software technology is an essential component, implementation must consider all the fundamentals. People "comes" with their experience, education, training and support. **Their experience streamlines the consumption of time, materials and energy, allows the reduction of search time, anticipation of results with a high probability of success. Through training, people learn what to do, and through education they understand why**

they do it. The information that accumulates during the life cycle management of the product significantly improves the efficiency of education and training.
In the management of the product life cycle, it must be taken into account that both the processes (e.g., design, manufacturing, sales) and practices (the user acts according to his own experience) must be captured and virtualized. All applications that are part of a PLM system and that refer to certain stages of the product life cycle must be compatible and interconectable. One criterion in choosing applications for the different stages of the process / product / technology life cycle is to allow the transfer of process / product / technology information to other stages of the process / product / technology life cycle as easily and accurately as possible.
One of the most important results of the PLM adoption is the increase of profitability, by reducing the cost of the process / product / technology and the costs with their development, stimulating the technological transfer as well as increasing the quality of the processes / products / technologies.
It is an opportunity to modernize the management systems and to integrate them in the systems of research entities, companies and firms in order to obtain a better performance of their entire activity, of the business in general.

3. Conclusions

Knowing and understanding the fundamentals of PLM will help managers plan research, design and manufacturing processes, achieve goals with greater efficiency, lower costs and increase the speed of launching new research (processes / products / technologies), research work in general. PLM is an integrated business approach based on information, consisting of people, processes / practices and technologies, which covers all aspects of a product's life, from design to production, use and maintenance, ending with decommissioning and recycling, in order to increase the efficiency and productivity of the entity. PLM is not a tool, but a business approach. In our vision, PLM is a set of capabilities that allows an organization to innovate and effectively and efficiently pursue its products (projects, services, etc.).

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