LEAN APPROACH TO INTEGRATE COLLABORATIVE PRODUCT DEVELOPMENT PROCESSES AND DIGITAL ENGINEERING SYSTEMS

Thomas Vosgien (1,2), Marija Jankovic (2), Benoit Eynard (3), Thomas Nguyen Van (1), Jean-Claude Bocquet (2)
(1) Snecma - SAFRAN Group (2) Industrial Engineering Laboratory - Ecole Centrale Paris (3) Department of Mechanical Systems Engineering - Université de Technologie de Compiègne

ABSTRACT
Lean approach has proven its positive results concerning efficiency and reduction of overall business process time. Product Development Processes (PDP) has an important role in the value definition since it aims at defining the product and customer value, and this definition largely impacts production costs and production times. Therefore, in the past few years industrialist and researchers have shown a great interest in transferring the lean principles to PDP; called Lean Product Development (LPD) or Lean engineering. This paper addresses the LPD principles in design and integration and the difficulties in developing an appropriate value system. Moreover, it is about to expand the definition of the value and related metric system within research study currently ongoing in aircraft industry. The proposition concerns developing digital systems capabilities while matching them with the requirements of some integration processes. Based on a lean-6σ approach, the goal is to demonstrate how this matching can be a value creation driver within the Collaborative Product Development (CPD) of an Integrated Power Plant System, i.e. design and integration of turbojet engine, nacelle, pylon and connected equipments.

Keywords: collaborative product development, lean product development, value engineering, digital engineering systems

1 INTRODUCTION
Since the 90’s and since the publication of “the machine that changed the world” [1], the Lean approach, concepts, methods and tools have been largely implemented in the automotive and aeronautics industry in the field of manufacturing. They have proven positive results concerning efficiency and reduction of overall process time [2]. This fact influences also the recent attempts to implement Lean approach to the whole organization of the company.

Nowadays, competitive firms are those that are able to quickly transform new ideas into products or upgrade their products by managing their Product Development Processes (PDP) [3]. Therefore, the reduction of the time to market has become a strategic variable for firms, particularly for manufacturers of complex systems such as aeronautics products. PDP, by definition, plays an important part in defining customer value [3]. Thus, in the past few years, industrialist and researchers have shown a great interest in transferring the lean principles to PDP; called Lean Product Development (LPD) or Lean engineering. Hence, LPD is expected to have positive effects on PDP efficiency and value creation [4]. However, contrary to production, PDP are multidirectional, processes and process chains are highly connected, and the feedback loops and iterations intersect at multiple hierarchical levels.

Collaborative Product Development (CPD) involves several companies and several design teams (intern or extern) which need to design a product using communication and IT technologies to access and exchange all information to combine to bring about the product design in a context of simultaneous and concurrent engineering [5]. In the aircraft industry, projects are evolving through large-scale partnership. A large amount of data is then created by the different partners. In such a collaborative context, data has to be processed and managed in the most consistent way so as to be used by the different partners and through the different activities [6]. Consequently the collaborative

dimension of PDP makes them even more complex. It also requires a clear understanding of the role of data, information and knowledge along PDP.
Therefore, this paper addresses the questions of value engineering during PDP. Moreover, in order to address this issue it is proposed an experimental study in the aeronautics industry for the design-simulation-integration of an Integrated Power Plant System. The objective is to identify the difficulties in the definition of the value and propose an adequate value system and related metrics. The value system has double objectives: increase the value of the CPD process and diminish the waste as well as use this value system to demonstrate the contribution of new digital systems capabilities to the performance of these design and integration processes. The second part of the paper addresses the principles of the Lean Philosophy and CPD and the difficulties in developing adequate value definition for this process. The third part gives an overview of the ongoing experimental study within an aircraft industry. In the end, first conclusions are drawn and main future works are mentioned.
What creates value and what generates waste in PDP is the starting issue of this research work. Then, the paper proposes an innovative value system for CPD in the aeronautics extended enterprise. Adequate collaborative design environments are needed to ensure that partners and co-design teams can share or/and exchange product data created all along the product development life cycle [7]. Thus partners should be able to bring together their mutual expertise to build dynamically new collective know-how [8, 9]. According to McManus [10] communication systems can aid in establishing pull systems for information access and enable more efficient flow within the PDP. The improvement of the IT environments for supporting CPD can then be seen as real value driver in CPD. Hence in addressing this issue, the first part of this paper presents lean philosophy and the PDP specificities. The second part of the paper introduces recent developments proposing Lean Product Development and related challenges. These challenges serve as a base for the proposition of further research developments and the design of research study. The main goal is to explore how integration and adequacy between collaborative design environments and design business processes can contribute to value creation in CPD.

2 INTRODUCING LEAN COLLABORATIVE PRODUCT DEVELOPMENT

2.1 Lean: philosophy and approach

Lean thinking is essentially a corporate culture oriented towards customer satisfaction in terms of added value as well as in terms of permanent reduction of the time required for creating this added value. Therefore Lean philosophy consists in doing the “just needed” to create the desired value. This “just needed” can only be achieved through the identification, monitoring, analysis and continuous improvement of value chains in the company. The purpose of this approach is to create a continuous flow of material and information to deliver the desired customer value with the least possible waste of resources and minimized delays. In "Lean Thinking" [2], the authors define an iterative approach, inspired by the Deming‘s “quality wheel”, sequenced in 5 basic steps:

1. Defining what makes or creates value for customers: customers must not pay the additional costs of products and /or services purchased to compensate for its supplier inefficiency and waste (with the risk to see the client going to a more competitive supplier). To set the value correctly will also permit to see if we make over-quality.
2. Identifying the value stream: it means mapping processes and identifying added value activities and non added value activities that waste resources.
3. Promote the flow of the stream by ensuring that the stages of value creation are optimized: once the sequencing of the tasks is set for an optimized workflow, it is necessary to standardize and make processes transparent in order to be able to monitor and control them.
4. Pull the flow downstream: the production is triggered only after a customer order (with some safety stock to overcome all unpredictable variations in demand).
5. Striving for perfection to achieve excellence: repeat the loop indefinitely in a continuous improvement process.

2.2 The development phase in the Product Life Cycle (PLC)

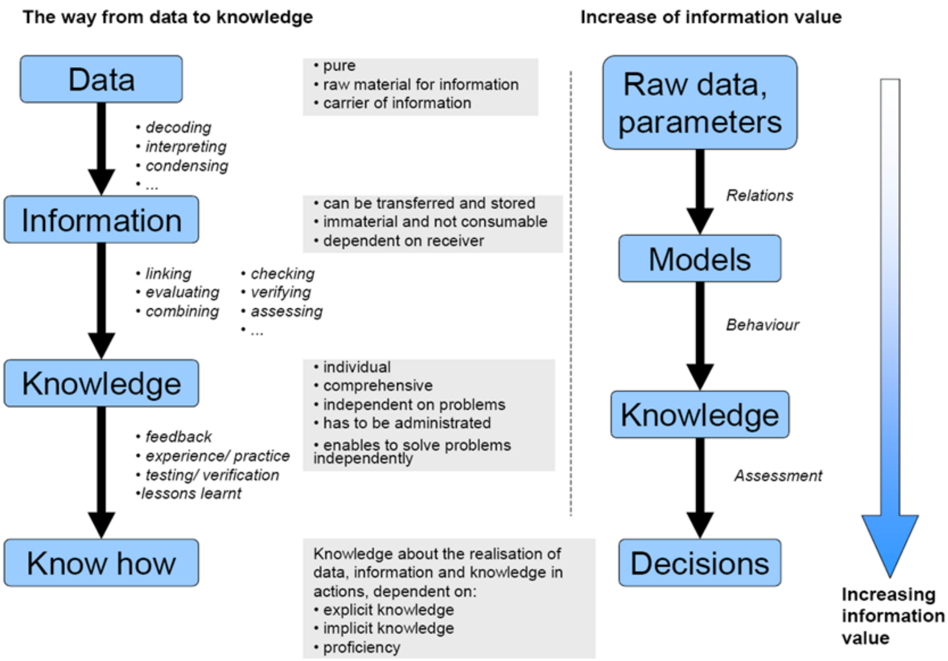
Due to the collaboration process in product development, the delivery delays in aeronautics products have considerable financial impacts for all collaborators in this process. Some studies have shown that

delays in development were factors that had the most negative impact on expected profits, and that exceeding the development budget was the factor with the least impact [11]. Perrin proposes an average evolution of the incurred costs throughout the different phases of the product life cycle (subject to mass production) that also represent the actual expenditure during these phases [12]. This study underlines that the design activities represent only 5% of the total cost of a product when they freeze 75% of the total cost. Moreover, the importance of the design is represented by the fact that it is a phase with the most opportunities to change the design choices and reduce global cost, and where the modification cost is the lowest [3]. Due to the difference in design practices and design projects, many descriptions and design patterns can be found to represent a generic PDP [13, 14]. For all these models, there is a sequential cutting of activities, which comes from a need to segment time and provide validation steps. What differs in those models is the content of the intermediary product representations [15]. Whether it is a sequential or simultaneous approach, the design process is always iterative and sequenced in phases; but in the second case (simultaneous engineering), there is an overlapping of activities in order to reduce the development time [16].
Multi-project development is a concept consisting in developing new products that share common key components, while using different design teams so that each product will differ enough to appeal to different customer segments. As far as possible, this is about overlapping the projects in time in order to rush out several products based on recent technologies [17]. It has already been demonstrated that, applying these principles, companies can significantly reduce the development time and hence the time-to-market. It permits to make huge cost savings in development and increase their sales and their market shares. It is also a way to create opportunities for generating a continuous stream of new products covering multiple market segments, therefore increasing the efficiency of R&D investments [17]. However, managing several projects simultaneously is not a trivial issue, especially for companies developing different complex products like aero engines. One of the key issues is the resource allocation and finding the balance between single project optimum and overall organizational benefits. For engine manufacturers, multi-project management becomes even more complex due to the fact that the different projects are developed and managed with different partners in the context of the aeronautic extended enterprise (this concept is developed in §3.1). Aeronautics PDP is referred as multi-firms and multi-project management. In the aircraft engine sector, it is also important to notice that a partner on a project can be a competitor on another project developed at the same time.

2.3 Information: the product of the product development process

Bauch [18], Chase [19], Graebsch [20] and others consider PDP as an "information creation factory", hence, "the product of product development is information". Slack [21] distinguishes four types of information: product information, project information, process information and business information. Although this distinction has to be done, Graebsch [20] highlights the fact that sometimes the separation between each type of information is not necessarily clear (project information can become product information and vice versa). Information is a multifaceted element of a complex context, embedded in transfers, time, project [20], tools, products and people's mind. Assuming that, it is possible to argue that studying PDP performance aims at analyzing the generation of the different type of information produced within the PDP, as well as the quality of these different types of information. Several models have been developed to represent the process which permits to transform raw data into information and information into exploitable and capitalized knowledge [18, 22, 23, 24, 25]. Bauch (Figure 1) presents a well detailed model [18], drawing a good parallel with the information value creation process. Indeed, through these different transitions, information becomes more valuable, since it is more and more usable through this process. The last stage (knowledge and know-how) is supposed to enable designers to take good and rational decisions about the design choices. Information is an immaterial product. It can be precious for the user, if it is taken into account in carrying out his tasks. Moreover, it is necessary to emphasize that the information value depends upon the context and the moment the information is used. This concept will be detailed in § 2.4.1. The transition from data to information requires knowing the context in which it was generated. Graebsch [20] even argues that information does not exist without awareness of the context. For Ahmed et al [25], in contrast with Bauch [18], the interpretation permits the transition between information and knowledge and not between data and information. The way in which information flows and is organized during PDP is also a crucial factor for creating value. Information flows through communication. Whatever its form (verbal, written, digital, etc.), communication is the basis for team work and collaboration.

Collaboration involves the exchange of information, ideas, experiences, and insights. It occurs when the exchange are jointly undertaken and purposeful, with the expectation of mutually beneficial results [26]. In CPD, people must be able to communicate through their discipline, organization and with other organizations. Wastes in CPD are often due to broken communication links, bad coordination of activities, or to a bad information channels management. Thus, communication, collaboration, coordination and cooperation are essential for effective CPD. They are important especially to follow-up design changes and conflicts between internal or external design teams. They are important



components of value in CPD.

Figure 1: Data, information, knowledge and their value added
(copied from Bauch [18] but according to Schwankl [22] and Irlinger [23])

2.4 Lean Collaborative Product Development

2.4.1 Value creation in CPD

Value is not only what makes something desirable. In Latin "valere" means "being in good health", but the word "validity" has the same etymology, meaning valid or reliable. Then, a true value cannot be just a purely subjective and arbitrary principle. **Speaking of the truth of one value, it has a meaning only if one considers truth as the result of a practice; as something which has revealed itself to be true and not as an impersonal and preconceived dogma.** That is why lean approach is pertinent since the value definition is not frozen but has to be refined for each iteration.

Value definition is the starting point of the Lean approach. According to the literature, PDP aims at defining the product and customer value and this definition largely impacts production costs and production times, i.e. the process value. But customer value is not only defined but is also partially created in PDP, since product development time would directly impact the time to market. The main difficulty is induced by the fact that we are dealing at the same time with the value dimensions (product and process value) and the perception of the stakeholders or perspective (customer value). It is necessary to make a clear distinction between dimensions and components of value and the different value perceptions of the stakeholders. Womack and Jones [2] state that only the customer can define the value, which is "a capability provided to a customer at the right time at an appropriate price, as defined in each case by the customer". This definition, according to Chase [19], is useful for applications where the final product is explicitly defined, such in manufacturing. Moreover, the author underlines that the focus on identifying and analyzing activities that add or not value for customer can often highlights obvious wastes. Therefore, in view to the optimization of PDP, he proposes a more specific value definition considering product, process and organization value, integrating different perspectives. The same author proposes (Figure 2) a framework that underlines that PDP activities aim at increasing information and knowledge about the product definition in time while reducing risk and uncertainties on the product, hence on the project. This is a good simplified model to delimit the process and product value.

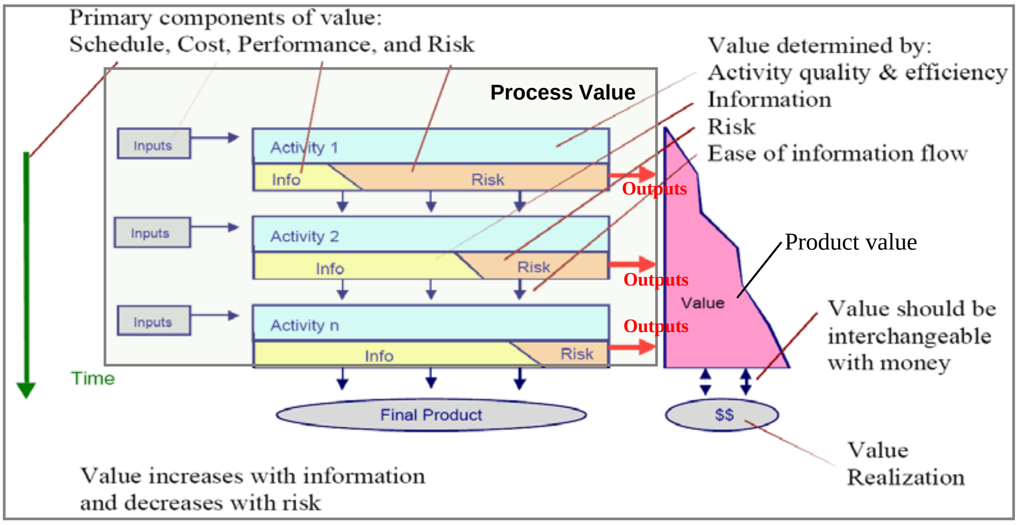


Figure 2: Conceptual framework for Value creation in PDP (adapted from Chase [19, 27])

The objective is to define the value system for an Integrated Power Plant System (IPPS)[1].This study proposes to further develop Chase's approach integrating project value and other points of view. Should a project that fails to provide the expected customer value be considered having no value at all? Therefore, the definition of the "customer value" considering different stakeholder perspectives is of importance for this work. It is proposed to integrate in the definition of the process value the specificities of the collaboration process and the notion of the extended enterprise. Hence, this proposal has to address the following issues:

- **Process analysis** (performance, achievement of objectives, created and added value information, capitalized knowledge on product and process, quality of information, etc.);
- **Waste and problems identification, elimination or/and reduction** (cf. §2.4.2);
- **Collaborative design performances** (whether they are internal or external);
- **The development and the optimization of IT resources to support the business processes and associated collaborative processes**.

Since value components and attribute definition depend upon the dimension of value and the considered stakeholders' perspective, taxonomy is needed to classify these components. This taxonomy will be the base of the value system. This value system is supposed to encompass the definition of the value components (e.g. information quality) and its related attributes (e.g. exactitude, accessibility, reliability, completeness, ease of understanding and interpreting, etc.), as well as to be the basis for the definition of performance metrics in PDP.

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[1] Integrated Power Plant System = Turbojet engine + Nacelle + Pylon + Equipments. This corresponds for the aircraft to the propulsion system/assembly.

2.4.2 Waste in CPD

The question of waste definition is crucial if one wants to contribute to the global optimization of the CPD system and to increase this process efficiency. What is the waste in CPD processes? And what are the waste drivers in CPD? These two questions have already been addressed by several authors in PDP. The first question was initially addressed by transposing seven types of production waste to the area of PDP and eventually adding some categories (Womack and Jones [2], McManus [10]). Morgan [28] considers other specific types of waste, but he has sometimes mixed types of waste and waste drivers. This mixing can be confusing in the implementation phase. Bauch [18], and then Kato [29], map all the ideas from the previous studies in order to identify all potential type of waste. Then Bauch elaborates a cause and effect diagram in order to distinguish waste types from waste drivers. Kato [29] states that from a measurement perspective, the desirable categories of waste in PDP are the ones that can easily be identified and the waste time measured. The author also highlights the fact that effects are easier to measure than causes. Kato's approach [29] is relevant to make the distinction between the different categories of waste and their drivers. His definition of waste indicators can be expanded because he only considers the waste indicators related to time. For instance, time is only one of the six secondary categories of waste defined by Bauch [18]. The primary waste type is the waste related to project targets (quality to market, time to market and cost to market). Regarding these studies, the distinction between real waste and waste driver does not seem to be trivial. However, it can be considered that the categorization done by Bauch is a necessary basis to track down the waste in PDP. The author defines 6 categories of waste: Resources, Time, Information / Knowledge, Opportunity/ Potential, Money/Investments and Motivation. Since these 6 categories are strongly linked to the project targets, he adds to this list project flexibility and quality to market. He also [18] defines 10 categories of waste drivers that encompass 37 sub-categories. However, Graebsch [20] states that only information is creating value in PDP. Then, his study focuses on information waste in PDP and the author derives the Bauch's categories to define his own list of waste drivers related to information flows. In view to the completeness of this study, the related research work will use this proposition of waste category definition.

2.4.3 Lean engineering and LPD components

Mc Manus [30] defines three goals of Lean engineering:

- Creating the right products
- Effective lifecycle and enterprise integration
- Using efficient engineering processes and applying lean thinking to eliminate wastes and improve cycle time and quality in engineering

In his PhD dissertation [3], Hoppmann resumes the work of his predecessors at the Lean Enterprise Institute (LEI) and within the Lean Aerospace Initiative (LAI), describing different approaches and definitions found in LPD literature. He proposes a single "framework" composed of 11 basic components intended to enable creation of a roadmap for application of the five Lean principles. These components are derived from the work of Morgan and Liker "The Toyota Product Development System" [31]. In this book authors define the 13 components which are supposed to help managers to implement a LPD system (Figure 3). Regarding this system and its components, the major high level challenge for implementing a LPD system is to be able to integrate the triptych: People – Process – Tools & Technology. This paper suggests adding to this triptych an additional transversal component which is the "Information conveyed" through this triptych. Analyzing and optimizing the way information flows through this triptych will contribute to build a learning organization and to capitalize the knowledge produced during PDP and which is profitable for operational value streams.

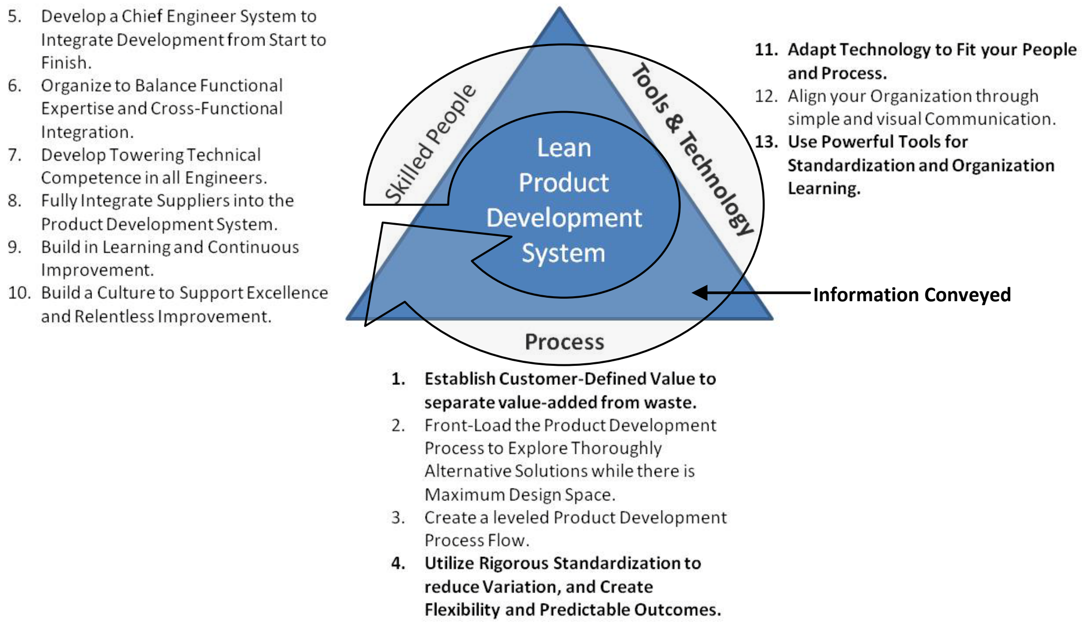

Figure 3: The 13 LPD components (extracted and adjusted from [31])

In order to address the value definition of the design and integration of the IPPS, as well as to enhance the digital systems capabilities supporting PDP, this paper mainly focuses on the first and eleventh LPD components:

- **Establish Customer-Defined Value to separate value-added from waste:** however the definition of PDP value is expanded considering other dimensions and perspectives.
- **Adapt Technology to fit your People and Process:** optimizing and integrating design-simulation-integration processes through the development of digital systems capabilities and their alignment with the concerned processes and activities.

3 RESEARCH STUDY AND CONTEXT

3.1 Extended enterprise: new trends in the collaboration design configuration

The extended enterprise notion is based on a product-oriented strategy that aims at influencing the development phase so as to make it more effective and shorter while making it answer to needs that can be felt downstream [32]. In order to accomplish this organization, it is necessary to use available competencies, both within and outside the company:

- Inside: through the different specialists who belong to the company
- Outside: through the different partners' firms, suppliers, sub-contractors, distributers, customers etc. composing what is called "the extended enterprise".

The extended enterprise requires a deep change within the enterprise organization and needs adaptation of bilateral agreements with its partners (Customer or Supplier) to implement partnerships in specific areas. This also important for the use of systematic cross functional processes, methods, tools and the implementation of concurrent engineering principles and advanced technologies [33]. In this configuration, CPD relies on the integration of design contexts between the different partners. As shown in Figure 4, in large-scale projects, products are decomposed into modules, sub-modules and so on, and work-packages of the studies on this product are externalized to partners and/or sub-contractor [5, 34].

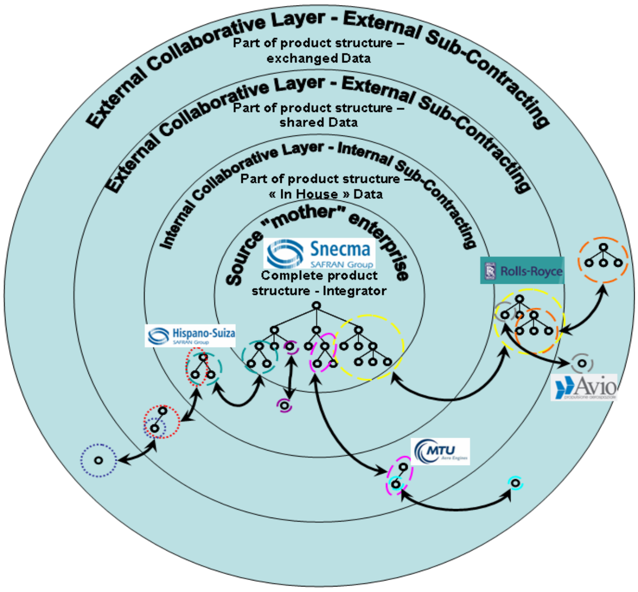

Figure 4: Multi-layer and multi-partner work breakdown into design packages (extracted from [15])

This leads to deal with two industrial issues that currently impact the aeronautics industry: the collaboration between project partners and the improvement of the IT environments for CPD support.

3.2 Collaborative Design Environments in the aeronautics extended enterprise

Aeronautics industry and more especially PDP activities have been impacted in recent years by the advent of the use of **digital engineering** such as **CAX** (computer-aided for X) systems. According to the various application fields, different CAX-systems were developed: **Computer Aided Design (CAD)** for product design [5, 35, 36]; **Computer Aided Engineering (CAE)** for validation of the product definition/design (validation on virtual product behavior); the **Digital Mock-Up (DMU)** enabling collaboration and contextual design. The DMU permits different partners to delimit their 3D working environment through an integrated view of the models [5]. The DMU is as a major tool of Concurrent Engineering [37] and has enabled multiple enterprises to limit physical prototyping and to turn to CAD/DMU technologies [38].

However, the enhanced use of CAX technologies has increased the amount of data created during the PDP. It has also created a big potential for value creation and conversely, information and knowledge waste. Enabling movement of such masses of data through the different activities has enhanced the need for **Data Management Systems** (DMS). Their use is nowadays inseparable from CAX systems. This approach coupled with the need to manage and access different data created all along the lifecycle (for the use of connected activities such as configuration management or manufacturing) increases the need for DMS deployments, including **Product Data Management** (PDM) systems. PDM aims at providing the right data at the right moment for the right actor with the right semantic objects for activity [39]. In other words, PDM should manage consistent and meaningful information regarding the lifecycle stage and the activity, in order to create the most adapted environment for the engineer. This leads to the concept of **Product Life Cycle Management** (PLM). PLM solutions help to define, execute, measure and manage key product-related business processes. Manufacturing and operational process plans are also now viewed as an inherent part of PLM. Processes, and the workflow engines that control them, ensure complete digital feedback to both users and other business systems throughout each lifecycle stage [40].

The new trend in PLM systems, is to integrate and manage simulation data (inputs, CAE structures, FE models, analyses results) resulting from analyses performed with CAE tools. This is a very important performance and hence value driver in CPD for the following reasons:

- Performed digital simulations provide an approximate (depends on the detail degree of models) knowledge on the product behavior and hence create PDP value.
- Digital simulations of complex models require many data inputs which are difficult to obtain and the overall simulation process is very time consuming, and hence it can be a big waste driver.
- The more accurate virtual prototyping and simulation are performed, the less testing prototypes are needed. These physical prototypes are expensive, and hence increase development and product costs.

Simulation Life Cycle Management (SLM) is then considered as a component of PLM, but simulation data, processes and their lifecycle are so unique and central to PLM’s success that it merits its own category [41]. Therefore SLM tends to be more and more strongly linked to the area of knowledge management and the intellectual property associated with simulation tools, data, and processes as related to product or process development.

In such a heterogeneous environment composed of CAX technologies and DMS, a common environment is necessary to ensure the continuity of information between working teams. This is called a **Digital Collaborative Platform** A great number of various CAX and DMS solutions have been developed and, presently, industrial collaboration suffers from the **heterogeneity and diversity of software**, data exchanges and their management among partners and along activities. Data exchanges’ efficiency and interoperability between systems, and the control through an integrated reference framework for product development are required [42]. Digital collaborative platform can be seen as this reference framework and should aim at tackling the issue related to the **lack of interoperability and integration between partners systems**.

3.3 Research scope and proposition of a lean-6σ approach

The development, spread and diversification of digital engineering tools require understanding and matching the triptych Processes - Tools - Information conveyed. In order to tackle the issue of optimizing the performances of the triptych, an experimental study in the aircraft industry is proposed (Figure 5).This study aims at demonstrating how the use of digital engineering and the improvement of existing tools capabilities can contribute to optimize the design and integration processes (including simulation) of the IPPS. This optimization can be performed only considering the entire mentioned triptych, as well as considering the other important LPD component: the human factor (Skilled People). To ensure the scientific validation of the approach, the methodology is based on a Lean-6σ approach: the DMADV (Define-Measure-Analyze-Design-Verify) which is an iterative approach. This approach is based on the methodology described by both Samuel (2008) in “Design for Lean Six Sigma” [43] and Mc Carty et al in “The six sigma black belt hand book” [44]. Since this approach is iterative the study encompasses several iterations.

The left part of Figure 5 presents the study scope encompassing two design teams (mechanical and aerothermal integration), and the triptych Business Processes – Information conveyed – Supporting tools. The potential future tools are related to tools which are being implemented and tools which have to be developed in the frame of the study. The study emphasizes on the use of these tools for acquiring and exploiting data inputs for activities related to mechanical and aerothermal simulations. Two disciplines are considered because their needs for data inputs differ and it enables to deal with the multi-disciplinary issue in CPD.

The main expected outcomes are:

- A demonstrator encompassing innovative digital capabilities to support CPD processes and particularly the process of acquiring simulation data inputs at an integration level.
- A set of performance metrics (derived from the value system) applicable on the concerned processes; to demonstrate the gains and benefits of the new digital capabilities.

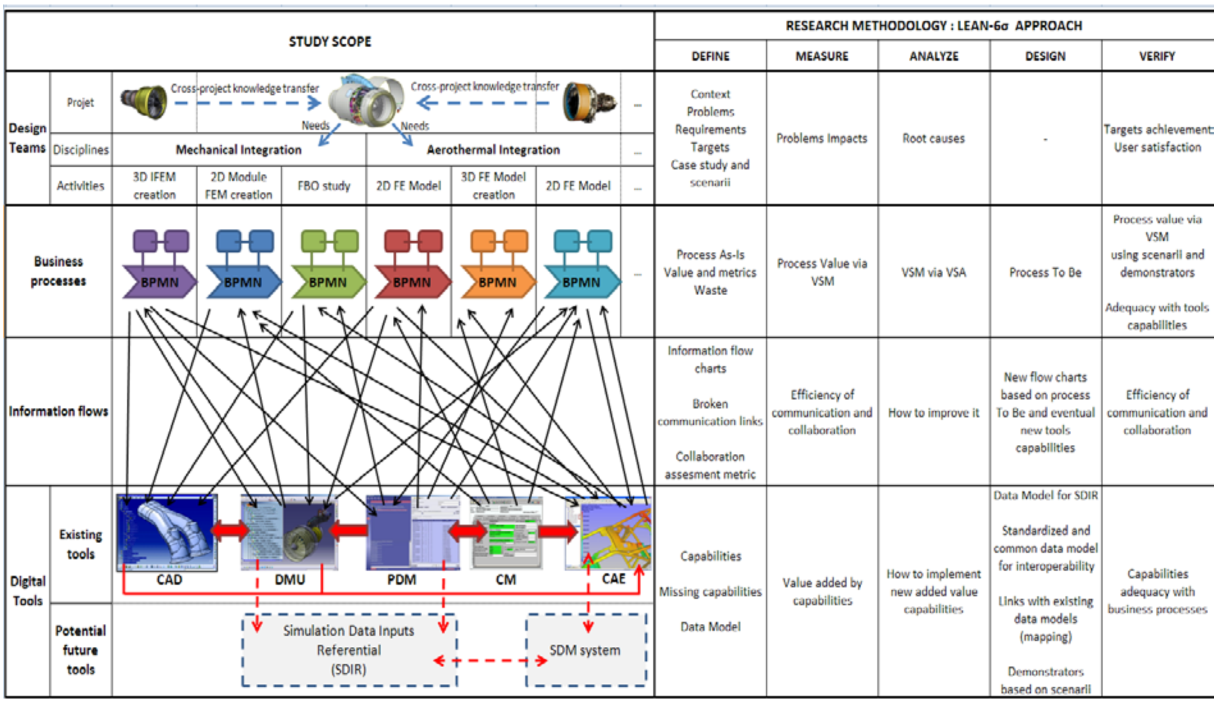

Figure 5: Study scope and research methodology

4 CONCLUSIONS AND FUTURE WORK

Since 90's, Lean principles and philosophy have been implemented in the industry. It has been found that this approach has positive impact on the overall efficiency of one company and the reduction of the global manufacturing time. Regarding the importance of the PDP in defining and creating the customer value, recently there exist some interesting works addressing the challenges in developing the Lean approaches. The adapted Lean approach is called Lean Product Development (LPD).

This paper provides an overview of the recent research studies addressing the LPD systems and challenges that are important to solve in order to insure the implementation feasibility. It is also exposed the changes undergone in the PDP that impose new problems to LPD development. It also highlights the importance and the characteristics of the PDP in the product life cycle, especially in the context of collaborative aeronautics projects. This preliminary study underlines the importance of data, information and knowledge management in PDP. This process permitting to pass from data to information, from information to knowledge and know-how is considered in this study as a generic value engineering process. Therefore, an extension of the value definition for CPD is given. Its application for the design and integration of an Integrated Power Plant System under development.

The preliminary research outcomes lead to new questions. Is value determined only by the customer? Are product, process and organization the only dimensions of value? What is the difference between product and process value? Why "project" has not been defined as an additional dimension for value definition? Considering project value, other perspectives (points of view) than the customer perception have to be considered to define PDP value: value for the company, value for project partners, value for employees, and so on. Creating value through PDP activities aims at **increasing information and knowledge** (activities 'outputs) about the product definition in time while **reducing risk and uncertainties** on the product, hence on the project. The involved activities and tasks require internal and external **inputs supported by resources** (human, material, IT resources) to provide the **added value outputs**

Moreover, the aim is first to characterize the bottlenecks and the waste related to data and knowledge management within design and simulation business processes. Secondly, the objective is to demonstrate how the following concepts can become major drivers for value creation in CPD:

- The development of digital capabilities within the existing collaborative design environments (CAD, DMU and PLM systems);
- The alignment of design and simulation processes with these capabilities and vice versa;
- The development of digital collaborative platform supporting the various kind of collaboration and ensuring consistency between product data and the data related to the collaborative processes.

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