Organizing Concurrent Engineering Through ICT Platforms

Blueprinting Product Lifecycle Management Platforms across Disciplinary Agencies

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ISBN: 978 90 8666 417 7

Publisher: Boekenplan, Maastricht.

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DISSERTATION

to obtain the degree of Doctor at the Maastricht University,
on the authority of the Rector Magnificus,
Prof. Dr. Rianne M. Letschert
in accordance with the decision of the Board of Deans,
to be defended in public
on Thursday, 24 November 2016, at 14:00 hours

by

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Acknowledgments

I would like to thank Antonio Cordella and Harro van Lente, my co-supervisors, for their support and guidance throughout this research.

I thank also the members of the assessment committee, Prof. Dr. Wiebe Bijker, Dr. Maha Shaikh, Dr. Serdar Türkeli, Prof. Dr. Robin Williams, for their constructive feedback on a text that is – to say the least, not straightforwardly accessible.

I would like to thank also the GPAC faculty for the valuable advice during the various steps of my research. My special thanks goes to Mindel van de Laar for her empathetic encouragements from the first to the last steps of this journey.

I would like to thank my GPAC fellows – particularly, those of my cohort, for sharing ideas and experiences during the (too short…) sessions in Maastricht.

This dissertation is the result of a long learning process accomplished with customers, partners and my colleagues at PTC. I would like to thank them for sharing their knowledge and providing useful feed-back throughout the numerous projects that nourished this research.

This research would not have been possible without the organisational and financial support provided by my former employer. I am particularly thankful for the friendly and sustained support from Patrick Bionducci.

I also want to express my gratitude to my sons Max and Arthur, for stimulating me to complete this dissertation – a big thanks goes to Arthur for the help on putting together the final manuscript.

I'm most grateful to my wife, Eliane. She inspired and motivated me to carry out a project which had long been in the works.

Contents

CHAPTER 1/ INTRODUCTION

This chapter presents our research domain and positions our research question within the academic debates concerning the relationship between organising distributed engineering and Information & Communication Technology (ICT).

After outlining the three research traditions that structure our questioning, we describe a gap in the literature and a possible path to address it through our research question.

We describe also how the research question is explored through three operational propositions.

We conclude the chapter with the research design presentation. A brief description of the scope of the two case studies is followed by the approach guiding data collection, data coding and data analysis.

1.1. Research domain

Our dissertation studies the relationship between the organisation of complex concurrent engineering processes and Information & Communication Technology (ICT). We wish to contribute to contemporary academic debates about the role of ICT in organising distributed agencies across disciplinary boundaries. Our line of reasoning is structured around the interactions between an industrial firm and a software vendor leading to the blueprint of an ICT platform mediating an assemblage of practices, software applications, roles and responsibilities at cross-disciplinary level.

1.1.1. Addressing the concurrent engineering paradox

The increasing complexity of industrial products generates the need for organisational capabilities enabling continuous collaboration between specialised disciplines. Teams involved in concurrent product development processes, engage in long projects/programs, where emerging knowledge about a new industrial product is constantly changing. Challenges emerge as representations and models of the product become more and more unstable.

The growing complexity of relationships between the various disciplines involved in concurrent product development, is characterised by a paradox: engineers need to stabilise conflicting relationships knowledge *exploration* and knowledge *exploitation* (Lavie et al. 2010).

In order to *explore* and create new knowledge, engineers need to create consistent relationships between heterogeneous – and potentially conflicting features of the industrial product. To do so, they need to establish *equivalences* between a large number of modelling software applications and related practices, enabling them to process and manage common *accounts* about the emerging product.

In order to *exploit* the increasingly large amounts of engineering related information, engineers need also to be able to accurately trace information's consistency, dependability and completeness as well as control information transfer mechanisms across disciplinary boundaries.

Currently, most industrial organisations develop *ad hoc* compromises between the need to continue to iterate on requirements elicitation (*explore* new designs) and the need to end investigations and freeze specifications to engage in a final verification phase (*exploit* existing product information) (Brown & Eisenhardt 1995; Dougherty et al. 2010).

Challenges grow as product specifications move from sub-systems down to the component level (Clark et al. 1990). When products embed electrical-electronic and software components, specifications tend to be scattered across a large number of dedicated software applications. Each discipline uses its own relatively standalone set of software applications to specify the product requirements falling under their particular area of expertise. Tensions occur during early phases of the *"requirements flow-down"* phase through which product specifications are partitioned between hardware, electric & electronic, software, and services related implementation requirements. As *top-down* requirements are defined - including expected performances about time-to-market, reliability, manufacturability, serviceability, costs, etc., engineers need to get *bottom-up* confirmations about the reliability of the physical design solutions. Specialised disciplines are compelled to first work independently on their own specific set of requirements and then try to converge and build compromises on verified engineering options.

Throughout concurrent engineering processes, engineers need to address a growing number of contradictions:	
Secure tightly coupled coordination.	… and enable loosely coupled cooperation.
Enforce “top-down” product development processes Allocate and flow-down System requirements to lower levels (sub-systems and components).	… and enable “iterative/bottom-up” product development practices Determine iteratively the system requirements impact (achievability).
Impose Hierarchy Finalised-aligned projects supported by strict configuration management rules and regulatory policies.	… and preserve Adhocracy “Open ended” conversations based on unstable “boundary objects.”
Share existing information about the emerging industrial product.	… and create new information about the emerging industrial product.

Table n° 1
The concurrent engineering paradox

ICT platforms appear as a well-adapted response to these conflicting demands – particularly, the *“Product Lifecycle Management”* (PLM) platforms.[1] The latter not only facilitate the interactions between engineers from different disciplines, but also shape and change the way their work can be organised to cope with the growing complexity generated by these conflicting demands.

[1] CIMdata, a consultancy firm, defines *“Product Lifecycle Management”* (PLM) to be a strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, spanning from product concept to end of life — integrating people, processes, business systems, and information. (http://www.cimdata.com/en/resources/about-plm). – see also: (Merminod & Rowe 2012; David & Rowe 2015).

Given our interest in how ICT platforms enable and shape collaborative engineering, the study of PLM platforms provides an excellent research site to address contemporary academic debates about how *"socio-technical assemblages"* (Callon 2008) may actively reconcile *differences*, bridge *discontinuities*, and tie *distributed* agencies across disciplinary boundaries. We decided to focus on the so-called *blueprinting* process of a PLM platform which is typically a collective exercise taking place when an industrial company engages in the acquisition of a standard software to address its business and organisational challenges.

Our line of reasoning about the blueprinting process focuses on the interactions between two entities: on one hand, the industrial firm looking for improvement of its business processes; on the other hand, a software vendor providing a standard PLM platform aimed at improving ways to define and share product information across organisational boundaries. The interactions are characterised by intensive negotiations around the functional characteristics of the required PLM capabilities. Controversies emerge over how the standard platform provided by the software vendor could be used by highly diverse engineering disciplines.[2] Negotiations concern also how the standard COTS [3] platform could be cost effectively adapted to the specific organisational context (Pollock et al. 2007). We study how these negotiations and controversies engender the exchange of disciplinary knowledge and mutual expectations leading to a new *frame of reference* composing a common *account* about the emerging product across organisational boundaries. We are particularly interested in capturing two dimensions of the term *account* – as Stark (2000: 5) pointed out, *"etymologically rich, the term* [account] *simultaneously connotes bookkeeping and narration."* The blueprinting process forms a favourable setup to study how the PLM platform brings together these two dimensions which permeate the concurrent engineering paradox mentioned above.

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[2] Predominantly, in the Product Lifecycle Management case, design, engineering (hardware, electrical & electronic, software), quality and services related disciplines.
[3] COTS means *"Commercial-Of-The-Shelf"* or standard capabilities provided by the vendor of ICT platforms.

By investigating the relatively underdetermined, contingent process leading to the stabilised, *"black-boxed"* (Latour, 2005) PLM platform blueprint, we adopt a heuristic stance that is able to seize what makes the active role played by ICT mediations, "*before the box actually gets closed"* (Lanzara 1999).

1.1.2. Studying the role of ICT in organising concurrent engineering

Interactions between ICT and organising have been extensively studied by different research traditions. We have drawn on academic debates that have significantly contributed to a better understanding of how ICT enables, coordinates and shapes distributed engineering - that is, how ICT plays a *mediating* role.

The literature review presented in Chapter 2 hereafter, concern research on "Organisation & Management," "New Product Development", "Science & Technology Studies," and its developments in the direction of "Actor Network Theory".

We have organised the presentation of the outputs of the literature review around three main theoretical debates that have guided the construction of our research question. Firstly, literature drawing on Knowledge-based Theory studying integrative capabilities that mediate knowledge transfer and exchange. Secondly, the "practice turn" in the Organisation and Management literature that pointed to the importance of studying *"intersubjective"* cognitive practices within their organisational context. Thirdly, debates about the performative role played by material artefacts in composing "*interobjective*" interactions mediating heterogeneous and discontinuous elements as these are shaped and assimilated into a network.

Organisational principles enabling knowledge transfer and creation

Knowledge based theories have shown that *new product development* processes are closely linked to the existence of "*integrative capabilities."* The latter constitute a key competitive advantages in innovation intensive markets

– particularly as they enable efficient knowledge *transfer* and *processing* among various specialised organisational disciplines (Nelson & Winter 1982; Kogut & Zander 1992) Subsequent debates have further analysed the importance of the *formalisation of paths* between *tacit & explicit knowledge* (Teece et al. 1997; Nonaka & Takeuchi 1995; Nonaka & Von Krogh 2009), the dynamics of *learning routines* (Feldman & Pentland 2003), and the challenges raised by *sticky knowledge* (Von Hippel 1994).

In this context, technology acts as a *support* for the expression of higher level principles (governance rules, modularity, learning routines, etc.) that guide effective knowledge transfer and creation. More specifically, literature on the product development processes have shown the role played by ICT in supporting knowledge sharing and creation across disciplines (Wheelwright & Clark 1992; Dougherty 1992; Eppinger & Salminen 2001).

Organising knowledge is embedded in "cognition in practice"

Practice based theories highlight the importance of *"situated interpretive schemes"* impacting the effectiveness of knowledge sharing and creation processes. Authors engaging in the "practice turn" in organisational studies stressed the need to understand the role played by *"cognitive competences"* and *"sense-making in context"* (Schatzki 2001).

Technology is linked to boundary spanning capabilities (Orlikowski 2002; Bechky 2003) structuring coordination in the *"trading zones"* (Kellogg et al. 2006; Dougherty & Dunne 2012). *Knowing* (the coupling of tacit & explicit knowledge) determines the capacity to collaborate across disciplinary domains (Lave & Wenger 1991; Brown & Duguid 1991; Blackler 1995; Gherardi 2009) – as the focus is placed on practical cognitive dimensions, technology is considered as part of the *"structuration process"* where social and material are *"constitutively entangled"* (Orlikowski & Robey 1991b; Cook & Brown 1999; Carlile 2002; Carlile 2004; Feldman & Orlikowski 2011)

In this context, ICT plays in fact a double role: on one hand, ICT enables "*knowing in context"* – it enables *new* knowledge co-creation through situated *"interpretive schemes"* (plans, assumptions, etc.) (Suchman 1987; Suchman 2005; Suchman 2007)

On the other hand, ICT conveys material constraints as it imposes structuring agencies to practical interactions. Materialised categories and standards shape the way knowledge sharing occurs (Bowker & Star 1999). The dynamics of "interpretation" is enabled by "boundary objects" (Star & Griesemer 1989) and "affiliate objects" (Suchman 2005).

Practice-based theory considers that the introduction ICT systems in organisations have *"both restricting and enabling implications."* So studying the role of ICT in organising implies understanding the situated accomplishment through which knowledge is *"constituted and reconstituted as actors engage the world in practice"* (Orlikowski 2007; Orlikowski 2009)

Knowing is actively mediated by material artefacts

The third research stream proposes a radical heuristic shift and reverses the mode of reasoning about technology. Emphasis is put on the ontologies of *what makes the relationships* between technology and organisational practices. Researchers study how realities get tied up with techniques through the *performative* components of material artefacts. Objects are investigated within arenas of negotiation where "*technical objects simultaneously embody and measure a set of relations between heterogeneous elements"* (Akrich 1992: 205) and where "*relevant social groups"* (Pinch & Bijker 1984) position themselves with regard to potentially conflicting solutions.

This approach goes beyond the singular *"cognitive competences"* – taking place in human minds – to take into account how "*socio-technical assemblages*" (Callon 2008) contribute to compose a *"frame of reference"* [4] that stabilises relationships across disciplinary boundaries. Building on earlier STS debates, the work of Bruno Latour, Michel Callon, and John Law aims

[4] *"ANT claims that it is possible to trace more sturdy relations and discover more revealing patterns by finding a way to register the links between unstable and shifting frames of reference rather than by trying to keep one frame stable."* (Latour 2005: 24).

at capturing how both human and non-human agencies stabilise the composition of "*techniques of staging the world.*" Academic debates progressed through various Actor Network Theory related topics such as the assemblage of *"centres of calculation"* (Latour 1987), *"metrological chains"* (Latour 2005) and *"calculative agencies"* (Callon 2005; Muniesa et al. 2007; Callon & Muniesa 2005).

At the core of this approach is the phenomenon of *"black-boxing"* (Law & Singleton 2000; Latour 2005). Instead of studying what takes place in people's mind, the approach seeks to understand how a *frame of reference* is made up of a collection of entities including human and non-human devices; the attention is placed in how the resulting associations *"are endowed with capacity of acting in different ways depending on their configuration"* (Callon 2008: 39) – above all, how socio-technical arrangements have the capacity to put forward *"preferred courses of action."*

Our dissertation builds on this research tradition to reach a better understanding of how local, specialized engineering practices and software applications are (or aren't) incorporated into more abstract, extended, interoperable, cross-disciplinary classification and *"calculative agencies"* (Callon & Muniesa 2005). We try to build on this heuristic framework to grasp the *performative* role played by ICT artefacts in composing the collective capabilities to represent an emerging product across discontinuous and "messy" organisational boundaries.

1.1.3. Bridging the gap in the literature

We will present in Chapter 2, a more detailed argumentation on the academic debates investigating the role of ICT in organising complex, distributed practices across disciplinary boundaries. For the moment, we would like to draw upon the brief characterisation of these three academic traditions, to position the debates through which we have developed our research question. Knowledge-based theories, approach ICT mainly as a *support* information transfer. Therefore, information about the information processed by ICT is considered as something that pre-exists the interactions between engineers.

We pointed out above that Practice-based theories question this point of view and consider that technology not only enables information and knowledge sharing, but also plays an important role in compensating for "cognitive limitations." In such a research framework, knowing is an accomplishment where ICT structures and is structured by organisational practices.

In both cases, the possible *active mediations* exerted by ICT mediations in organising concurrent engineering are less studied. How does this occur? What patterns and mechanisms are at play here? Our line of reasoning investigates what makes the *active* dimensions of ICT *mediations*. Drawing upon the heuristic framework proposed by Actor Network Theory,[5] we wish to study how ICT mediations *act* between parties sharing and creating information – our aim is more precisely, to investigate how ICT mediations reconcile different *"techniques of staging the world"* and *enact* connecting links between heterogeneous disciplinary agencies.

1.2. Research question

Our research question is formalized as follows:

- *How does the blueprinting process of a "Product Lifecycle Management" (PLM) platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?*

In the context of the dissertation, the term *agency* [6] encompasses (1) the *condition of being in action*, i.e. the operations of digital modelling to account for a new industrial product and (2) the *means* of acting – i.e. the *modelling artefacts* whereby the product is accounted for. By "*modelling artefacts"* we

[5] Particularly the insights by Law (2000); Law & Singleton (2000); Law (2007) on "*discontinuous instances of ordering"* and the work by Latour (1987) on "*collective hybrids, centres of calculation"* and more recent developments on *"calculative agencies"* (Callon 2005; Muniesa et al. 2007; Callon & Muniesa 2005).

[6] Agency (n.d.) (1) The condition of being in action; operation; (2) The means or mode of acting; instrumentality; in. *American Heritage Dictionary of the English Language, Fifth Edition*. (2011)

consider both software applications *and* the platform by means of which engineers account for the emerging product.

The research question is operationalised through three propositions structured around the way negotiations about the blueprint of the PLM platform alters the ways the emerging industrial product is accounted for across organisational boundaries.

Proposition 1/ The blueprinting process defines *what information needs to be known/shared* across disciplines.

- We look for empirical evidence of *how the PLM blueprint composes cross-disciplinary mediations* enabling disciplines to access, trace and account for information about the industrial product across disciplinary boundaries.

Proposition 2/ The blueprinting process defines *when & where* information sharing takes place.

- We look for empirical evidence of *how the PLM blueprint moves disciplinary practices and software applications* to a cross-disciplinary account about both the industrial product and its usage by the final customer.

Proposition 3/ The blueprinting process defines *accountability* across disciplinary boundaries.

- We look for empirical evidence of *how the PLM blueprint modifies the way roles and responsibilities are assigned* and how disciplinary judgments about the product and its usage *are enacted* across organisational boundaries.

1.3. Research design

The research approach is qualitative, adopting a case study methodology (Yin 2009; Eisenhardt et al. 2013). The case studies are based on two projects aimed at introducing PLM platforms within engineering organisations developing discrete manufacturing products - the first, in the defence sector, the second, in the biotechnology sector.

We will study how teams from both companies negotiate and reach an agreement about these topics and how the outcomes of the negotiations strengthen the concurrent engineering capabilities addressing a wide array of *discontinuous* engineering practices and *heterogeneous* software applications.

The following figure sketches the scope of the two case studies.

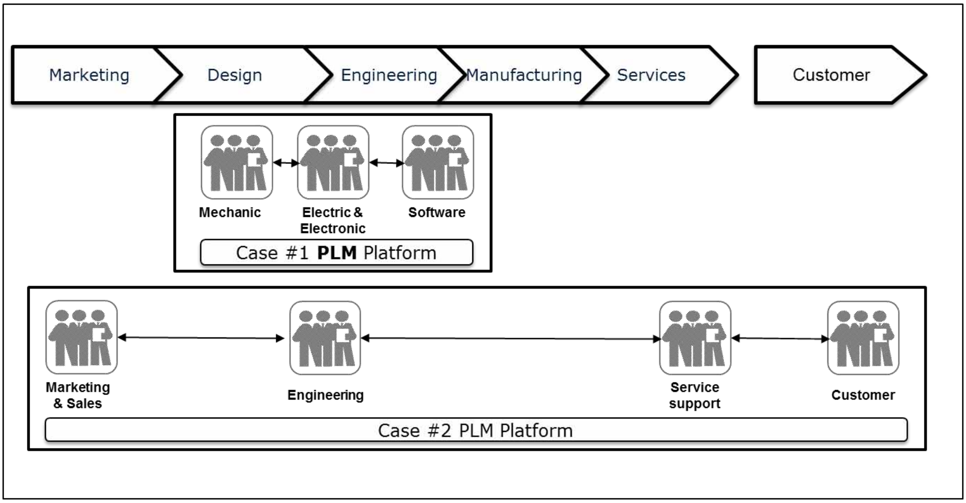

Figure n° 1
Scope of the two case studies

The first case study concerns the blueprinting process of a PLM platform supporting information sharing across mechanical, electrical and software engineers developing a combat management system for naval vessels. Our investigation presents how three specialised disciplines address the need to collectively enact a common account about the new combat management system. We point out how PLM mediations will ultimately lead to a more consistent – and *"auditable"* - account of the *"product release readiness"* throughout its lifecycle.

The second case study is about the blueprinting process of an extended PLM platform intended to improve maintenance services of *in vitro* diagnostics machines used within the medical and industrial sectors. The biotechnology company is engaged in a major strategic shift of its "go to market" strategy. The introduction of a "servitization" [7] approach, requires new cross-disciplinary capabilities to capture the real-time performance of the *in vitro* diagnostics machines being used by microbiology laboratories and hospitals. We analyse how the PLM platform mediates the introduction of new ways to create and share information about *predictive maintenance.* We show how the negotiations between a biotechnology firm and a PLM vendor redefine maintenance and services operations – particularly, by moving local troubleshooting practices to a cross-disciplinary account of *"predictable product serviceability"* throughout its lifecycle.

The two case studies bring empirical evidence on how the PLM blueprinting process composes and perform a common *frame of reference* assembling the disciplinary agencies accounting for the new product.

Ultimately, the new frame of reference contributes to enact, trace and validate the *cross-disciplinary accounts* about the industrial product as it evolves throughout discontinuous and distributed design and engineering processes.

Our dissertation wishes to contribute to a better empirical description of the *movement* that strengthens a set of cross-disciplinary capabilities that generates the new frame of reference.

[7] The service offer is added or integrated to the commercialisation of *in vitro* diagnostics machines throughout its lifecycle.

The table below summarises the way our argument addresses the mediating role played by PLM platforms in the composition of the cross-disciplinary frame of reference for concurrent engineering agencies.

<table>
<tr><td colspan="3">• RESEARCH QUESTION</td></tr>
<tr><td colspan="3">• How does the blueprinting process of a PLM platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?</td></tr>
<tr><td colspan="3">• The proposed heuristic model is structured around the collective exercise through which the composition of the PLM platform blueprint leads to a cross-disciplinary “frame of reference” for concurrent engineering agencies</td></tr>
<tr><td rowspan="3">• We study how the negotiations between an industrial firm and a software vendor address three main questions:</td><td colspan="2">1. What information needs to be shared across local disciplinary contexts?</td></tr>
<tr><td colspan="2">2. Where and when does information sharing take place?</td></tr>
<tr><td colspan="2">3. How is accountability assigned across organisational boundaries?</td></tr>
<tr><td colspan="3">• Empirical evidence describes how the negotiations about the PLM blueprint…</td></tr>
<tr><td>… bring together (move):
• disciplinary engineering practices
• disciplinary software applications
• distributed judgements about the evolving industrial product</td><td>… establish equivalences between disciplinary entities …</td><td>… articulate discontinued and distributed dimensions of concurrent engineering relationships</td></tr>
</table>

We will present in the following chapters the theoretical debates that lead to our research question followed by the presentation of the methodological approach supporting the three propositions described above.

CHAPTER 2 / THEORETICAL FRAMEWORK

This chapter presents the main theoretical contributions leading to our conceptual framework for the study of mediations composing a common account of the product lifecycle across organisational boundaries.

We bring into play three research traditions that have contributed significantly to the study of the way PLM mediates organising within innovation intensive organisations.

We describe how we progressively build our own conceptual model.

We conclude the chapter by presenting how we propose to address the knowledge gaps that we have identified in the three research traditions and present how our conceptual framework is used to analyse the empirical data collected through the two case studies.

2.1. Introduction

The interaction between technology and organising has been extensively studied by different research traditions in management and organizational research.

We have considered a subset of this literature dealing with the role played by Information and Communication Technology (ICT) in the organisation of complex product and services development processes within innovation intensive industries.

Following recommendations by Dougherty (1996), emphasis is put not on the search for normative models about how the adoption of ICT contributes to successful innovation but rather on the search for a better understanding of how ICT mediations contribute to knowledge sharing and creation in *"dispersed ecologies"*. Dougherty (1996:436) does "*not argue that the vast literatures on tools and techniques for measuring, managing, strategizing, evaluating, organising, and so forth are not important, since they are (see Wheelwright and Clark 1992; Griffin and Page 1993).* [She argues] *that organizations cannot simply adopt all these tools and techniques. Rather, they must also develop underlying capacities for action which enable people to use these tools effectively for innovation"*.

We review different theories conceptualising these *capacities for action* within innovation intensive organisations.

First, we study how the literature addresses the *intersubjective* dimensions structuring the relationship between on one hand, organisational principles generating innovation and on the other hand, the complex *cognitive* capabilities structuring interdependent knowledge sharing and creation practices. Focus is placed on understanding the contribution of ICT to the integrative capabilities mediating knowledge transfer and exchange.

Second, we apprehend how authors conceptualise the barriers to boundary spanning knowledge sharing and how *"distributed organising"* (Orlikowski 2002) is linked to, and depends on, the way tensions between potentiality contradictory principles are addressed.

Third, we draw upon STS and ANT literature to better understand the radical shift engaged by a heuristic model describing how "*interobjectivity"* (Latour 1996) is embedded in, and enacted through human and non-human entities and how material artefacts both enact *"what is known and shared"* and perform a cross-disciplinary *"knower"*.

2.2. The importance of emergence and experience in knowing and organising

Organisation sciences scholarship has extensively studied how *organisational capabilities* contribute to the optimisation of knowledge transfer and processing. The underlying heuristic model, conveyed by dominant approaches considers that the control over information transmission and processing is impacted by cognitive limitations influencing decision making and the consequences of *"bounded rationality"* (Herbert 1991; Hatchuel 2001). [8]

Collective organisational capabilities are also an important dimension of the Resource-based View (RBV) of the firm. Scholars analyse how knowledge sharing may become key competitive advantage in innovation intensive markets – particularly as they enable efficient knowledge *transfer* and *processing* among various specialised engineering disciplines. Going beyond the Resource-based View of the firm, focus of is put in the early 90' on more *"dynamic capacities"* that support processing of codified knowledge to address rapidly changing competitive environments (Teece et al. 1997).

For the Knowledge-based Theory, innovation intensive firms need to develop the appropriate capabilities to manage knowledge as a constitutive component

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[8] Cognitive limitations impacting information processing dispersed across organisational boundaries is already present in the classic study by (Lorsch & Lawrence 1965) that identified the systemic importance of information processing and initiated consequently a stream of work on the "contingent" balance between differentiation and integration. Information processing activities appears in this context as one of the main features of *"the process of achieving unity of effort among various subsystems in the accomplishment of the organisation's task"*.

of the *learning capabilities* that enable a better coupling with the competitive environment.

Evolutionary theories of organization consider that these capabilities may take different forms: structured clusters of routines (Nelson & Winter 1982; Becker 2001b; Becker 2001a), combinative capabilities (Kogut & Zander 1992), integration and dynamic capabilities (Iansiti & Clark 1994).

2.2.1. Problem solving routines require cognitive competences

Problem solving routines supporting knowledge processing and transfer across organisational boundaries grow into a key dimension of scholarship on "New Product Development" (NPD) efficiency.

The study of "*capabilities and competence based competition"* (Brown & Eisenhardt 1995) shows that the notion that *information processing* is a *balancing act* between (1) relatively autonomous problem solving routines by project teams (2) the discipline of a heavyweight leader, strong product management and (3) overarching product vision. Authors point out to three *higher level principles* around which the research on New Product Development is structured:

- Rational planning (careful planning, well organized cross-functional operations, appropriate support of senior management, innovation process is a fixed series of activities, stage gate approach);
- Communication web (having effective communications through gatekeepers, power project managers, and cross-functional teams);
- Disciplined problem solving.

These three "*higher level principles"* considered as forms of problem solving routines, require particular competences. The latter can be defined as "*an ability to sustain the coordinated deployment of assets in a way that helps a firm achieve its goals."* (Sanchez & Mahoney 1996). Hence, *"The goal is to develop those core capabilities that will be effective for multiple strategic segments in several different possible futures"* (Schoemaker 1992). Platforms convey patterns of interaction between technological innovation and economic competition (Gawer 2014).

In this context, ICT plays a mitigating role overcoming *"cognitive limitations"* impacting knowledge transfer and processing efficiency. For example, ICT is a support for the implementation of more efficient problem solving routines such as *"front loading routines"* (Thomke & Fujimoto 2000); *"modular product architectures"* with stabilised interfaces across sub-system/components (Baldwin & Clark 1997; Baldwin & Clark 2004; Clark & Fujimoto 1991); scalable *"platforms"* that reduce coordination needs through standardised cross-projects capabilities (Cusumano & Nobeoka 1992; Eppinger & Salminen 2001); structured concurrent engineering methodologies (matrix organisations, project teams, cross-functional networks) driven by *"heavy weight"* program managers (Wheelwright & Clark 1992) - and more specifically, in the Information Systems literature, the work on digital platforms (Yoo et al. 2012; Leonardi & Barley 2010; Tilson et al. 2010) and performativity of modular principles (D'Adderio & Pollock 2014).

This literature in line with earlier Knowledge based theory insights, produces interesting outputs about, on one hand, the obstacles to the *extension* of cross-boundary *"relational conditions,"* and on the other hand, the challenges faced by firms coping with the *acceleration* of innovation pace:

- *The need to extend cross-boundary integration*: firms seek to extend cross-boundary collaboration in order to involve all the expertise necessary to design and develop new products. The number of stakeholders increases and *relational conditions* become more complex - even, potentially conflicting. Hence the need of ICT to strengthen the functional interdependencies - a prerequisite to manage the balance between the pursuit of skill specialization and knowledge co-creation required to develop innovation intensive technological products (Thomke & Fujimoto 2000; Gerwin & Barrowman 2002; Le Masson et al. 2011; Hatchuel 2001).
- *Coping with the acceleration of innovation pace:* firms require collective capabilities to rapidly *create* new knowledge. The

> development of concurrent engineering intensifies the pressure to reduce time-to-market by superimposing certain design and engineering stages. The configuration of "*cognitive schemes*" enabling the coordination between specialised disciplines become increasingly problematic. Hence the weakness of organizational interdependencies stemming notably from the difficulty to validate accounts about the emerging product across boundaries - both within complex organizational structures and also within inter-firm *"ecologies"* (Dougherty & Dunne 2011; Zammuto et al. 2007; Kellogg et al. 2006; Pich et al. 2002; De Meyer, A., Loch, C.H. and Pich 2006).

We will see hereafter, that this approach of problem solving routines is questioned by researchers emphasising the importance of *situated practices* in knowledge sharing and creation.

2.2.2. Knowledge as a continuous accomplishment

The initial component of our literature review revealed conceptual limitations that points to the need to take into account the *dynamic emergent and situated interplay* between technology and organising. We review hereafter Practice-based Theories and their potential inputs from the study of ICT mediations in organising knowledge sharing and creation.

A major change in scholarship occurs when researchers take into account the assertion that "*we can know more than we can tell"* (Polanyi 1966). This means that learning from experience mobilises both codified and tacit knowledge. Making sense within distributed collaborative processes involves more than transferring codified and formalised knowledge (Weick et al. 2005; Maitlis & Sonenshein 2010). It depends on *learning from experience* and *interactions* (Argyris & Schön 1978).

Practice-based Theory aims to improve the understanding of the role played by *"situated cognitive competences"* and *"sense-making in context"*

(Schatzki 2001; Gherardi 2009). In this context, knowledge should be viewed rather as a *continuous accomplishment* (B. Kogut & U. Zander 1992; Birkinshaw et al. 2002). Explicit knowledge is always grounded in tacit knowledge that resides in situated practices creating challenges to sharing mechanisms as they may be blocked by the existence of "*sticky knowledge"* (Cook & Brown 1999; Brown & Duguid 1991; Baldwin & von Hippel 2011; Von Hippel 1994).

This line of research produces interesting insights on organisational barriers impacting teams working with different bodies of knowledge. Hence the importance of better understanding how knowledge sharing and creation is accomplished within *"communities of practice*" (Wenger 2000; Lave & Wenger 1991).

Analysing innovation intensive product development processes, Leonard-Barton (1995) underlined, on one hand, the difficulties in establishing a balance between organizational flexibility and rigidity, and on the other hand, the consequences of these organizational rigidities that tend to encourage people's compliance and engenders unpredictability around knowledge sharing. Leonard-Barton (1995) insists upon the importance of *"creative abrasion"*. It consists in *"institutionally combining people with different skills, ideas and values"*. As "*innovation occurs at the boundaries"* organisations must enable *"cognitive diversity",* or *"creative chaos"* encompassing the creation, combination, and recombination of knowledge (Leonard-Barton 1995).

Nonaka opens a significant stream of work about the importance of *"relational conditions"* and barriers to knowledge management – particularly about the role played by *"knowledge brokers"* (Nonaka & Takeuchi 1995; Nonaka & Konno 1998). He develops an influential *organizational knowledge creation theory*, explaining why knowledge *transfer* mechanisms encompass a series of mechanisms of *"knowledge conversion"* – particularly, from tacit to explicit and, inversely, from explicit to tacit. In subsequent work with Georg Von Krogh, he develops insights around the idea that *sharing* knowledge inherently entails a combination of individual and collective creativity (Nonaka & Von Krogh 2009; Von Krogh et al. 2011).

We observe that researchers studying what makes situated sense-making processes question the notion that companies can organize the actual management of knowledge. Criticising the "reified" (Wenger 1998: 63) definition of knowledge, they tend to moderate the enthusiasm about "knowledge management" initiatives (Blackler 1995).

Pushing this critique further on, Antonacopoulou & Tsoukas (2002) consider that the distinction between explicit and tacit knowledge is not *operational* to analyse situated knowledge sharing practices. They highlight the fact that all knowledge involves a tacit component and proposes instead to study the firm as an *emergent* decentred knowledge system.

2.2.3. The importance of emergent components occurring through knowing

In a series of influential papers, Carlile (2002; 2004) proposes a framework to *operationalise* the study of emergent and situated knowledge sharing practices. He proposes to frame *"the task of knowledge integration as a cycle"* and analyses emergent *"surprises"* that happen in *"fringes between fields*". Standardized forms and methods can provide *"concrete means for individuals to specify and learn about their differences and dependencies across a given boundary"* (Carlile 2002: 452) (Levina & Vaast 2005).

The *"Practical challenge is to represent, specify, negotiate, compromise and transform their current knowledge to accommodate the novelty present at a boundary.*" Carlile (2002) takes Susan Star's (1989) classification of four types of "boundary objects" as a starting point for his own model of three types of *"standardized forms and methods"* that can provide *"a concrete means for individuals to specify and learn about their differences and dependencies across a given boundary"* (Carlile 2002: 452). Accordingly, Carlile develops a series of empirical analysis about mechanisms leading to a (more or less) successful integration of knowledge across work domains: boundaries are conceptualized as *syntactic* (a common stable syntax guarantees information processing), *semantic* (translation mechanisms are necessary to support interpretations across domains), and *pragmatic* (joint enquiries involve negotiations leading to the transformation and/or creation of new knowledge).

2.3. ICT supports organization of diversity

The efforts to conceptualise the *"relational conditions"* enabling boundary spanning collaboration contributed to what was called the "practice turn" in organisational studies (Gherardi 2009; Nicolini 2011). By engaging in a *"practice turn",* researchers necessarily come across the need to build a framework that is able to grasp potentially contradictory activities and competing demands generated across disciplinary boundaries. The relationships between standardisation/obduracy and flexibility/interpretation inevitably create tensions. Dougherty (1996:425) asserts that these tensions generate "*organizing challenges of iterating between diverse activities, working around barriers, combining insights, and resolving the conflicts of seemingly opposing forces, all of which can be found in the innovation process."*

Researchers move their attention towards the ambiguities and tensions that were, according to Dougherty & Dunne (2011), relatively underestimated by the mainstream literature on *"ecologies of complex innovation"*.

It is particularly the case of engineering activities that generate tensions between routinized *exploitation of existing knowledge* and more *ad hoc explorations of emergent knowledge*. In their seminal work about *"The missing dimension"* of innovation, Lester and Piore (2004:175) sustain that*:* *"Analysis and interpretation are not distinct; they are in many ways contradictory and antagonistic to each other. Analysis is organized around projects; it strives for clarity and closure. Interpretation is not a project but a process, ongoing in time, open ended. It operates in the space created by ambiguity – a space that analysis seeks to close up and ultimately eliminate"*.

In other words, instability constrains distributed collaborative processes and generates the need to establish organisational devices to combine *exploration* (interpretive, open-ended practices) and *exploitation* (analytical, finalised processes).

We have mentioned above that "*knowing*" is an active accomplishment that is *"mediated, situated, provisional, pragmatic and contested"* (Blacker 1995). Tensions between exploration and exploitation generate risks particularly when there is an important *"knowledge gap"* due to a major innovation (Lester & Piore 2004) (Stark 2009).

These inputs are valuable to build our conceptual framework aimed at studying the role of ICT mediations within disparate and distributed organisational settings that characterise our empirical case studies. If we want to apprehend the relationships between technology capabilities and production of *"cognitive competences"* enabling distributed *knowing* practices, we need also to take into account the role played by ICT in *"open ended joint enquiries"* and better understand how ICT contributes to the "*organization of diversity"* (Lester and Piore 2004).

The conceptual framework aiming to study complex engineering practices must be able to apprehend *in context*, how a large number of engineers and technicians collectively use ICT devices to make sense of ambiguous accounts about an emerging industrial product – including how engineers develop collective capabilities to act across numerous interdependent and constantly evolving organisational boundaries. We need also to take into consideration organising as *"something arising out of ongoing activity, enacted rather than predetermined"* (Suchman 2007: 177).

More than addressing the question of knowledge *acquisition*, it is imperative to understand how *new* knowledge is co-created through situated *"interpretive schemes"* (categories, assumptions, etc.) (Cook & Brown 1999).

2.3.1. ICT articulates ostensive and performative dimensions of relational routines

Winter (2003) insists on the importance of studying routines: *"the strategic substance of capabilities involves patterning of activity"*. Feldman & Pentland (2003: 105) expand the dominant definition of routines putting the emphasis on the importance of learning from experience and interactions - routines are defined as "*a repetitive, recognizable pattern of interdependent actions carried out by multiple actors. The involvement of multiple actors introduces the diversity of goals, information, and interpretations, while the interdependence of actions blurs and opens the boundaries of the routine to outside influence"*. So beyond the ostensive "*repetitive, recognizable patterns",* routines also transform knowledge. Feldman and Pentland (2003) opens a stream of work that conceptualises the performative dimension that enables capturing sources of flexibility and change. Their framework incorporates challenges generated by breakdowns of the transfer process, blocked by the lack of a common lexicon (Carlile 2004; Pentland & Feldman 2008; Adderio 2007; Parmigiani & Howard-Grenville 2011; Turner & Rindova 2012).

In summary, because the *"trading zone is always in the making"* (Kellogg et al. 2006), cross-boundary coordination is a contingent, emergent, and dynamic outcome that cannot be planned or prescribed, but is highly dependent on the situated activities of the various communities. Hence the need to take into account *patterns* characterised by more or less evident *routinized relational conditions* that may also facilitate the emergence of knowledge diversity leading to innovation.

2.3.2. ICT plays a dual role in distributed organising

Orlikowsky seizes the influence of the "practice turn." In a series of prominent articles (Orlikowski 2007; Orlikowski 2002), she conceptualises the introduction ICT systems in organisations as having *"both restricting and enabling implications."* ICT plays a restricting role by formalising, standardising and structuring explicit knowledge. ICT plays also an enabling role facilitating "*knowing in context.*" It enables *new* knowledge co-creation through situated *"interpretive schemes"* (plans, assumptions, etc.). ICT is part of the *"structuration process"* where social and material are *"constitutively entangled"*. As *"Information technology has both restricting and enabling implications,"* social and material are *"constitutively entangled"* (Orlikowski & Robey 1991a).

Structure in this view is understood as an ongoing accomplishment, emerging from actors' continuous engagement in everyday life, rather than a static property of social systems (Giddens 1984). The *structuration process* is always grounded in *tacit* knowledge that resides in situated experiences (Orlikowski 2007). Researchers need to capture organisational order as it emerges from practical interactions. So studying the role of ICT in organising implies understanding the situated accomplishments through which knowledge is *constituted and reconstituted as actors engage the world in practice* (Orlikowski 2000; Bechky 2003; Carlile 2002; Kellogg et al. 2006; Dougherty & Dunne 2012). Building on this assertion, Orlikowsky unlocks a stream of research about "Technology-as-practice" that aims to go beyond the study of the sole optimisation of problem solving routines. It seeks to better apprehend the relationship between less and less predictable *relational conditions* and corresponding required *situated cognitive competences*. Orlikowski (2002: 249) defines *"distributed organizing"* as *"the capability of operating effectively across the temporal, geographic, political and cultural boundaries routinely encountered in global operations."*

Starting from the initial inputs of the Knowledge based framework, researchers evolved their questioning to grasp how ICT plays a dual "*structuring"* role in enhancing engineer's cognitive capabilities within the constantly evolving contexts. The table below is an effort to sum up the oppositions that can be tied together through the adoption of the "practice turn" in organisation studies. The "practice turn" *ties together* the following ICT characteristics:

ICT conveys ***restricting*** **implications**	ICT conveys ***enabling*** **implications**
- ICT contributes to the Exploitation of existing knowledge - Ostensive routines optimise information processing capabilities impacts competitive advantage; - Through routines, the information about the innovative product is processed & transferred across organisational boundaries to better adapt to a competitive environment.	- ICT contributes to the Exploration and creation of new knowledge - Performative routines enable knowledge creation and create competitive advantage through learning from experience and interactions; - Learning capabilities enable better coupling with competitive environment.
ICT contributes to *Analytical* capabilities: - Focus on transfer of codified knowledge across organisational boundaries - ICT plays an organising role by reducing ambiguity across bodies of knowledge	ICT contributes to *Interpretive* capabilities: - Focus on combinative forms of knowledge (tacit, explicit…) across organisational boundaries; - ICT plays an organising role by enabling cross-disciplinary teams to cope with ambiguity of knowing practices in context.
- ICT supports problem solving and process alignment.	- ICT enables joint enquiries through "*active experimentation and probing of environments.*"

Table n°2
Summary of the "*practice turn*"

The *practice turn* brings forward the *emergent* phenomena occurring through boundary spanning *knowing*. So, technology is conceptualised as conveying two aspects: ICT may constrain but also generate knowing practices.

The table below summarises how ICT both *facilitates* the emergence of capabilities supporting *knowing* together across disciplinary boundaries.

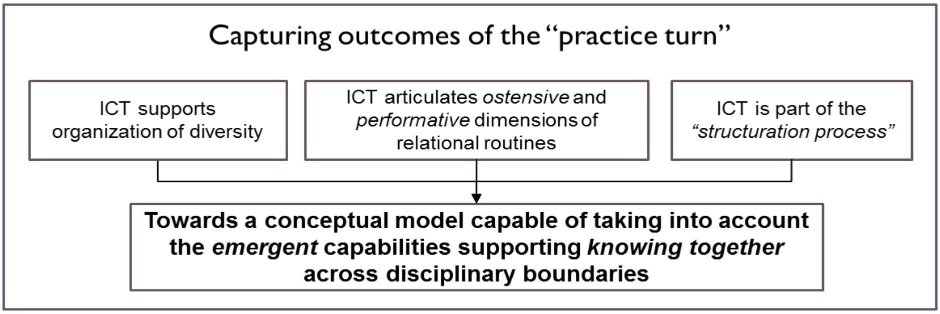

Table n°3
Outcomes of the "practice turn"

2.4. Understanding material components of knowing and organising

In the previous section we have brought forward scholarship attesting the importance of the *path dependent* knowledge practices structured by chaos and diversity of *"cognitive schemes"*.

Routines are unavoidably disrupted by the diversity of situated experiences.

Consequently, the study of the role played by ICT in knowledge sharing and creation moves beyond the consideration of knowledge as an *object* to consider knowing as a *routinized accomplishment.* Notwithstanding its apparently routinized nature, boundary spanning knowing necessary transforms knowledge and inherently disrupts interpretations (Abbott 1995). This generates constant changes in organisational patterning of knowledge sharing practices (Santos & Eisenhardt 2005; Whitford & Zirpoli 2014).

A subsequent step of the study of mediations exerted by technology in boundary spanning *knowing* practices consists in looking for developments in the literature about how *"distributed organizing"* depends on material objects (Pickering 1993).

In this section, we will see why ICT is not only a *support* of boundary spanning collaboration. It plays also an active role in configuring new routinized agency leading to knowledge sharing and creation (Czarniawska 2009).

To do so, we draw upon complementary research traditions starting with Science and Technology Studies (STS) and symbolic interactionism – followed by later developments within Actor Network Theory (ANT) - traditions in which technological artefacts are understood as *"social constructs"*.

2.4.1. Technological artefacts enable distributed organizing

In a seminal article, Star & Griesemer (1989) put forward the concept of *"boundary objects"* referring to tools, objects or concepts that allow for cooperation across organisational boundaries. The authors analyse how material objects may be a source of *"flexible interpretation,"* shaping and contextualizing cognitive capabilities that enables *"distributed organizing."*

At the core of their reasoning about scientific work, is the notion of *"ecology of institutions"* formulated by symbolic interactionism (Hughes, Strauss), stating that a material infrastructure may facilitate a process representing a community to itself (Star 1999).

Three main findings may help us in formalising our conceptual framework. The first finding concerns the operative relationship between the cognitive capabilities (enabling "*interpretive flexibility*"), material categories, and standards (infrastructures, material objects, models, schemes, etc.). Engaging in the debate about interpretive flexibility (Pinch & Bijker 1984; Orlikowski & Robey 1991b) while also discussing with ANT authors, Star and Griesemer (1989) consider that adaptability is a key feature of boundary objects: *"Boundary objects are both adaptable to different viewpoints and robust enough to maintain identity across them"* (Star and Griesemer 1989:37). A "boundary object" acquires its provisional, contingent meaning in relation to a particular context.

For Star and Griesemer (1989:51) *"the creation of boundary objects both respects local contingencies and allows for cross-site translation."* This interpretation is close to the ethnomethodological line of thought. Suchman et al. (2002) consider that *"objects take their shape and meaning not in any single location but through their incorporation across diverse milieu."*

The second finding, establishes that *"boundary objects are a sort of arrangement that allow different groups to work together without consensus"* (Leigh Star 2010: 602). Large scale information infrastructures are forms of knowledge classification that are both *opaque* and *transparent* (Bowker and Star 1999).

Opaque in the sense that large information infrastructures "black-box" the way interdependencies are constructed and stabilised. *Transparent* as they reveal these interdependencies - the way interdependencies are constructed becomes visible when tensions are exacerbated and when accidents and breakdowns occur.

This explains how "boundary objects" facilitate "flexible interpretation" across heterogeneous organisational settings by exposing a *transparent* frame for knowledge sharing while simultaneously, preserving the *opacity* of the performative ("invisible") work done by standards, classifications, models, schemes, etc. that contribute to represent a community to itself (Star and Bowker 1999). For example, "virtual prototypes" may play a role as "*organizational memories": "Delegation of organizational memory to software* [creates the] *ability of heterogeneous organizational groups, functions and communities to co-ordinate their efforts and share across function, discipline task specific boundaries"* (D'Adderio 2001; D'Adderio 2003).

The third finding brought forward by Star and Ruhleder (1996) and Star and Bowker (1999) is that boundary objects convey standards, rules and norms *across* heterogeneous *"social worlds"* - in this sense, they participate in delegating activities between local and global contexts. *"An infrastructure* *occurs when the tension between local and global is resolved. That is, an infrastructure occurs when local practices are afforded by a larger-scale technology, which can then be used in a natural, ready-to-hand fashion. It becomes transparent as local variations are folded into organizational changes, and becomes an unambiguous home—for somebody"* (Star & Ruhleder 1996).[9]

These three findings about "boundary objects" help us understand on one hand how cross-disciplinary *interpretation* may be enabled by material artefacts. and on the other hand how engineers may collectively *represent* their functional interdependences while preserving control over their own practices.

2.4.2. Technological artefacts convey obduracy

A third step in the study of the role of material objects is accomplished by Information Infrastructures studies. Authors define information infrastructures as "*evolving assemblages of interlinked systems"* characterised by *"openness to number and types of users (no fixed notion of 'user'), interconnections of numerous modules/systems (i.e. multiplicity of purposes, agendas, strategies), dynamically evolving portfolios of (an ecosystem of) systems"* (Hanseth et al. 1996; Hanseth & Monteiro 1997; Monteiro 1998; Monteiro et al. 2013).

At the core of this approach is the interest in capturing tensions between large scale *standardisation* (the production of "universal standards") and *flexibility* (the use of localised, contextualised typologies) (Bowker & Star 1999). Authors shift their focus from discrete technological artefacts to engage in the analysis of *"platform organisation"* (Ciborra 1996), *"systems in action"* (Lanzara 1999; Lanzara 2006), *"infrastucturing"* (Cordella 2010; Cordella

9 According to Star and Ruhleder (1996), there are eight dimensions of information infrastructures: embeddedness, transparency, reach or scope, learned as part of membership, links with conventions of practice, embodiment of standards, built on an installed base, becomes visible upon breakdown. See Trompette & Vinck (2009) for a detailed analysis of the epistemological origins of the concept of "boundary object" and its subsequent developments within multiple disciplinary domains – see also (Leigh Star 2010).

2011; Cordella 2006), the *"biography"* of large scale interlinked information infrastructures (Pollock & Williams 2010), the process of *"delegation"* of agency to technology (Ribes et al. 2013), the role of *"epistemic object and artefact"* mediating practices (Miettinen 2005) and the active work that objects perform in organising cross-disciplinary collaboration (Nicolini et al. 2012a).

Every "universal" description conveys an organizing theory that equips technology "users" with concepts to describe their singular actions (Pollock and Williams 2010). By pointing out the intricacies and mediations of ICT leading to enduring forms of *inscription* of "users" in material artefacts, authors are able to demonstrate the *performative* component of ICT in producing obduracy.

Obduracy is conveyed through "inscriptions" (Akrich 1992; Akrich et al. 2002) that establish new forms of relationships between localised, singular contextually embedded practices and large scale, standard ICT artefacts. *"Technical objects thus simultaneously embody and measure a set of relations between heterogeneous elements"* (Akrich 1992: 205).

In this sense, large information infrastructures contribute not only to spell out the dependencies between different cross-functional efforts. Above all, they convey structuring forms of *obduracy* combining heterogeneous resources, deliverables, and deadlines. Information infrastructures are *"shaped by an installed base of existing systems and practices (thus restricting the scope of design, as traditionally conceived). (…) stretched across space and time: they are shaped and used across many different locales and endure over long periods (decades rather than years)"* (Monteiro et al. 2013).

The study of large scale information infrastructures captures how local, specialized engineering practices and artefacts are (or aren't) incorporated into more abstract, extended, interoperable, cross-discipline classifications and calculation systems. We can therefore better grasp how ICT ascribes agency and assembles scalable information *standards* and *categories* across organisation boundaries.

2.4.3. Capturing the role played by technological artefacts through tensions

We have mentioned above that efforts to conceptualise tensions, challenges, obstacles, impacting *"relational conditions"* required for boundary spanning collaboration, are at the centre of the "practice turn" in organisational studies (Czarniawska 2009; Nicolini 2013; Nicolini 2011; Gherardi & Nicolini 2005; Nicolini et al. 2012b).

This evolution was described by Miettinen et al. (2010) as a move from an epistemology of *possession* (where knowledge is an object) to an epistemology of *practice* (where knowledge is a more intangible accomplishment).

When adopting the epistemology of possession, researchers can trace relatively straightforwardly how ICT structures knowledge transfer and processing.

However, if the researcher adopts the epistemology of practice to study knowledge as a *situated, emergent accomplishment*, she may face two potential risks: the first risk consists in losing trace of obduracy factors while focusing mainly on the emergent situated practical accomplishments – this is typically what dominates in the *Computer Supported Cooperative Work* (CSCW) research stream.[10] The second potential risk consists in reducing the situated practical accomplishments to the creation of a consensus amongst stakeholders about ICT expected impacts – this is characteristic of mainstream IS research that seeks the sources of the convergence between stakeholder's interests.

A possible path to avoid these challenges is outlined by Leonardi et al. (2012: 9) when they recommend analysing materiality by *"understanding technologies in terms of the consequences they bring about"* in organising activities. The introduction of a temporal dimension expressed in terms of *consequences*, creates the means to operationally observe knowing as an

[10] See discussion by (Monteiro et al. 2013) on the need to accommodate *"non-local constraints"* when studying work practices. See also (Cecez-Kecmanovic et al. 2010 ; Cecez-Kecmanovic et al. 2014)

accomplishment and apprehend how large scale ICT platforms contribute to organise *situated practices* of knowledge sharing and creation across boundaries. In other words, the possibility to incorporate a temporal dimension expressed in terms of *consequences* opens opportunities to study reflexively the *"becoming of things"* (Hernes & Maitlis 2010).

Researchers may therefore, better articulate on one side, the analysis of how data is assembled through algorithmic reasoning and statistical techniques (IS operations such as editability, interactivity, reprogrammability) and on the other grasp the ecology of relations in which practices are embedded (Kallinikos et al. 2013) and the *"rhetorical space"* configuring promises and expectations associated with the new technology (van Lente & Rip 1998; Mulder et al. 2011) .

The table below shows how this line of research helps us better grasp the complementary dimensions of our research question – and understand *how the blueprinting process of a PLM platform assembles the disciplinary agencies accounting for a new product across organisational boundaries?*

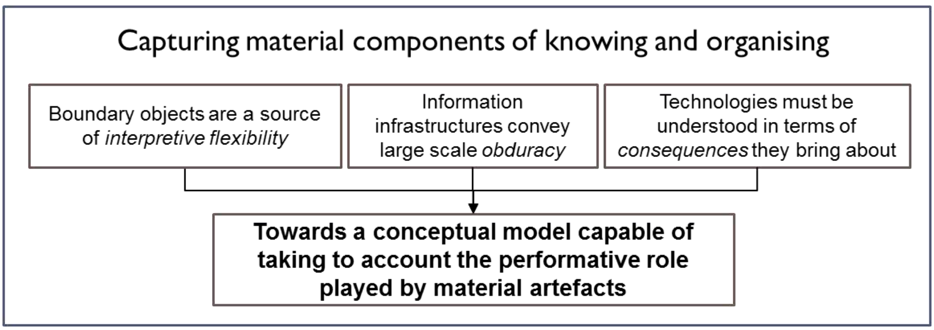

Table n°4
Outcomes of the "material turn"

2.5. Understanding the interobjective relationship between knowing and organising

We have seen above that the opposition between social and material is a central topic of the literature on *"relational conditions"* supporting knowledge sharing and creation.

Researchers engaging in the "practice turn" emphasise that technology is more than a "support" for organising knowledge sharing and creation. According to Practice-based theories, the *"entanglement"* of *"social"* and *"material"* is best conceptualised by an *intersubjective* relational ontology in which "*human choice and agency are made originally possible through the very resources that objects and structure disposes"* (Leonardi et al. 2012). So according to this heuristic model, organising must be studied through the *intersubjective* consequences of materiality (Leonardi 2013; Leonardi 2011). We will see below that Actor Network Theory (ANT) brings into question this *intersubjective* dimension of the dominant relational ontology in organisational studies.

At first, we present in this section main arguments leading ANT scholarship to the definition of an *"interobjective"* relational ontology. We will then be able to better understand why we have adopted elements of the analysis of "*techniques of staging the world."* to build our conceptual framework that studies ICT mediations in organising knowledge sharing and creation across organisational boundaries.

2.5.1. Social order is an interobjective practical accomplishment

ANT introduces a radical shift in the study of the role played by materially by stating that organising is an assemblage of observable "*techniques of staging the world"* composing *"chains of reference"* that (re)distribute agency to (human and non-human) agents - or, "*actants"* (Latour 2005). In a much quoted article, (Latour 1996) discusses the differences between interactions among primates and humans. He indicates that unlike baboons, human interactions benefit from observable, stable ("*black-boxed*") instances of ordering embedded in material entities. Consequently, humans benefit from previously instituted, observable "*techniques of staging the world"* and thus are not required to permanently recreate the whole "society" to accomplish their situated interactions.

Latour (1996:230) proposes to capture *what makes* these "*techniques of staging the world"* through the concept of "interobjectivity." In a discussion with the interactionists and the advocates of social structure, Latour affirms that *"The very existence of an interaction presupposes a reduction, a prior partitioning"* from the social (Latour 1996:230). The concept of interobjectivity is defined to account for the agency exerted by *"frames, partitions, hideaways, fire-doors"* - which are "nonhuman" entities performing an active role in stabilising "human" interactions. Interobjective agency generates the *chain of reference* for the interaction and prevents it from "*the contagion of the social."*

ANT puts forward a relational ontology that shifts from an *ostensive* definition of organisations to its *adverbial* mode of existence (Latour 2011). In this context, knowledge does not *represent* a pre-existing "reality." Knowledge is an accomplishment that composes sets of *"inscriptions"* and *"programs of action"* – composing "*metrological chains"* that perform sequentially, forms of discontinuity between entities. Discontinuity (i.e. the moving assemblages of disconnected parts performed by *"frames, partitions, hideaways, fire-doors")* maintains coherence by allowing for alignment and relationship. [11]

Moreover, in Latour's *"flattened topography",* the definition of the "social" is understood as associations, where actors remain side by side, *"if any action has to be transported from one site to the next, you now clearly need a conduit and a vehicle."* (Latour 2005:174).

[11] A similar conceptualization is proposed by Niklas Luhman: functional simplification and closure *"involves the demarcation of an operational domain within which the complexity of the world is reconstructed as a simplified set of causal or instrumental relations. Functional closure implies the construction of a protective cocoon that is placed around the selected causal sequences to ensure their recurrent unfolding"* (Kallinikos 2005).

We will see in the next chapter, why such a *flattened* ontology leads us to adopt a methodological framework that is built to follow these *"vehicles"* [12] that transform *"intermediaries"* [13] into *"mediators"* - mediators "*are beings out there that gather and assemble the collective just as extensively as what you have called so far the social, limiting yourselves to only one standardized version of the assemblages; if you want to follow the actors themselves, you have to follow us as well."* (Latour 2005:240).

We can now better understand why ANT's heuristic stance is interested in operations such as the assemblage, alignment, translation, and inscription of programs of action. These operations are stabilised patterns of relationships as they reveal *observable instances of ordering* – or, in other words, they express and make public how extended and simplified inscriptions stabilise and *"keep the information in your camp*" even when it's far away, hidden and voluminous (Latour 1987).

2.5.2. Limitations of a constructivist interpretation of ANT

The conceptual framework proposed by ANT to better understand "*techniques of staging the world"* is often adopted by ICT literature. However, as shown by Cordella (2011), a significant part of this literature adopted a constructivist stance that uses Actor Network theory as an *"interpretive lens."* The argumentation is centred mainly on the *effects* generated by the "black-boxing" of organising practices in information technology (Cordella & Shaikh 2006).

The outcome of such a stance brings about a deterministic, and rather Machiavellian explanation of the relationships between ICT and organising. The role of "translations" is abridged to a matching process between

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[12] We will explain later, how our methodological framework capture these "vehicles" through "trials of connections" between ICT platforms and engineering practices (Nicolini 2009).

[13] *"An intermediary, in my vocabulary, is what transports meaning or force without transformation: defining its inputs is enough to define its outputs. For all practical purposes, an intermediary can be taken not only as a black box, but also as a black box counting for one, even if it is internally made of many parts."* (Latour 2005: 39). – see also (Lynch 2013).

"technological" artefacts and "social" problems. Actors suffer more or less passively, the "enrolment/alignment" leading to irreversible conversion within a "stabilised" black-boxed condition.

For (Cordella 2010) the investigation of ICT should not be limited to "*the study of the effects that specific actors have on the black-boxing of inscriptions in a specific actor-network, but on the interplay analysis taking place in the actor-network that can, but not necessarily, result in a black-boxed relationship.*" In other words, research on ICT must bring together a framework adapted to the study of "*infrastructuring*" (Cordella 2010:43) – that is, a heuristic stance that is able to seize *what makes the performative dimension* of an actor network by tracing the process "*before the box actually gets closed*" (Lanzara 1999).

In order to avoid the limitations conveyed by a constructivist use of ANT we turn our attention to the heuristic stance through which Bruno Latour conceptualises the *recursive movements* that *makes* the relationships between technology and organisational practices.

2.5.3. Accessing interobjective techniques of "staging the world"

In line with the heritage of Wittgensteinian and pragmatist traditions and building on the ethnomethodological understanding of the composition of social order as accountable observable practical accomplishments (Rawls 2011; Rawls 2009), Latour points out that *"we need others to help us transform a claim into a matter of fact"* (Latour 1987:107).

The corresponding heuristic stance consists in *following* the "black-boxing' process through *controversies* about "matters of concern." Controversies reveal the production of practical accomplishments through which human and non-human entities are associated to form stable, and therefore *observable,* instances of ordering.

More precisely, the researcher follows how the *techniques of staging the world* move, transport, and transform the components of the actor network up until human and non-human entities are assembled to become (or sometimes to not become) more or less "*undeniable facts.*"

For example, (Callon 1986) traces controversies about how the decline in the population of scallops in St. Brieuc Bay is performed, enacted, and staged by *"enrolling/aligning"* human and non-human entities. Latour (1995) studies how Louis Pasteur assembled heterogeneous elements that perform, enact, and stage new relationships between microbes, antibodies, standardised instruments, practical techniques, public health campaigns, and military and government officials. Law (1984) traces the *"conditions"* and *"tactics"* enabling the Portuguese expansion through the performed, enacted, staged *"networks of heterogeneous entities."*

These early seminal ANT articles defend similar arguments stating that *"the stability and form of artefacts should be seen as a function of the interaction of heterogeneous elements as these are shaped and assimilated into a network"* (Law 1984).

2.5.4. ICT mediates techniques of staging the world

Techniques of staging the world act upon controversies by *transforming claims into matters of fact.*

This process comprises two dimensions. First, a cognitive component. The composition of orderly interactions between heterogeneous human and nonhuman entities is not explained by something taking place in people's mind. On the contrary, objects/things are conceptualised as "parliaments" that enact the heterogeneous "black-boxed" interactions. By making visible instances of ordering, the techniques of staging the world reveal how a *"net-works"* to stabilise interactions (Mol 2003; Latour 2005; Muniesa 2014).[14]

[14] For example, in a well-known study about "Plans as Situated Actions," (Suchmann 1987:3) affirms that plans are not "something situated in the actor's head." Plans embody the "formulation of antecedent conditions and consequences of action that account for action in a plausible way." MacKenzie et al. (2007), have shown that models are performative when use increases its predictive capabilities. See also Mackenzie (2012) MacKenzie (2009).

Second, a normative component. ANT studies – on topics such as *"centres of calculation"* (Latour 1987), *"metrological chains"* (Latour 2005), and *"calculative agencies"* (Callon & Muniesa 2005; Callon et al. 2007; Callon 2008) - have shown how *"techniques of staging the world"* (models, workflow schemes, standard templates, etc.) convey a normative role by exerting modifications within controversies. As we have mentioned above, mediations become "*mediators*" as the normative component of these techniques provokes distortions, transformations of the meaning that they carry. This means that these ostensive techniques induce associations ensuing that *"many work as one"* (Latour 1987). "*Mediators*" insure the convergence of interests leading to effective "translation" processes. By organising *"frames, partitions, hideaways, fire-doors"* (Latour 1996), mediators succeed in extending and simplifying relationships between humans and non-humans. By studying this process, the researcher gains access to how mediators succeed in stabilising the representations of complex relationships –

The table below regroups the main inputs for the study of the role of ICT in mediating the emergence, persistence and obduracy of knowledge sharing and creation.

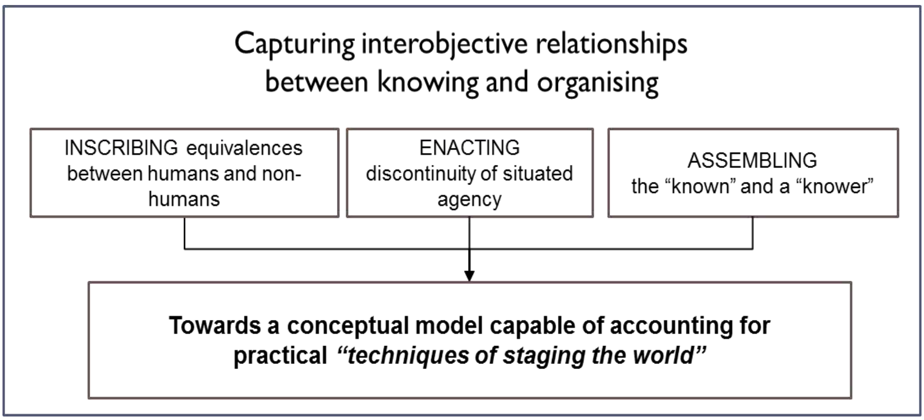

Table n° 5
Outcomes of the ANT heuristic model

According to this heuristic model, both cognitive and normative dimensions are conveyed by the enactment of *accounts* (techniques of staging the world) through which "*matters of concern*" are "*black-boxed*" to progressively become "*matters of fact*". [15]

We will see in the next section, how we take advantage of the conceptual framework to operationalise a heuristic model using the concept of *"trails of connections"* (Nicolini, 2009) to trace the relationships between ICT artefact and engineering practices.

2.6. Bridging the gap in the literature

2.6.1. The intersubjective heuristic model

We have mentioned that Knowledge-based theories study how *integrative capabilities* acquire, process and transfer knowledge. According to Knowledge-based theories, technology sustains/maintains the transfer of something that pre-exists the interactions between agents. Knowledge is an object processed across disciplinary domains within innovation intensive firms. Capabilities to better organise problem solving routines across organisational boundaries become a competitive advantage.

The *practice turn* opens a path for new approaches about *intersubjective* capacities for action and the role played by materiality. Knowing is seen as a practical accomplishment depending on collective cognitive competences that secure knowledge processing and also generates new knowledge. Challenges and tensions arise when boundary spanning collaboration involves conflicting interpretations of knowledge (analysis vs. interpretation).

The *material turn* draws attention to the entanglement between technology and organizing. The way knowledge is represented depends on the characteristics of artefacts used by engineers. "Boundary objects" – i.e. categories, schemes, models, etc. - concurrently support and shape the

[15] On the turn to ontology in STS see also (Barad 2003).and (Woolgar & Lezaun 2013; Woolgar et al. 2009).

practical accomplishments and *compensate for* limitations of collective cognitive competences.

Consequently, there is no intrinsic functional identity of technological objects. ICT structures and is structured by routinized *"knowing processes."* The latter are conceptualised as situated practical accomplishments unfolding within transformative cycles. Therefore, the study of ICT must take into account the practical accomplishments that enable (performative routines) and/or constrain (ostensive routines) interpretive cognitive schemes.

The figure below summarizes the heuristic model centred on relational and emergent properties of an artefact. It shows how materiality *induces* ways of acting and knowing - and how this process prompts *"consequences."*

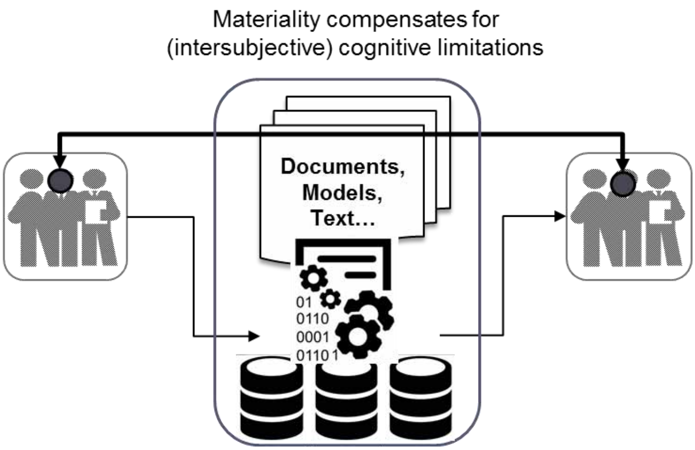

Fig. n° 2
Inter-subjective epistemological model

In summary, the *intersubjective* conceptual model conveyed by Practice-based theories, considers that technology not only enables knowledge sharing but also plays a role in *structuring* interactions between organisational disciplines.

2.6.2. The interobjective heuristic model

Following the review of the main components of the *interobjective* ontology, we can now better understand the whys and wherefores of the radical shift proposed by the Actor Network Theory. The conceptualisation of the *active* role played by technical artefacts in organising does not refer anymore to an intersubjective consensus and or an agreement among diverse stakeholders. The approach proposed by ANT does not depend on the individual "cognitive competences" - placed at the discourse level. ANT *"pictures a world made of concatenations of mediators where each point can be said to fully act"* (Latour 2005:59) – in this framework, knowing is to be found in *"the material and discursive activity, body, artefacts, habits, and preoccupations that populate the life of organisational members"* (Nicolini 2013:7).

Callon (2006, 2007, 2008 and 2010) recommends to use the French word, *agencement* to account for the concatenations between statements and their worlds. *"The term agencement is a French word that has no exact English counterpart"* [16](…) *"Agencements are arrangements endowed with the capacity of acting in different ways depending on their configuration"* (Callon 2008:39).

Agencements perform a movement that conveys the *"preferred courses of action"* that compose it. It does so by making visible a *web of relations* to itself. *"A socio-technical agencement includes the statement[s] pointing to it, and it is because the former includes the latter that the agencement acts in line with the statement, just as the operating instructions are part of the device and participate in making it work".* (Callon 2006:26)

The socio-technical *agencement* is a practical performative accomplishment. The table below shows that *"In this version of knowing, the epistemological (issues to do with knowing or knowing well) is bound up with the ontological (the question of what exists). What is, as well as the knowledge of what is, are*

[16] Callon (2006:26) highlights that "*In French its meaning is very close to "arrangement" (or "assemblage"). It conveys the idea of a combination of heterogeneous elements that have been carefully adjusted one another. But arrangements (as well as assemblages) could imply a sort of divide between human agents (those who arrange or assemble) and things that have been arranged".*

produced together" (Law 2000:350). So *"In this way of thinking, an object may be imagined as a set of relations that changes. Oxymoronically, it is something that both changes and stays the same"* (Law & Singleton 2005: 6).

"Collective hybrids" - or interobjective *"metrological chains"* (Latour 1987; Latour 1986; Latour 2011; Latour 1996; Latour 2005) associate…	
- things - *"parliaments"* (humans and non-human entities)	- and mediators – organisational scripts going from *disinterest* to *interest*, *composition* of a new goal, *obligatory passage point, alignment, blackboxing, convergence*
"Calculative (or qualculative) devices" (Callon & Law 2003; Callon 2007; Callon 2005; Callon & Muniesa 2005) performs the *agencement* between…	
- a *"web of relations that makes and remakes its components"* …	- and the *"operating instructions"* and *"statement[s] pointing to it"*
"Conceptual objects" (Law & Hassard 1999; J Law 2007; Law & Mol 2002) bring and hold together…	
- what is to be known about the world…	- and the materially heterogeneous knower
"Calculative devices" (Muniesa 2014: 17) bring together	
- *"things happening"* - reality as effectuation (a thing done, brought about) …	- *"signification as an act"* - accounting for reality as an active, performative process.

Table n° 5
Main concepts of the interobjective heuristic model

In this heuristic model, there are no *exterior, pre-existing* technological assets that "influence" human behaviour. *"Knowledges and the objects that they know may be understood as being produced together"* (Law 2000:349).

The study of the role played by technological artefacts such as the "Product Lifecycle Management" platforms studied in this dissertation, calls for apprehending the expression of their relational and emergent properties. This means grasping how the webs of material and social practices generate and perform realities – *"we are dealing with enactment or performance (...) everything plays a part relationally"* (Law 2009: 151).

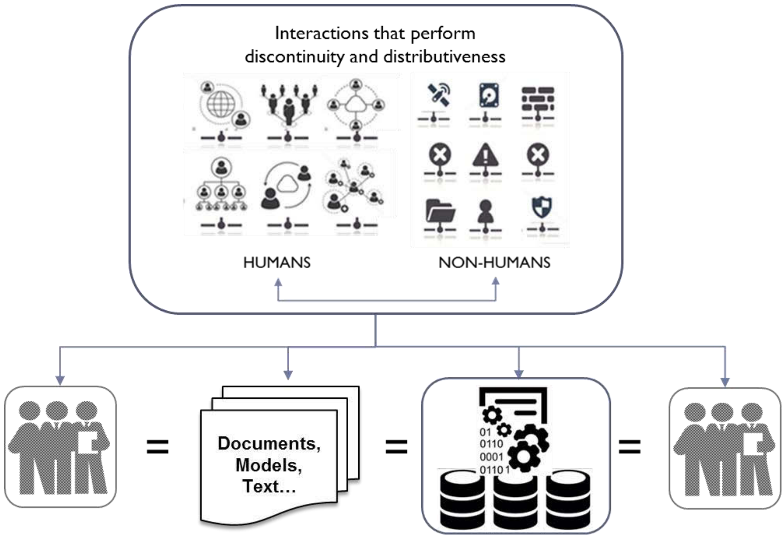

Fig. n° 3
Interobjective Heuristic Model

So our approach consists in apprehending how the negotiations leading to the PLM blueprint:

- *add* forms of discontinuity, diversity, multiplicities… to a *frame of reference* organising ways to account for the industrial products across organisational boundaries,
- *and by doing so, compose forms of commensurable equivalences that strengthen the concatenation of heterogeneous elements as these are shaped and assimilated into a network.*

Our research question seeks to articulate these two dimensions of the relationship between something known or known about and something or someone that actively does the knowing.

2.6.3. Summary of opposing heuristic models

We have presented in the introductory chapter the logic leading to our research question about what actively modifies instances of ordering composing a cross-disciplinary account of the product lifecycle across organisational boundaries.

The literature review showed that the study of the role played by PLM in organising concurrent engineering, is most often grounded on a heuristic model that is interested in explaining sources of "continuity" of knowing practices – in this sense, ICT is seen as a means to *overcome* the discontinuities, diversity, multiplicities… We contend the contrary. ICT is more than just a *support* of continuity of the intersubjective dimensions enabling the representation of the industrial products across organisational boundaries. [17]

Our research question is built on a conceptual model that is able to take into account,

- on one hand, how ICT mediations actively *add* to the stability and obduracy of organising, and

- on the other hand, how ICT mediations *enact* accounts about *"things that don't quite fit"* (Law 2003), forms of discontinuity, diversity, multiplicities, inconsistencies, ambivalence, and ambiguities.

The figure n° 4 (next page) shows the opposing ontologies.

[17] *"Knowing is not tied to any particular location: in the head, on a spreadsheet, in the skills of bricklayers, in a text, within a machine, on the tip of the tongue, across an organization, knowing is a relational moment or an effect, not a substance"* (Law 2000:350) – on the underlying "paradigm" conveyed by ANT see (Law & Hassard 1999; Hassard & Cox 2013).

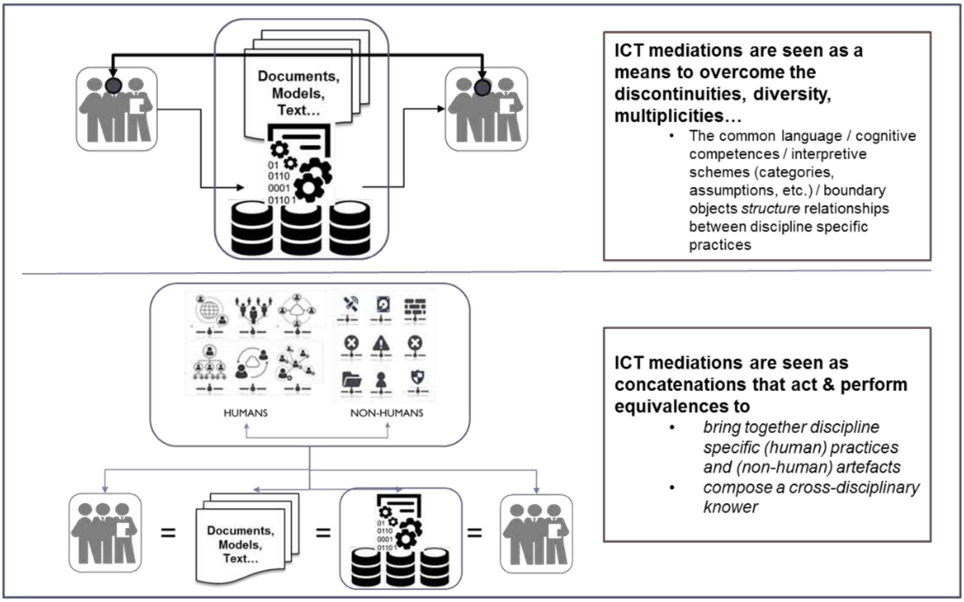

Fig. n° 4
Intersubjective vs. Interobjective heuristic models

2.6.4. Capturing what actively modifies instances of ordering

Building on ANT's *"flattened"* ontology, we study how ICT artefacts bring together, enact and perform the concatenations acting as a *frame of reference* for accounting for the industrial products across organisational boundaries.

The case studies provide empirical evidence about the emergence of *interobjective* accounts conveying *discontinuities* that bring together, enact and perform the *"messy"* (Law 2007) relationship between:

- something known or known about	- something or someone that actively does the knowing
- the organisationally assembled human & non-human entities	- the performing entities composing the "*knower*" that contributes to assimilate heterogeneous elements into a network

In other words, our objective is to contribute to the study of how *forms of discontinuity* between entities are *accounted* for. As mentioned above, we adopt the term *account* as it brings up two dimensions of engineering practices studied in our case studies: first, the results of a specific formalisation of *something known or known about* (the attributes of the industrial product) and second, the narrative produced by *something or someone that actively does the knowing* (narrative about the product evolution throughout its lifecycle).

2.6.5. Tracing accounts about *"things that don't quite fit"*

The first component of the operationalisation of the conceptual model is achieved by the apprehension of mediating agencies (practices, software applications, documents, categories, templates, etc.) that account for the discontinuity between entities. We investigate how the PLM platform add mediations that are nonhuman entities that are placed between two discipline specific agents and that contribute to modify cross-disciplinary relations – what Latour (2005) calls "mediators:" The latter is conceived as a nonhuman that necessarily adds *"something to a chain of interaction or an association"* (Sayes 2014: 138). We investigate more precisely how PLM mediations become "mediators" – the latter *"make a difference"* by generating new forms of *equivalences* across organisational boundaries and enacting the interactions among heterogeneous elements as these are shaped and assimilated into a network.

The second component of the operationalisation of the conceptual model is achieved by tracing the formation of a cross-disciplinary "knower" that contributes to assimilate heterogeneous elements into a network. The "knower" *does the knowing of what is to be known* by (1) framing "what is to be known", (2) assigning attributes to human and non-human entities and (3) contributing to stabilise interactions. We will present hereafter, how we collect empirical evidence about the *active* role played by ICT mediations in enabling and performing an *account* of the socio-technical *agencement*.

CHAPTER 3 / RESEARCH DESIGN

Our aim in this chapter is to describe the methodological framework that enables us to undertake an in-depth enquiry of the two case studies on the way *PLM platforms mediate the composition of a cross-disciplinary account of an industrial product* within concurrent engineering settings.

We present in a first section hereafter, why we have adopted a qualitative approach and how we designed the empirical enquiry about an emergent phenomenon – the blueprinting process of PLM platform that brings together disciplinary practices and software applications.

We then propose a brief description of concurrent engineering challenges – and how PLM platforms occupy a cross-disciplinary position that is able to reconcile differences / discontinuities / oppositions that jeopardise dominant product development processes.

In the subsequent sections, we present data collection and data coding approaches that mobilise the concept of "trails of connections" mediating the account for the emerging product.

We conclude with a presentation about how we have reassembled and analysed the data that will be presented in more details in the two case studies. We also address the question of our qualitative research's validity, and how we have controlled for bias, taking into account our participant observer stance.

3.1. A qualitative approach to study an emergent phenomenon

The research approach is qualitative, adopting an exploratory posture with the aim of contributing to the understanding of the practical efficacy of PLM platforms mediating the composition of a cross-disciplinary account of the product lifecycle across organisational boundaries.

As stated by (Yin 2009:18) qualitative case studies are used to bring evidence about the emerging phenomenon within a complex organisational setting: a case study is *"an empirical enquiry that investigates a contemporary phenomenon in depth and within its real life context, especially when the boundaries between the phenomenon and context are not clearly evident"*. The qualitative approach is well adapted to the study of the relationship between mediating agencies bringing together engineering practices and disciplinary software applications through the PLM platforms.

Our methodological argument (adapted from Booth et al. 2008) is structured as follows: our research question - *How does the blueprinting process of a PLM platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?* – is operationalised by the study of how the negotiations leading to the blueprint of the PLM platform *alters* our three propositions:

- changes in the scope of *what information needs to be shared* across disciplines;
- changes in the organisation of *when & where information sharing takes place*;
- changes in the ways *accountability* is assigned across organisational boundaries.

The propositions are studied through the composition/concatenation of a novel *frame of reference* that generates organisational consequences.

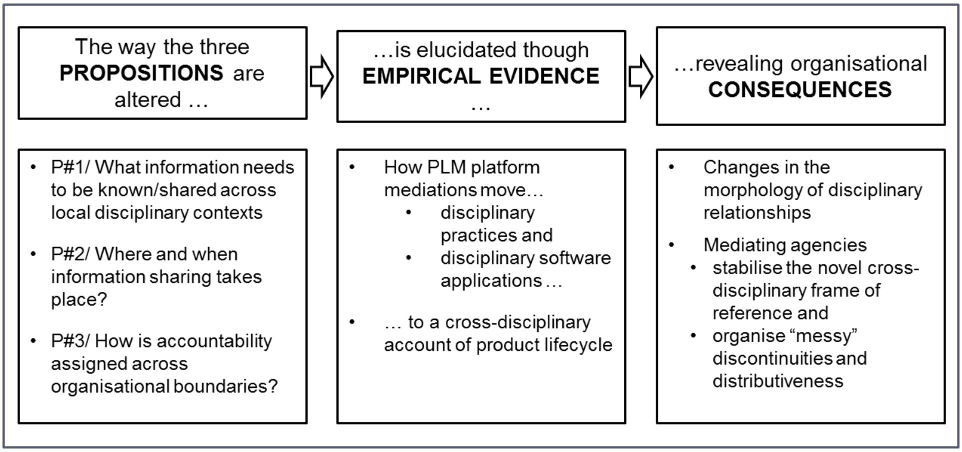

Fig. n° 5
A qualitative approach to study an emergent phenomenon

3.1.1. Concurrent engineering challenges in discrete manufacturing industries

Before presenting the details of how empirical data is collected, coded and analysed, we need to describe what is at stake in the composition of a "frame of reference" for concurrent engineering agencies.

The two case studies investigate new forms of concurrent engineering practices within discrete manufacturing industrial sectors - the first case is about a firm in the defence industry and the second case is about a firm in the biotechnology industry.

Both companies design, engineer and service complex innovation intensive products. The pressure to increase the pace of innovation in discrete manufacturing industries imposes new co-development models, characterised by complex forms of task partitioning between a wide number of organisational entities. Current project governance dynamics based on highly structured and "compulsory" sequential procedures evolve to enable more "loosely coupled" collaborative environments. Companies face important challenges organizing concurrent engineering processes involving geographically distributed teams (marketing, engineering, manufacturing and services related disciplines) mobilising interdependent knowledge about the emerging industrial product. They are typical *"ecologies of complex innovation"* (Dougherty & Dunne 2012) where engineering teams need to define and manage massive product configurations and accommodate design alternatives to satisfy evolving regional market-specific needs.

Consequently, the two firms also face organizational challenges when trying to track requirements consistency and manage the information status throughout the product lifecycle. Researchers pointed out that co-development also implies sharing responsibilities and creating knowledge "together" – mainly about product interfaces (Sosa et al. 2003; Eppinger et al. 2014). This creates inconsistencies and controversies with regard to dominant project management practices.

Concurrent engineering of complex industrial products involves many components with *unknown interactions.* Multi-disciplinary teams struggle to take into account the "emergent behaviour" of the various components of the industrial product (Maccormack et al. 2010; Baldwin 2012; Brusoni & Prencipe 2001). The existing "concurrent engineering" methodology implemented in both companies is more and more threatened by increasing intricacy, not only of concurrent but also of distributed engineering processes (Bautzer 2005).

Engineers need to share the existing knowledge, create new knowledge and, execute *impact analysis* about the potential interactions between key components and make the necessary trade-offs. [18]

[18] *"The systems engineering process has an iterative nature that supports learning and continuous improvement. As the processes unfold, systems engineers uncover the real requirements and the emergent properties of the system. Complexity can lead to unexpected and unpredictable behaviour of systems, hence, one of the objectives is to minimize undesirable consequences. This can be accomplished through the inclusion of and contributions from experts across relevant disciplines coordinated by the systems engineer. Since systems engineering has a horizontal orientation, the discipline (profession) includes both technical and management processes. Both processes depend upon good decision making. Decisions made early in the life cycle of a system, whose consequences are not*

3.1.2. The dominant "waterfall" organisational model

Engineers and technicians work is dominated by a rather *adhocratic* organisational environment as defined by (Mintzberg & Mchugh 1979) - "adhocracy" is a structural configuration that *"is able to fuse experts drawn from different disciplines into smoothly functioning ad hoc project teams*".

The limits of adhocracy are also identified by INCOSE's *"Systems Engineering Handbook"* as follows:

- *"System requirements cannot be established without determining their impact (achievability) on lower level elements. Therefore, requirements definition and analysis is an iteration and balancing process that works both "top-down" (called allocation and flow-down) and "bottom-up." Once the top-level set of system requirements has been established, it is necessary to allocate and flow them down to successively lower levels. As the allocation and flow-down process is repeated, it is essential that traceability be maintained to ensure that all system level requirements are satisfied in the resulting design"* (Hamelin et al. 2010: 76).

The two case studies concern the development of complex products and services dominated by a rather sequential ("waterfall" model) approach of product requirements qualification that can be defined as follows.

At the early "Define" phase, Design and Engineering disciplines prioritize main functional attributes of the industrial products. The subsequent "c*ascading"* phase consists in associating the expected functional requirements to related means.

Step 1/ When faced with a request for product requirements modification, Engineers typically start by trying to elucidate product enhancement opportunities. Product items are affected by type of improvement opportunity of product performance and a "Problem report" is submitted to specialised Engineering teams. The assessment concerning new parts, components and assemblies and sub-assemblies is submitted to a detailed business plan

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clearly understood, can have enormous implications later in the life of a system. It is the task of the systems engineer to explore these issues and make the critical decisions in a timely manner." International Council on Systems Engineering, INCOSE Systems Engineering Handbook v. 3; June 2006 supported by a formal "return on investment" (ROI) assessment. The next step consists in investigating the need for improvement and validating the proposed *account* of the functional requirements. An initial review of the solution proposal is accomplished and an initial justification is formalized to describe the impact, risk and cost for future requirements modification.

Step 2/ A first trade-off is introduced by a Control Board where a cross-functional team involving representatives from different company departments, reviews the change request and makes a business decision whether or not to proceed with implementation planning. The decision is then communicated to all stakeholders (Marketing, Design and Engineering). If a Control Board decides to introduce a modification of the product, a first *joint enquiry* is launched to plan subsequent activities and *clarify the scope of change in requirements* - e.g., minor (fast track) vs. major change (full track). The project team develops a detailed plan for change implementation including resources, tasks and scheduling. The plan is then submitted to the Board that approves or rejects the detailed plan and the decision is communicated to relevant stakeholders.

Step 3/ The following step is the actual *implementation* of the request for change in product requirements. A second joint enquiry is launched involving a more complex multi-function "loosely coupled loop" where both, product integrity teams (engineers responsible for the control of the product configuration) and project teams (engineers responsible for *"cascading"* the high level functional requirements description to a specific customer application) update product requirements definitions. The new product configuration is captured within a stand-alone software application. [19]A key moment requiring reliable joint enquiries is the step where teams proceed to *verifications* of actual vs. planned changes including reviews about complex *interfaces* that are not easily specified a priori. We observe that Program managers often ignore the actual flow of decisions generated by highly interdependent technical decision making processes.

[19] Tensions tend to aggravate as cross-disciplinary reviews are performed involving geographically distributed teams.

Step 4/ The final step occurs when engineering project teams release an "official account" about the new validated product configuration to all concerned functions - manufacturing, quality, support services, etc. A new source of tension appears as agreement around divergent requirements is needed to validate the *effectivity* date – the date on which an item is released and available for its intended use. A first list of *verification* targets may be formally established. Engineers obtain inputs from design and verification tasks to - eventually - re-evaluate customer requirements and check the "manufacturability" and "serviceability" of the proposed design.

3.1.3. Articulating contradictory components of concurrent engineering

Starting from these generic questions about product development challenges within discrete manufacturing industries, the two case studies address the role played by PLM platforms in addressing tensions between the two following contradictory requirements.

On one hand, concurrent engineering needs *tightly coupled coordination* across disciplines, structured by formal milestones ("*stage-gates*") securing consistency throughout a "*waterfall*" development processes of the product and services. They require *commensurable artefacts* securing collaboration and reducing business and technical risks through (1) more formalised, (2) codified and highly structured requirements management processes, (3) better-aligned concurrent engineering methodological frameworks defining a *"manufacturable and serviceable product"* from conception to manufacturing – and eventually, to its retirement.

On the other hand, concurrent engineering requires *loosely coupled cooperation* between engineering and services related disciplines preserving *contextualized discontinuities* and forms of *organisational slack* to enable flexible interactions across discipline specific knowing practices. *Discontinuities* expressing the need to develop more flexible collaborative practices where all involved disciplines are able to address unforeseen events amidst a competitive scene which is more unpredictable. Information sharing and creation depends on adhocratic practices – such as peer review validation practices characterised by *evolving* levels of consistency and changing granularity of organisational contexts (Orton & Weick 1990).

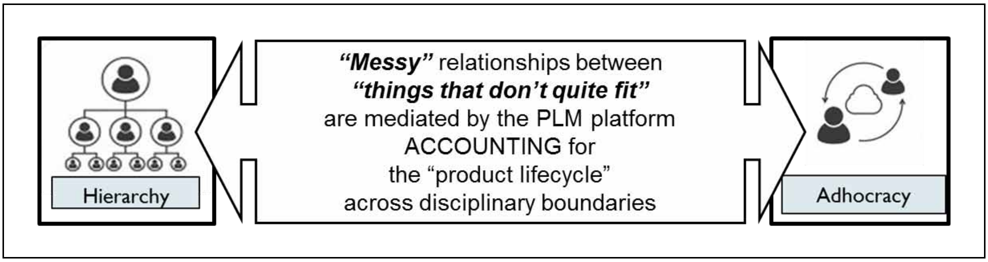
By studying how the blueprinting process of a PLM platform defines the mediations composing an account of the product lifecycle, we bring empirical evidence about the way organisations address the "concurrent engineering paradox" generated by the conflicting opposition between *tightly coupled commensurability* and *loosely coupled discontinuities*.

The two case studies describe how the negotiations about the PLM platform blueprint are caught within controversies concerning these two potentially conflicting requirements. We will see below, how the PLM platform is at the centre of the controversies generated by the need to bring together modelling software applications to secure traceable product integrity.

The research design can be summarised as follows:

<table>
<tr><td colspan="2">RESEARCH QUESTION / How does the blueprinting process of a PLM platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?</td></tr>
<tr><td colspan="2">OPERATIONALISATION OF THE RESEARCH QUESTION / How the negotiations about the PLM blueprint leads to the composition of a cross-disciplinary "frame of reference" that is able to both, enforce persistency, traceability and preserve differences, discontinuities that characterise concurrent engineering processes.</td></tr>
<tr><td colspan="2">COLLECT, CODE and ANALYSE EMPIRICAL EVIDENCE</td></tr>
<tr><td colspan="2">How the PLM blueprint …
- …occupies a cross-disciplinary position (for example, the definition of metadata about storing, processing and transferring product information across functional and disciplinary boundaries);
- …forms connecting links (for example, the way connections are established between various repositories containing different types of information under diverse standards, formats, locations);
- …acts between disciplinary entities (for example, formalise observable virtual mock-ups, fast prototyping devices, dashboards, etc.).</td></tr>
<tr><td colspan="2">- Study the CONSEQUENCES / Investigate how PLM mediations compose a cross-disciplinary "frame of reference" that accounts for both opposing dimensions:</td></tr>
<tr><td>- Tightly coupled coordination performing "auditable" representations of the emerging product</td><td>- Loosely coupled cooperation performing "unstable" / presentations of the emerging product</td></tr>
</table>

We study how changes in the morphology of "messy" relationships may become a stabilising component of the concurrent engineering paradox.



3.1.4. Unit of analysis of the case studies: the blueprinting of the PLM platform

PLM software packages are designed to be used "as is". By definition, there is a mismatch between the standard functional and technical characteristics of the COTS[20] software package and the actual operational processes and specific organisational requirements of the firm acquiring the software.

So the main unit of analysis to study this movement, is the negotiations about the composition of a blueprint of the PLM platforms involving primarily two entities.

On one side is a firm acquiring the PLM software package – represented by the IS experts in charge of acquiring the software package. The team includes engineers and technicians responsible for the definition of key functional requirements per business domain supported by the COTS software package. Final "users" of the future platform are not involved in the negotiation.

On the other side is a software vendor specialised in "Product Lifecycle Management" [21] – represented by a vendor team providing technical and

[20] COTS means "Commercial Of The Shelf."

[21] The software vendor is one of the main players in design & engineering related markets such as "product lifecycle management" (PLM), "application lifecycle management" (ALM) and "computer aided design" (CAD) software packages.

commercial information about the way the PLM platform supports (or not) the list of functional and non-functional requirements.

The methodological framework is designed to study the negotiations between these two entities and take advantage of the opportunity to gather data before the acquired PLM platform becomes stabilised ("black-boxed"). The negotiation is structured around three components of the blueprinting process: the demand, the offer, and the "proof of concept."

Unit of analysis of the case studies: the blueprinting process		
• The DEMAND expressed by the industrial companies	• The OFFER proposed by the PLM vendor	• The MOCK-UP of the PLM platform
• "Request-for- quotation" defining the functional attributes of the PLM platform	• "Scenarios of use" of the PLM platform	• "Proof-of-concept" (PoC) through which the relationship between offer and demand is enacted
• A list of functional attributes of the future PLM platform		• The enactment of the PLM mediations

Table n°6
Unit of analysis of case studies

We present hereafter in more detail these three components of the blueprinting process.

Collecting empirical data about the way expectations are framed (*demand*)

The "Demand" through which the industrial company expresses the required functional attributes of the PLM platform, is described through a series of documents composing the *Request for Quotation* (RFQ). The firm acquiring the software package presents (1) the functional and technical requirements defining the future PLM system and (2) the main interfaces to the legacy systems. The RFQ also frames the reciprocal expectations that guide the exchange of information between the industrial company and the software vendor.

On one hand, it defines the high-level purpose and the scope of the required PLM platform, the operational and business requirements, the functional and non-functional requirements[22] and the expected functional coverage of the future PLM platform. The document also presents the requirements about the overall systems architecture, and describes the key interfaces with legacy systems. On the other hand, it describes Use Cases [23] that form the operational links between a set of technical criteria and the expected business value linked to process automation and improvements.

Functional requirements are often related to one another. In order to get a better understanding of the interdependencies, we have also performed focused interviews with subject matter experts that authored the RFQ documents.

The actual planning and organisation of the interview with company experts was done by the industrial companies following our guidance on the sampling logic. We defined a list of target functions/departments to be interviewed: Product Development (Engineering, Mechanical, Electrical and Software development); Services (Support Services, Logistics), Supply chain (Quality, Regulatory affairs); IT (Architecture, Legacy applications).

Collecting empirical data about scenarios of use (*offer*)

The "Offer" is exposed through a series of documents through which the vendor proposes a generic COTS PLM platform. The "offer" conveys

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[22] Typical non-functional system requirements include: usability, configurability, supportability, reliability, error handling and conditions, performance characteristics, security, availability, scalability, audit and system control, localization, data constructs and standards, data access and availability, data migration, maintainability, software languages and standards, hardware infrastructure, system interfaces, system integrations, systems replaced, user interfaces, SOA- Service Oriented Architecture messaging protocols.

[23] A Use Case describe *"who does what?"* with the ICT application. It describes the interaction between a "User" and an "ICT application" by a sequence of simple steps. Use Cases also describe the ICT application behaviour of the system and general sequence of events performed by actors to accomplish tasks of a process for a specific goal. Use Cases may sometimes describe alternative or variant sequences of events to accomplish the same goal.

scenarios of use of the proposed platform that generates empirical evidence about alterations in the way classification categories are used to support boundary spanning engineering practices – particularly, the role played by product modelling *software applications* (requirements specifications, functional modelling, logical as well as physical simulation, and testing) in composing a common data model. We observe also alterations in the recurring changes are traced in product specifications from early requirements gathering phases down to manufacturing and services.

When offer meets demand through the proof-of-concept

Following the elicitation phase of the expected requirements, the Software vendor deploys a prototype of the future PLM platform - called, the “Proof of Concept”.

The first goal of the prototyping phase is the actual demonstration of the projected use case within an independent development server. The opportunity to demonstrate the feasibility to the required “use cases” contributes to sketch a compromise between the “demand” (specific business or process requirements) and the “offer” (COTS/standard capabilities conveyed by the software package). The vendor sets-up a “sandbox” (where servers are not connected to legacy systems) to perform the envisaged scenarios of use of the PLM platform.

Beyond these explicit goals about the functional coverage, the prototyping phase is an opportunity also for us to collect information about the more informal interactions between the company acquiring the software package and the software vendor. The demonstrations make public the potential alterations in current ways to account for the industrial products across organisational boundaries. As a result, we gain access to the (frequently unspoken) controversies about the interplay between the PLM capabilities and the related business process transformations. The “Proof of Concept” is used as well to officially validate whether the required functionalities are fully attained through the COTS/standard platform or whether there is a need for *configuration* - and sometimes, *customisation* [24] - or, if the *development* of specific code is necessary. Related cost assessments are also accomplished during this phase.

The outputs of the prototyping phase are meant to be “verifiable” and “attainable” according to technical, cost, schedule related criteria. The “Proof-of-Concept” is also used to review and validate the vendor’s response to the Request for Quotation. It consists in meetings between the various “prescribers” (subject matter experts, engineering managers and software vendor consultants) and the management sponsors of the project. During this phase, we collect data about a series of formalized compromises between on one hand, the expected business value generated by the future deployment of the PLM and on the other hand, the technical characteristics of the COTS software package.

The main data collected during this sequence covers two main topics. First, *data about metrics against which the offer is assessed* – particularly elements that contribute to prioritize, refine and eventually derive more detailed requirements that are joined to the documents about technical capabilities. These metrics express both business value (mainly process improvements) and technical feasibility (particularly the capacity to control interdependencies with existing applications and concurrent IT projects). Second, *data about the PLM implementation* and about the latitude of organisational transformation**.** The workshops about the PLM blueprint validation also make known the more or less controversial concerns such as the PLM platform deployment roadmap, the governance of the future deployment, the necessary evolution of the IS architecture, and the interfaces to be established with legacy systems.[25]

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[24] The COTS software package can be *configured* to be adapted a more or less wide-ranging scope of functionalities of the PLM requirements. The blueprinting phase is designed to limit the need for *customization* (i.e. development of specific code), thus lowering total cost of ownership and reducing implementation risks.

[25] ICT requirements also change during the development of the ICT platform. New requirements are expressed or new specific details of existing requirements are made explicit.

The outcome of these meetings contributes to formalise the final contractual framework for the acquisition (licences fees) and implementation (services fees) of the software package.

3.1.5. Formats and procedure of data collection

Most data are written documentation, graphical and video material, technical descriptions of the PLM platform, generic documentation about IS infrastructure, training material, screenshots of user interface, etc. We have also worked on formalised oral communication (interviews, meetings, participant observation) through memos, meeting minutes, and spreadsheets. [26] However, due to confidentiality constraints, interviews and meetings with subject matter experts and managers could not be recorded. Proceedings and meeting minutes were nevertheless reviewed by interviewees for validation. The data collection procedure is coupled to our professional role as a consultant working for the software vendor providing the PLM platform. This role opens direct access to all phases of the blueprinting process. We will explain in more details below the benefits and limitations of adopting such a participant observation stance.

3.1.6. Process and timeline of data collection

The overall blueprinting process (RFQ, Demonstrations, Blueprint validation) analysed in both case studies, is deployed over a relatively long period of time – varying from four to six months, and structured around the following milestones:

- 6-8 weeks: Elicitation and analysis of Request for Quotation
- 8-10 weeks: Demonstrations
- 2-4 weeks: Validation

[26] Documents about Demand and Offer are described in Annex 2

The two case studies follow the same data gathering sequence as described in the following table. Even though the three sequences are not actually flawlessly sequential, the following table helps us to summarise the adopted data collection approach.

Sequences	1. PLM Requirements elicitation	2. Demonstration of PLM platform ("Proof-of-concept")		3. Project approval
Data collection approach	• Meetings about project scope • Primary Document analysis • Semi-structured interviews	• Participant observation • to uncover evolution of the classification structure & data model • to uncover links with organising aspects of boundary spanning practices		
		• Meetings organised by Use Case category with business / disciplines representatives • Meetings with project teams		Meetings with sponsor & procurement team
Relevance of method selection	• Boundaries between phenomenon and context are still unclear (Yin, 2011)	• Need to confront "top-down" content (official documents) with "bottom-up" practices of boundary spanning traceability & collaboration • Enable triangulation between "demand" (industrial firms), "offer" (software vendor) and prototyping practices		Capacity to capture "infrastructuring" practices • Grasp consequences of ICT mediations in organizing dynamic
Expected Outcomes	• Uncover informal practices that are not stated in formal RFQ documents	Map links between "Use cases" (expressed in requirements about functional coverage) and enacted scenarios of use	Map the "trails of connections" where user roles are inscribed in the ICT platform	Collect data about the links between technical artefacts and organisational accountability

Table n° 7
Data gathering sequences

3.1.7. Eligibility criteria for case studies

The case studies selection criteria correspond to the need to capture at least three components of the mediating agencies exerted by the PLM platform.

Criteria #1/ On one hand, cases have to express the complexities of distributed cross-disciplinary collaboration. The *coherence of the organisational setting* is defined by the scope of product development processes. The two cases concern the development of complex industrial products deployed in highly distributed organisational settings.

Criteria #2/ On the other hand, cases have to correspond to a perimeter that can be studied in a coherent time period. The *temporal coherence* is ensured by the fact that we study the PLM mediations within a clearly bounded project aimed at defining the blueprint of the future PLM platform. The project timeline consists in a series of negotiations about both technical specifications of the new PLM software package and the economic considerations about the potential value generated by more effective cross-disciplinary collaboration.

Criteria #3/ Finally, cases must involve heterogeneous disciplinary software applications. [27] Cases must cover on one hand, complex organizational settings that can reveal the *"emerging developments in technology and work"* that goes from *"artefacts to infrastructures"* (Monteiro et al. 2013). On the other hand, cases must involve product innovation processes characterized by the creation, sharing, and modelling of emergent information - as opposed to IT applications used for *transactional* information processing.

3.2. Data coding

The coding procedure organises the collected data around the way PLM mediations alter the composition of a cross-disciplinary account of the industrial product. We follow the alterations through which disciplinary practices and software application become part of a common cross-disciplinary "frame of reference."

The *first order codes* express the agreement around a list of PLM capabilities that mediate the relationships between discipline *specific* practices and modelling software applications. At this stage, we capture the more or less consistent fit – or overlap - between the industrial company "demand" and the software vendor "offer."

The *second order codes* express different ways through which PLM mediations compose and stabilize *equivalences* amongst the heterogeneous and discontinuous discipline specific entities. We capture this movement by

[27] Including ICT Applications used for business process description (existing and target situation); organisational standards management (ex. ISO/IEC 15288:2008 on System life cycle processes); with (1) interfaces to Project management tools determining Load & lead time estimates and (2) interfaces to a "WBS" defining engineering tasks duration schedules and assignments. Moreover, the standard ISO/IEC TR 24748-1 (2010) defines six generic lifecycle stages and describes their purposes and decision gates criteria: Concept, Development, Production, Utilisation, Support and Retirement.

formalising "trails of connections" between on one hand, discipline specific entities (human and non-human) and on the other hand the account of the product lifecycle. Second order codes express how PLM mediations *add something* to the chain of cross-disciplinary interactions and perform the *condition of being equivalent* across disciplinary boundaries (Latour 1996) (Sayes 2014). By capturing the movement towards a cross-disciplinary level, we aim at elucidating the new *frame of reference* that accomplishes associations between disciplinary engineering practices and software applications. Our investigation tries to trace how the new frame of reference conveyed by the PLM platform compose an account of the emerging industrial product.

At the third step of the coding process, we reassemble the data in order to formalise the *consequences* of the movement generated by PLM mediations going from disciplinary to cross-disciplinary levels. We seek at this stage to capture the role played by PLM capabilities in *modifying* the morphology of relationships between disciplines as they become henceforth *inscribed* in a shared, lengthier, and more encompassing *frame of reference*. We also follow how this expanded frame of reference redistributes and reallocate the *"messy discontinuities"* (Law 2003) of the public, visible, commensurable *account* of the emerging industrial product and associated maintenance services.

3.2.1. Categorical aggregation is deployed through four sequences

As we will show in more details in the following chapters, both case studies give access to multiple data sources expressing the chronology of events encountered during the PLM blueprinting process – and, as (Yin 2009) recommends, we are therefore able to engage in:

- the *"categorical aggregation"* through which we identify observable instances of ordering to support our claim about the role of PLM in performing the *condition of being equivalent* across various disciplinary contexts;

- the *"cross-case analysis"* pointing out to patterns expressing persistent forms of "trails of connections" between engineering practices and material software applications.

We approach the data coding process through four sequences that correspond to different *forms of categorical aggregation* expressing *issue relevant meanings* about the interplay between the disciplinary entities (practices and software applications) and cross-disciplinary account of the emerging product (Yin 2009; Creswell 2007; Miles,M.B. & Huberman 1994).

Sequence # 1/ Quotes about PLM platform functional requirements

The first sequence consists in reading and selecting segments of the written documentation about *functional attributes* of the PLM platform expressing cross-disciplinary dimensions.

The coding sequence captures and isolates chunks of text and discourses in formalised *quotes* - *"a word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/ or evocative attribute for a portion of language-based or visual data"* (Saldana 2009).

At this stage, we focus on the formal, canonical *demand* for a PLM platform as it is voiced by the industrial company – the empirical material is mainly composed by the functional requirements stated in the *Request for Quotation* complemented by oral communication with subject matter experts during the interviews.

Particular attention is given to three types of Use cases of the PLM platform related to boundary spanning capabilities defining *"what information needs to be known/shared"*:

- Use cases about the interoperability of modelling software applications (common data model);
- Use cases about the traceability of engineering practices as described in "Change and Configuration management processes";
- Use cases about "Validation & Verification" processes throughout the product lifecycle.

Codes record alterations of *"what information needs to be known/shared"* by including and/or excluding functional capabilities – for example, a workflow *includes* the automation of routing capabilities through which a CAD model is sent to engineers for validation. Concurrently, the workflow, *excludes* human tasks that first, define a list of relevant roles and second, send the document for review of the CAD model.

Sequence # 2/ Quotes about scenarios of use

The second sequence consists in reading and selecting segments of the written memos about the way the scenarios of use *attach* discipline specific practices to the cross-disciplinary account of the emerging product. We look for evidence about the way PLM mediations move practices to cross-boundary processes and create consistent scenarios of use that transcend disciplinary practices.

Quotes formalise insights about the role played by the *offer* side - conveyed by the way *anticipations of the future use* of the PLM platform reveal modifications of current disciplinary practices.

More precisely, *quotes* trace all discursive and non-discursive resources that reveal how scenarios of use move disciplinary entities to cross-disciplinary level. The movement is expressed by:

- *evocative attributes* about the scenarios of use inscribing disciplinary practices in cross-disciplinary PLM platform;
- transformation of the *perimeter* of disciplinary modelling practices by inscribing them in cross-disciplinary PLM platform;
- extension of the *chain of interactions or associations* across discipline boundaries;
- delegation of cross-disciplinary "verification and validation" tasks to the PLM platform.

Sequence # 3/ Memos about what holds disciplinary practices and software applications together

We adopt an inductive analysis to study the blueprinting process. Strictly speaking, we don't analyse the actual *use* of technology but the way a *user is* *inscribed* in the socio-technical assemblage – we study *“the action of making rather than the process that made it”* (Cordella 2010:47).

To operationalise the inductive approach of the blueprinting *“in action”,* we mobilise the notion of *“trail of connections”* (Nicolini 2009) to trace what holds cross-disciplinary practices and material objects together.[28] Particular attention is given to what composes traceability and calculability across discontinuous, disciplinary practices and software applications. Drawing on Actor Network Theory, we look for cross-disciplinary *mediators* [29] (particularly taxonomies, use case narratives and modelling software applications) that express modifications in the *morphology of relations* and reconfigures the way responsibility is (re)assigned across disciplinary boundaries.

The third sequence consists in abstracting what was captured through first order codes, and establishing *Second order codes* capturing the *“trails of connection.”*

We bring to light the two complementary types of trails of connections exerted by PLM mediations: the ones that *compose enabling capabilities* (assembling what information is to be known/shared) and the ones that *perform the account of the industrial product* (mediations that act as a “knower”).

So s*econd order codes* capture:

- *Trails of connections revealing enabling PLM mediations:*
    - How technical software applications reconfigure the role of engineers and their *capacity to act* across disciplinary boundaries?

[28] According to Nicolini, (2009:392*) “a coherent practice approach needs also to address how translocal phenomena come into being and persist in time as effects of the mutual relationships between the local real-time accomplishments of practices as well as how they make a difference in the local process of organizing”*

[29] We trace how meaning is transformed when transported by *mediators.* As presented in the previous chapter, Latour (2005, 39) states that *“Mediators transform, translate, distort and modify the meaning of the elements they are supposed to carry”.*

- How PLM mediations contribute to the practical efficacy of "models"?
    - *efficacy of models of the industrial product:* how functional attributes of the PLM platform *abstract* local, discipline specific – and potentially conflicting - accounts of the product and inscribe them in a cross-disciplinary representation of the product lifecycle;
    - *efficacy of modelling practices:* how scenarios of use link together heterogeneous modelling practices; how models helps engineers to elucidate requirements specifications and evaluate alternate product concepts, investigate functional performances (modelling the required behaviour of the product), calculate the feasibility and reliability of the future product (simulating the operation of the product over time), verify and validate if and how, the industrial product and its associated services meet initial requirements and specifications. calculate the feasibility and reliability of the future product (simulating the operation of the product over time), verify and validate if, and how, the industrial product and its associated services meet initial requirements and specifications;
    - *efficacy of validity of the cross-disciplinary accounts:* how validation of the accounts about the industrial products are delegated to the PLM platform.
    - *efficacy of the* scaling-up process moving local agency to a cross-disciplinary level.[30]

- *Trails of connections revealing performative PLM mediations:*
    - How PLM mediations become "mediators" (Latour 2005) through situated sequences reallocating distributed agencies;
    - What is the role played by the multi-tier client-server architecture in reallocating agency towards the cross-disciplinary level?

[30] In this sense, trails of connections express the emergence of "mediators" (Latour 2005) that *expand* and *stabilize* the Actor-Network.

Sequence # 4/ Diagramming how the novel "frame of reference" is made durable

The fourth sequence captures how the industrial company and a software vendor try to reach a compromise between existing capabilities in the software package and specific business or process related requirements. Analytic memos obtained by semantically linking quotations - mainly from the *Proof of Concept* phase - capture the assemblage of technical and organisational stakes leading to the narrative about the cross-disciplinary "product lifecycle"

By defining more synthetic graphical representation – formalised "trails of connections" (Nicolini 2009) – we describe the links between:

- *material software applications:* PLM mediations that move disciplinary practices to a cross-disciplinary organisational context through the enactment of cross-disciplinary account about the industrial product.
- *engineering practices*: the inscription of scenarios of use in a *frame of reference* tracing mediations accounting for the industrial products across organisational boundaries;
- *controversies* about the assignment of responsibilities about improvement opportunities of the product development processes and potential benefits (quantitative and qualitative).

- An important part, of this fourth sequence consists in tracing empirical evidence about the inscription of disciplinary practices in the client-server architecture – this inscription is a key dimension of how disciplinary practices are on one hand, associated and inscribed into software applications to form an emerging account about the "product/service lifecycle" and on the other hand, modify, enact and transform the accountability structure.

The figure below summarises the data collection and coding approach capturing the way the PLM platform mediates the relationship between disciplinary entities and the cross-disciplinary account of the industrial product.

Data collection	Data coding (categorical aggregation)		
Blueprint of PLM platform	**First order codes**	**Second order codes**	**Consequences**
Demand • "Request-for- quotation" (list of functional requirements & Use cases) **Offer** • "Scenarios of use" of the PLM platform **Mock-up** • Offer meets Demand (Enactment of PLM functionalities)	• List of functional attributes of the PLM platform that mediate the relationships between heterogeneous discipline specific entities	• Composition of "trails of connections" expressing the inscription of disciplinary entities in a common cross-disciplinary "frame of reference"	• Distributed and heterogeneous mediating agencies (practices & software applications) become part of a cross-disciplinary account of the "product lifecycle"
	• Capability A	• Mediation "A" moves disciplinary entities to …	• Composition of new forms of equivalences between disciplinary entities • Changes in the morphology of relationships
	• Capability B	• Mediation B attaches disciplinary entities to …	
	• Capability … N	• Mediation … N acts …	

Table n° 8
Data coding structure

3.3. Data analysis

The coded empirical data formalised evidence about how PLM mediations play an active role in moving local, discipline specific entities to a cross-disciplinary level. The movement leading to alterations, adjustments and formalisations of "trails of connections," reveals the emergence of the *new forms of equivalences* across disciplinary boundaries: heterogeneous practices, software applications and roles & responsibilities can be measured, calculated and accounted for, through their inscription in a cross-disciplinary *frame of reference*.

Data analysis attempts to describe the *organisational consequences* of PLM mediations as they on one hand, establish new *forms of equivalences,* and on the other hand, generate changes in the *morphology of relationships* between disciplinary entities.

3.3.1. Understanding how new forms of equivalences are established

First, we analyse the *consequences* generated by the introduction of cross-disciplinary modelling capabilities leading to commensurable equivalences about what needs to be known/shared across local disciplinary contexts.

Commensurable equivalences generate collective capabilities that establish links between heterogeneous/ discontinuous "documents" (Requirements, Models, Builds, Tests and Certification), forming a "generic" hierarchical referential enabling the composition of a cross-disciplinary data model.

Second, we analyse the *consequences* generated by the introduction of PLM mediations that establish calculable equivalences and define *where and when information sharing takes place*. Calculable equivalences enable a more accurate traceability of the recurring *changes* in product specifications, from early requirements gathering phases down to service support at the final customer site. Questioning at this stage concerns mainly changes in the level of granularity of accounts and the synchronisation of the various *"local"* (disciplinary or project specific) development cycles.

Third, we analyse the *consequences* generated by the modification of Product validation & verification processes, and how the PLM mediations impact the reliability of reporting practices. Questioning concerns how PLM mediations establish *equivalences* between roles & responsibilities across discipline boundaries and transform therefore, accountability patterns as they become visible/observable across disciplinary boundaries.

By bringing empirical evidence about these three forms of equivalences we will be able to better understand the consequences of the emergence of a *"socio-technical agencement*" (Callon 2008) that, on one hand, brings discipline specific practices and software applications together, and on the other hand, composes a cross-disciplinary "knower."

3.3.1. Understanding what changes the morphology of relationships

Building on ANT's heuristic model presented above, we present hereafter the methodological framework used to analyse the empirical evidence on how the negotiation over the blueprint of the PLM platform leads to a new *frame of reference* that alters the collective capabilities to frame, enact and scale-up the *accounts* about the emerging industrial product. We trace controversies through which the heterogeneous associations through which many different attributes of the account are *"inscribed into many contradictory scripts"* (Latour 2011) [31] – we follow how, this *"circulation of scripts"* shapes and is shaped during the blueprinting process – we focus our attention on how PLM mediations *move* disciplinary engineering practices and specialised software applications to the cross-disciplinary level.

By focusing on *controversies* about the relationship between the engineering practices and the associated modelling software applications, we look to avoid two current problems that characterize studies of the role of ICT in organising concurrent engineering.

First we seek to avoid reducing the relationship to *causal* determination between what happens in people's mind and knowledge transfer across disciplinary boundaries.

Secondly, we do not reduce this relationship to the notion of *influence* – frequently adopted by the constructivist understanding of ANT.[32]

To avoid these difficulties, we propose to mobilise the concept of *"inscriptions"* (Akrich 1992) - a concept that has been extensively used to study the *performative* component of ICT. This is well summarized by Monteiro (2000) *"By inscribing programs of actions into a piece of technology, the technology becomes an actor imposing its inscribed program of action on its users."* - see also (Ciborra et al. 2000; Hanseth & Monteiro 1997; Cordella 2006). We consider that the "*inscription*" of practices in

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[31] *"Organisational scripts circulate through a set of actors that are either attributed some tasks or are in a momentary state of crisis to re-instruct the scripts with new instructions for themselves or for others"* Latour (2011: 9).

[32] See for example, the analysis of "instrumented routines" supporting managerial decisions by D'Adderio (2003).

"socio-technical assemblages," is more than a variable *influencing* the regularity of practices (routinisation). We consider instead that there is no direct *causal* determination as mediations entail two complementary aspects: enabling and performative.

ICT mediations *enable* the composition of a novel *frame of reference* enacting discontinuities between entities that give the cross-disciplinary "frame of reference" its overall coherence. Moreover, ICT mediations *perform* a movement that makes human and non-human entities *"do things"* (Latour, 2005) and form the ontology of the cross-disciplinary "knower" establishing equivalences across discipline boundaries (Law & Singleton 2000). Our analysis of *"inscriptions"* brings forward the interplay between ICT's *enabling* role and ICT's *performing* role.

3.3.1. Understanding the consequences of PLM mediations

We now have all the elements to better understand our use of the notion of "trails of connections" between engineering practices and material software applications. However, we still need to explain how the qualitative approach may contribute to an in depth understanding of both PLM enabling and performative roles. To do so, we propose to trace/follow the transformation of the morphology of relationships that configures the novel *frame of reference* and defines *what* information needs to be known/shared, *when and where* information sharing takes place, and *who is responsible* for the account of the industrial product.

We propose therefore to analyse how our empirical data sets account for two movements.

The first movement consists in *"zooming-in"* (Nicolini 2009) [33]on the details of how PLM mediations:

- establish *equivalences* between heterogeneous software applications, modifying relationships between disciplinary practices;
- render heterogeneous things the "same" (*commensurable*) – to account for the industrial products across organisational boundaries;
- render things *distinct/discontinuous* enough to allow discrete economic calculations and transactions;
- The second movement consists in *"zooming-out"* (Nicolini 2009) on to how PLM mediations:
- redistribute *agency* by allocating accountability from local, disciplinary contexts to cross-disciplinary level;
- extend the enactment of the "product/service lifecycle" across disciplinary boundaries);
- synchronize cross-disciplinary *traceable* "verification & validation" practices (PLM platform enacts "lateral" organizational accountability);
- change the *scope and the scale* of accountability practices by enforcing predictable relationships.

3.3.1. Position of the enquirer and strategies to control for bias

Data collection process is accomplished within our professional role as a consultant working for a PLM software vendor. When collecting the empirical data, we have adopted a participant observation stance. The approach builds on the ethnomethodological recommendations (Heritage 1984), that were subsequently developed and operationalised by Actor Network theory. The resulting inductive elicitation process describes the public, visible categories accomplished by "members" – in our case,

[33] Building on Actor Network Theory, Nicolini (2009;1394) affirms that social agency *"is constituted through assembling, aligning and stabilising patterns of relationships so that any form of social order is in fact the outcome of observable instances of ordering."*

engineers qualifying IT systems supporting boundary spanning *accounts of the industrial products across organisational boundaries*.

The researcher must develop a *"vernacular competence"* to identify what makes the connections between human and non-human entities and follow where they lead.

Our aim is to extract from the observed "vernacular categories" about "offer", "demand" and "infrastructuring", the empirical evidence revealing various forms of inscription of engineering practices in the PLM platform leading to new mediations accounting for the industrial products across disciplinary boundaries.

We have had an active role in the blueprinting process as a "prescriber" of the software platform. Our role is positioned within the pre-sales team of the software vendor. This team is in charge of building an engagement model that may last for many months encompassing various pre-sales activities – such as, capturing the current processes and executing root-cause assessments, qualifying the potential value generated by the adoption of the proposed PLM platform (business case), supporting presentations of the prototype ("proof-of-concept") of the future software platform, and establishing a roadmap for the future implementation.

Empirical data is identified reflexively from the work that we *accomplish* and *observe* and also through interviews and workshops with managers and subject matter experts. As we have had an active role in the blueprinting process, our *"vernacular competence"* enables us to access the practices of engineers and map relationships between the "offer" (the *novel* collective capabilities introduced by PLM capabilities) and the "demand" (requirements formalising the need to change *existing* knowing practices across engineering disciplines).

However, our role in the blueprinting process may also create potential bias with regard to the detached neutrality of the academic posture.

This is why we have adopted the recommendations stated by (Yin 2009: 79) to deploy the following strategies to secure the validity of qualitative data collection and analysis.

1/ *Intensive long-term field involvement:* working for a software vendor opens direct access to first hand data and enables the acquisition of the *vernacular competence* through a practice driven learning process. We benefited from full immersion throughout the PLM blueprinting phase to understand how the "demand" for a PLM platform was formulated initially and how it evolved throughout the negotiations between industrial companies and the software vendor. There are however also limitations to the data collection process generated by the model of our field involvement. Limitations are generated by the fact that for confidentiality reasons, interviews cannot be recorded. A first level of validity of the information collected through interviews is obtained by requesting interviewees to validate transcriptions based on detailed personal notes - the latter are validated through subsequent email exchanges with interviewees.

2/ *Use of several data formats with varied data sources:* we had access to three main data sources: first, we started by primary document analysis. We then carried out interviews and workshops with managers and subject-matter-experts from main departments (Engineering, Marketing, IT, Services, etc.). We were able therefore to trace and elucidate inconsistencies between informal statements about the PLM requirements and the more formal documentation conveying the "official demand" - in particular, the "Request-For-Quotation" (RFQ) issued by the industrial companies.

3/ *Iterative feedback from the people studied to lessen the misinterpretation of their self-reported views.* We have proceeded to the comparison of the "official demand" with regard to actual, contextualised "offer". As we were in charge of managing a team of vendor consultants and developers in charge of the prototype, we were able to confront the "official demand" (RFQ, marketing and technical document, standards related documents) with the more informal controversies observed during the workshops aimed at assessing the *functional coverage* provided by the PLM mock-up. We were also able to observe the final steps of the negotiations leading to the final validation workshops where formal links are established between the "target functional coverage of the required use cases" (the expressed "demand") and the PLM "proof-of-concept" (the proposed "offer").

<table>
<tr><th colspan="4">SUMMARY of Research design Chapter</th></tr>
<tr><td rowspan="2">Data Collection</td><td colspan="3">• Collect documentation and realise interviews/workshops to establish a list of functional attributes of the future PLM platform</td></tr>
<tr><td>“Demand”
• “Request-for- quotation” (list of functional requirements)</td><td>“Offer”
• “Scenarios of use” of the PLM platform</td><td>“Mock-up”
• “Demand” meets “offer” through a Mock-up of the PLM platform</td></tr>
<tr><td rowspan="2">Data Coding</td><td colspan="3">• Coding describe “Trails of connections”
• Steps leading to the composition of a cross-disciplinary “frame of reference” to collectively account for an emerging industrial product across boundaries</td></tr>
<tr><td>• We capture “Trails of connection” expressing mediations between disciplinary practices and software applications through three questions =></td><td colspan="2">• What information needs to be shared?
• When and where information sharing takes place?
• How are Accountability patterns defined?</td></tr>
<tr><td>Data Analysis</td><td colspan="3">• Analysis points to consequences generated by the novel frame of reference
• Commensurability, calculability and visibility of the account about the emerging product
• PLM platforms compose an account of the product lifecycle
• that includes both components (persistency and transiency) of concurrent engineering relationships</td></tr>
</table>

Table n° 9
Research design

CHAPTER 4 / CASE STUDY # 1 - ACCOUNTING FOR *"PRODUCT RELEASE READINESS"*

The presentation of the case study is structured as follows.

First, we present the circumstances that lead to the Request-For-Quotation of a PLM platform.

Second, we present how the industrial firm expresses its requirements with regard to the functional attributes of the PLM platform (eight functional domains that constitute the *Demand*) in relation to *scenarios of use* introduced by the vendor's proposal (the *Offer*).

Third, we describe how in the course of the blueprinting process, the industrial firm and the software vendor address the eight corresponding Use Cases leading to the generation of novel *equivalences* between discipline specific entities – these equivalences are accounted for through four *trails of connections*.

We review in conclusion, our three Research Propositions in relation to the empirical evidence revealing how PLM mediations perform a transformation of the way concurrent engineering agencies account for the industrial products across organisational boundaries.

4.1. The context of the PLM blueprinting process

The case study concerns the role played by PLM mediations in accounting for evolving industrial products within a complex industrial setting – the development of a Combat Management System (CMS) for naval vessels.[34]

An industrial company - referred hereafter as CMS-Co [35] - faces typical challenges encountered by firms developing innovation intensive products requiring new forms of concurrent engineering processes. Current digital modelling applications are not able to address the indispensable assemblage of distributed, discontinuous practices across discipline boundaries.

The PLM initiative is part of a wider Systems Engineering initiative that attempts to address on one hand the implementation of a methodological framework to improve concurrent engineering,[36] and on the other hand the novel PLM platform. CMS-Co puts forward three main types of product development challenges to justify the launching of the blueprinting initiative.

First, CMS-Co states the necessity to better ensure that customer needs are met in a timely manner. Profitability in the Defence sector is driven by *"Time to CMS Certification*." As drifts in schedules are very penalizing, CMS-Co seeks to enhance the reliability of the information about the *"auditable product time-to-market"*. This means that it is crucial to have accurate visibility of the predictable time needed to deliver the "*auditable*" CMS product features - including traceable compliance of CMS characteristics with regard to customer requirements and DoD related standards. In this context, the capacity to better assess *"Product Release Readiness"* is key.

[34] The company faces typical challenges of discrete manufacturing sectors in search of more modular product architecture that can enable: increased design commonality, increased product variants, distributed development, protected core competencies, long and complex outsourcing processes (see previous chapter above).

[35] For confidentiality constraints, actual name of the firm is omitted. CMS-Co is an industrial company that provides advanced technology for naval defence sector with a large portfolio of worldwide customers.

[36] ISO/IEC 15288 formalises a standard definition of the "system lifecycle processes" and describes the requirements to stabilise relationships between Enterprise processes, Project processes and Technical processes.

However, this is not possible because customer requirements, systems models, design and test cases are captured and managed in many non-interoperable formats and heterogeneous software applications. Errors are frequently found late in the lifecycle when they are most penalising and costly to repair. So the first, justification for improving cross-disciplinary collaboration is the collective capacity to provide auditable visibility into product release readiness.

Second, CMS-Co states the need to adapt to a constrained Defence market resulting from the reduction of national DoD demand. This leads CMS-Co to engage in the international shipbuilding market where competition is fierce. Hence the need to address topics such cost reduction, schedule over-runs and, above all, product development productivity. The PLM platform project is part of an overall initiative aimed at improving the efficiency of internal product development processes. The second justification for improving cross-disciplinary collaboration is the need to provide a holistic view of product performance throughout its lifecycle that can contribute to reduce indirect expenses (primarily labour and other indirect costs). At present this is not possible because there is no reliable assessment of the impact of the (lack of) cross-disciplinary collective capabilities on the overall product development performance.[37]

Third, CMS-Co emphasises the need to move from the current "engineering-to-order" model – where CMS systems are unique, highly customised products equipping warfare systems – to a "Product Line" model based on more modular, reusable product architectures. Current engineering practices characterised by complex cross-disciplinary collaboration patterns cannot enforce a standard-based, *top-down* process supporting product line engineering. This blocks attempts to reduce product development costs and avoid development rework. The PLM platform is designed for building the collective capacity to enable and formally track the re-use of modular technological solutions across sub-projects. The third justification for improving cross-disciplinary collaboration is the need to enhance visibility to

[37] A Capability Maturity Model Integration (CMMI) certification initiative was ongoing during the data collection campaign.

part commonality and data reuse – and ultimately, support the shift towards *Concurrent engineering* aimed at shortening product development cycles.

4.1.1. Components of the "Request for Proposal" (the demand)

The blueprinting process is primarily structured by a *Request for Quotation* (RFQ) addressed to software vendors in the "Product Lifecycle Management" domain. The RFQ is the starting point of a process characterized by a negotiation to determine how a software package could address the concurrent engineering challenges described above.

The RFQ is structured around the search for a *"single source of truth"* supported by a centralised repository (relational database) aiming to support Systems Engineering *"document management processes using a federating tool"* to improve collaboration across *"organisational silos"* (RFQ, internal document).

CMS-Co. teams must cope with diverse, specialised, and context dependent representations of the CMS product. So CMS-Co seeks to define a common referential (*"single source of truth"*) to increase efficiency of the representation of the new industrial products across Mechanic, Electric & Electronic and Software related disciplines.

The actual definition of future the *"federating tools"* is expressed through an addition of functional and non-functional requirements.

The blueprinting of *"a federating PLM tool"* is meant to improve the collective capabilities to manage the connectivity and the interactions between the main discipline specific software applications:

- First, applications conveying *free text documents containing contractual requirements* (for example, MSWord, spreadsheets or rich text format files). Rich text format is the most common *notation* used in contractual documents and certification procedures imposed by procurement departments from final customers (DoD, government agencies, etc.). They are most frequently low structured documents (statements of work, compliance documents, standards, etc.). These documents are managed in structured applications [38] used for requirements management. They manage "files" supporting the various steps of the "waterfall model" and describe the relationships between CMS-Co customer requirements (rich text account of the product requirements) and the functional architecture models (models accounting for the product functional performances).

- Secondly, applications used for *modelling languages expressing functional behaviour of the components of the systems* (for example, UML, SysML). This type of modelling notation is used to establish the required *interfaces* between sub-systems (communication ports & communication protocols). The outcome of this representation is a "validated design pattern" that can be used across Hardware and Software disciplines.

- Third, spreadsheets used to generate traceability *matrices* showing where and how requirements are satisfied, identify orphaned requirements and define custom traceability *links* for relationships specific to CMS-Co. business process. The outcome of this representation is the collective capacity to establish formal cross-disciplinary traceability between customer needs, market requirements and their associated technical specifications and designs, including all testing information (planning, execution, defects tracking, alerting on changes).

- Fourth, applications used for parametric *Computer Aided Design* (CAD) modelling. These applications are employed to design mechanical, electrical and software components within the complex overall CMS product assembly. Computer Aided Design modelling consists in: first, capturing all geometry for mechanical and electrical

[38] Mainly Doors and Rhapsody that are dominant solutions in the Defence sector.

components; Secondly, designing and reviewing in context the entire assembly through parametric visualization capabilities. Third, validating the geometry of the entire assembly against functional mechanical requirements. The outcome of 3D virtual prototyping is the capacity to work within one specialized discipline on the creation of sophisticated geometry and effectively share the prototypes of large assemblies through "multi-discipline design viewables". These 3D viewable devices enable the synchronization of specialized ECAD and MCAD domains.

The table below summarises the organisational scope and diversity of disciplinary applications involved in the blueprinting process analysed in the case study.

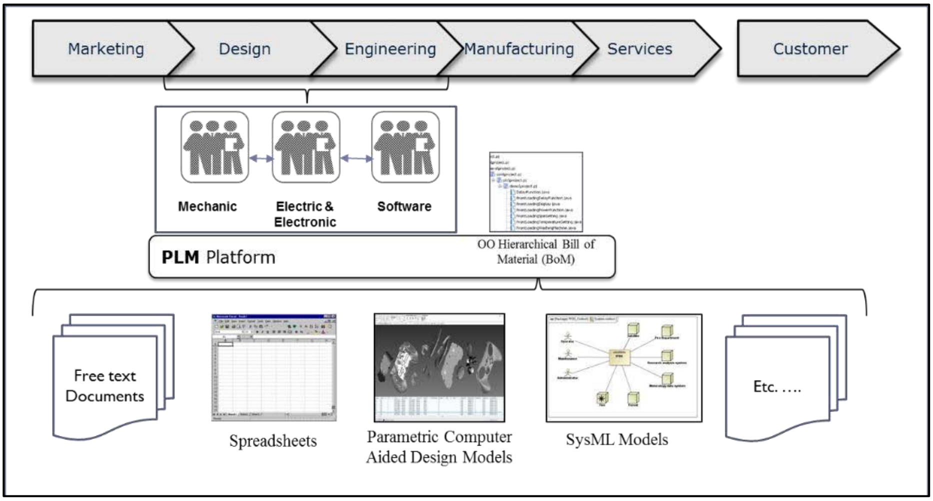

Fig. n° 6
Diversity of disciplinary software applications

This diversity of ways to define the future industrial product prevents engineers from continuously *evaluating* the integrity of the representation of the emergent product. Current organisational challenges jeopardise efforts to present *auditable accounts* of the CMS systems and sub-systems against customer requirements throughout the product lifecycle.

We present hereafter, how the PLM platform creates *equivalences* across the relatively diverse, specialised and context dependent *accounts* of the CMS product development process.

4.1.2. When "offer" meets "demand"

At first glance, the "demand" is driven by a pragmatic but rather poor narrative about the *replacement* of various software applications disseminated across disciplines. A COTS/standard PLM platform should integrate, and partly replace, the legacy software applications processing both technical data (requirements specifications, functional modelling, logical and physical simulation, design and testing) and business related data (particularly "time to market" related data).

The PLM platform mobilising *Object-Oriented models* is designed around a hierarchical Bill of Materials (BoM). BoMs are modelling schemes used to classify large product configuration in distributed environments. The Bill of Materials is based on hierarchical tree notation describing the physical product structure characterizing the "Parts" used during the Design and Manufacturing phases. The taxonomy supports version control, workspace management, parallel development support, and build auditing. For example, the assembly including components developed by different disciplines sharing a same BoM can be traced (Version control) validated (Defect tracking) and verified (Build auditing).

The dialogue about the operational aspects of the replacement/integration of existing software applications is structured around use cases describing scenarios of use of the PLM platform. Use cases are a way to organise the encounter between the functional requirements (the demand) and the proposed scenarios of use of the PLM platform (the offer).

We have mentioned above that negotiations consist in identifying, reformulating and organizing demonstrations of the PLM mock-up. The actual operationalisation of the blueprinting process is based on the creation of a mock-up of the future PLM platform – the “Proof-of-Concept” (PoC). The PoC enacts the correlation between a set of *functional attributes* (the “Demand” presented by CMS-Co) and *scenarios of use* of the future PLM platform (the “Offer” provided by the software provider).

The vendor proposes to address the seven domains defining the functional requirements through scenarios of use as described in the following table: [39]

The *demand* expressed by the CMS-Co	**The *offer* proposed by the software vendor**
Use cases concern:	Scenarios of use focus on:
1/ Product Architecture 2/ Systems and Solutions 3/ Pre-industrialization	Customer requirements management Scenarios of use focus on authoring and managing customer requirements, modelling well written, well understood, consistently covered inbound requests, and ensuring consistency checking and traceable gap analysis.
4/ Detailed design	Multi-CAD data management Scenarios of use focus on ways to manage CAD data (MCAD, ECAD) in a single integrated way; accessing, reusing & synchronising design data across specialised CAD systems (piping, HVAC, etc.).
5/ Configuration management	Change & Configuration Management Scenarios of use focus on defining computational links between containers to better manage and control modifications of individual requirement definitions and specification approval throughout the product lifecycle; ensuring persistency of the links between heterogeneous information accounting for “product release readiness”

[39] See Annex 3 for detailed description of scenarios of use of the PLM platform.

	throughout the product lifecycle; automating rapid and accurate communication about changes in "product release readiness" – regardless of complexity; generating rules for each option and variant of the CMS product based on selected options.
	Complete BOM management Scenarios of use focus on combining ECAD, MCAD and software domains in a single product structure; continually developing the mBOM and eBOM in the design phase.
	Workflows Scenarios of use focus on versioning, branching, sharing information about customer requirements; graphically defining and managing product development processes; providing links to tests of requirements describing verification methods at each level of decomposition in the system design; Providing systematic means to ensure requirements have been met by the design).
6/ Re-use policies	Document management Scenarios of use focus on managing document structures and inheriting complex relationships; enabling tasks such as search, retrieve and update data into and from central repository; tracking data changes and audit trails.
7/ Extended enterprise collaboration	Distributed collaboration Scenarios of use focus on managing access rights; controversies concern the capacity to contain disruptive effects of growing "agile" product development practices; Main scenarios describe ways to control "product release readiness" - particularly within disciplines in charge of software development; ensuring compliance with approval processes.

	Visualisation Scenarios of use focus on viewing capabilities to access CMS product data (CAD, ECAD, PDF, etc.) without the authoring tool; conducting real time collaboration, analysis and simulation regardless of location.

Demonstrations of the PLM platform are realised with *"archetypal data sets"* provided by CMS-Co, so as to take into account the particular organisational environment and specific business processes of the Defence sector.

4.2. Trails of connections reveal how PLM mediations compose a new "frame of reference"

We describe in the subsequent sections how - through four trails of connections between disciplinary practices and software applications - both teams from CMS-Co and the PLM vendor reach an agreement about how a novel *frame of reference* could consistently account for the emergent CMS product.

We will then be able to review our three propositions about how the PLM blueprinting negotiations transform the morphology of relationships across disciplinary boundaries.

The figure below outlines the approach articulating the four trails of connections (composing equivalences between disciplinary practices and software applications) and our research question about *the composition of common, cross-disciplinary PLM mediations accounting for an industrial product* across organisational boundaries.

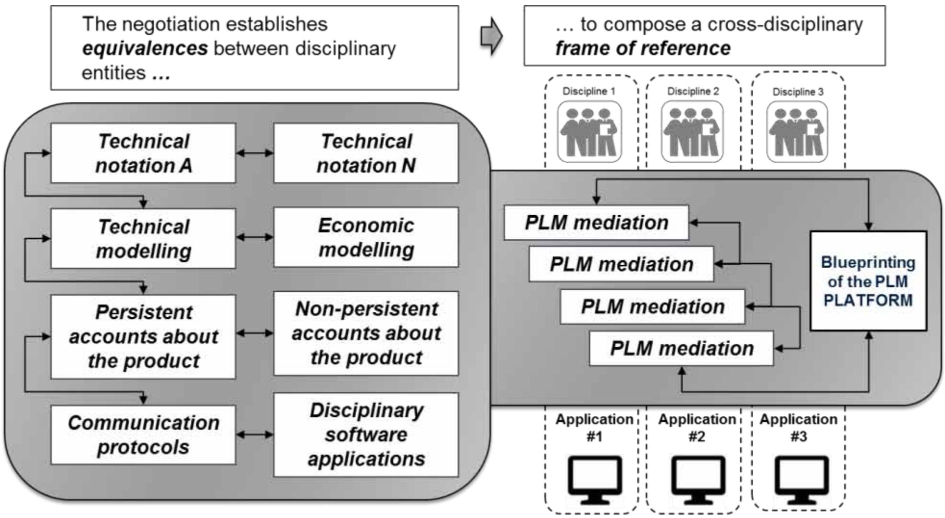

Fig. n° 7
Composing the morphology of Cross-disciplinary relationships

4.3. TRAIL # 1 / Producing equivalences across taxonomies of product attributes

The first trail of connections concerns the diversity of *taxonomies* through which CMS-Co teams represent the relationships between customer needs and the (future) CMS product attributes. Challenges emerge as information about the product attributes is represented through a variety of *notations* such as, *textual notation* describing the product requirements (e.g. usually compiled in spreadsheets), *logical notation* describing the performance of the a product (high level UML or SysML based representations), *logical notation* describing the physical attributes of the a product (e.g. descriptions of the product assemblies in Bill-of-Materials), *three-dimensional notations* describing the parametric characteristics of the product design (e.g. CAD – computer-aided design models used to build Digital mock-ups).

We observed that this creates problems to ensure on one hand, that customer needs are met by the envisioned technical solution and on the other hand, that the required CMS product features can be accurately and predictably measured.

4.3.1. The need to establish relationships between heterogeneous notations

At the initial steps of the PLM blueprinting process, the vendor team proposes an approach to model the connections between these heterogeneous *notations* used to define the CMS product features and attributes. A logical data model is defined to form a simplified and logical mapping of all specialised applications supporting the CMS representation throughout the various steps of the development process.

Relationships between applications are modelled through Object-Oriented Programming (OOP) connecting “objects” that “encapsulate” the heterogeneous attributes of the CMS product description.[40] The numerous documents describing the CMS attributes may therefore be represented through interoperable “objects”. For example, the object “Item type” assembles a series of *attributes* describing the *design intent* (such as description, classification, etc.), the associated *data elements* (standards), *management related information* (such as assigned user, state, completion dates) and also the *relationships* to other software applications (such as test workbenches where validation will be realised).

An *Item type* has its own workflow which describes how it moves from state to state. State transition rules, conditions and permissions are defined by a cross-disciplinary administrator and enforced by the PLM system. State transition history is displayed to all relevant discipline specific roles. Transition rules can require notifications and approvals name, number, description, category, state, authored by, hierarchical editability, root document, creation data and, revision date. An “Item type” can also be

[40] An “object” is a “particular instance of a class where the object can be a combination of variables, functions, and data structures”. (http://en.wikipedia.org/wiki/Object_%28computer_science%29)

associated to *attachments* (e.g. quality related documents) and to an organisational *context* (e.g. project, program).

4.3.2. Formalising equivalences between abstracted product attributes

The data model creates links between abstracted product attributes. “Links” are separate objects apart from the files that are connected. As we mentioned, links can be computed through automated algorithmic sequences of instructions structuring the interdependencies between discipline specific engineering practices.

These logical associations between attributes can be “computed”. The links between logical “objects” perform *syntactic* [41] equivalences between specialised disciplinary software applications. For example, according to the proposed scenario of use of the PLM platform, an engineer can automatically compute that

- a certain <u>CMS Requirement</u> is *“Validated by…”* a <u>Test case</u> occurring downstream;
- the data model formalises a number of step-by-step procedures that are typically executed at disciplinary level.

Henceforth, these procedures accomplished daily at discipline level, are encapsulated at cross-discipline level by the instruction:

- *<u>the CMS product requirement ‘x’</u>*
    - is *“<u>satisfied by</u>…”* a particular *<u>Part structure ‘y’</u>*
    - and this association is *“<u>validated by</u>…”*
    - the *“<u>management role ‘z’</u>”*.

[41] Syntactic equivalences establish a common rules and structural patterns for sharing and assessing knowledge at disciplinary boundaries (Carlile 2004).

The figure below is an example of formalisation used to describe this scenario of use during the blueprinting process. It represents the data model that forms equivalences between attributes of the CMS product represented here as *containers* (logical objects). The data model abstracts the actual content described by the various non-interoperable disciplinary *notations.* It enables consequently, a first level of mediation between discipline specific *content*.

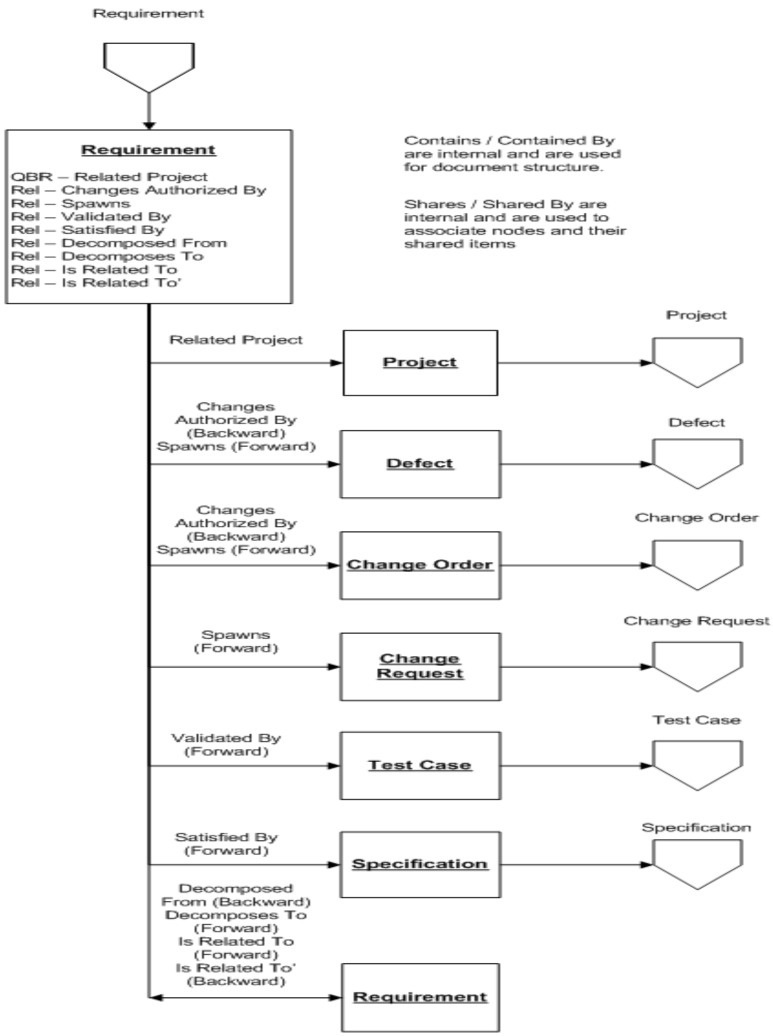

Figure n° 8 /Example of formalisation of the data model structuring scenarios of use

4.3.3. PLM mediations organise the logical commensurability across engineering practices

The definition of syntactic equivalences constitutes a first step of the abstracting process that progressively defines *what needs to be known/shared* across disciplines. By modelling (logical) *links* between heterogeneous notations (text, SysML, CAD, etc.), the data model strengthens the *trail of connections* between discipline taxonomies at cross-discipline level.

In other words, the approach does not look for ways to merge discipline specific applications. Instead of formalising “paths” for knowledge (“content”) sharing, the data model approach proposed by the PLM vendor seeks to map the relationships between “objects” (“containers”).

The approach insists on the fact that supporting information sharing practices doesn’t mean only *transferring* information across discipline boundaries to compile it within a centralised data base (a “*single source of truth”*). Sharing the highly specialised engineering knowledge involves an abstraction process that establishes commensurable equivalences between the heterogeneous characteristics of local notation practices leading to the definition of the CMS product attributes.

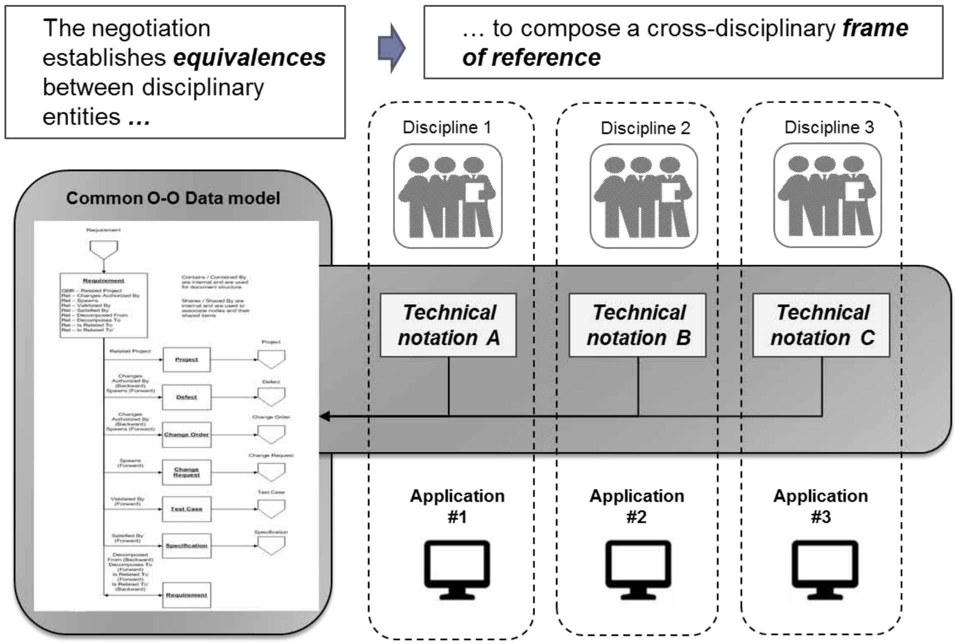

Figure n° 9 / PLM mediations enables cross-disciplinary commensurability

In summary, Trail of connections #1, outlines a logical "*data model*" across heterogeneous applications.

Consequences/ Object-Oriented modelling notations become commensurable across disciplinary boundaries. The Data model introduces a first form of commensurability across engineering disciplines. It defines a *static* depiction of cross-disciplinary interdependencies/discontinuities.

We will see hereafter that the *frame of reference* must evolve to integrate *emergent* and more *dynamic* attributes of the CMS product.

4.4. TRAIL #2 / Producing equivalences between performance modelling devices

The second trail of connections concerns the way teams assess *predictively* the CMS product performance.

Most frequently, the assessment of the target performance of the CMS product relies on numerous risk assessments executed through more or less informal *adhocratic* relationships between specialised engineers from the various disciplines. Risk assessments contribute to evaluating the impact generated by multiple problems concerning the product's reliability, quality, time-to-market schedule, cost, etc. Program managers are not always aware of the local discipline specific trade-offs.

The PLM platform is supposed to overcome this state of affairs by formalising more consistently the impact of *technical* modifications on the *overall CMS product* performance. This second trail contributes to the formation of equivalences that will improve the commensurability of CMS product performance assessments across disciplinary boundaries.

4.4.1. The need to bring together technical performance and economic profitability

At CMS-Co., risk assessment processes are structured by *traceability matrices* aimed at capturing and organising the interdependencies across technical trade-offs realised within each discipline. *Traceability matrices* convey three main frames of reference guiding product performance assessments.

On one hand, engineering teams study how innovative technical modifications of the CMS product improve its overall *functional* performance. Teams responsible for a sub-system or a complex product assembly engage their responsibility guaranteeing the reliability of its contribution to the overall account of the CMS product performance.

On the other hand, experts in charge of overall program profitability calculate the *economic* impact of such technical improvements. This complicates the modelling process of the product performance and makes it harder to produce an auditable account of the future product.

Finally, program managers must *track* the relationships between technical modifications and the overall product performance to establish a consistent account of the product "release readiness".[42]

4.4.2. Improving the reliability of cross-disciplinary risk assessments

We observed that the lack of commensurability between these technical, economic, managerial frames of reference result in controversies about the reliability of current *traceability matrices.*

Program managers are often at the mercy of "black-boxed" technical arguments. As Program managers rely on unstable data conveyed by *traceability matrices* they don't have access to the underlying logic leading to a specialised, discipline specific decision. Program managers most frequently rely on outdated reports produced by the various disciplines. Problems are discovered *"too late"* at cross-disciplinary stage-gate meetings.

The software vendor team puts forward an alternative frame of reference that could support more reliable cross-disciplinary risk assessments.

4.4.3. PLM mediations form equivalences to enable performance simulations

One of the main components of concurrent engineering initiatives concerns the development of modelling capabilities of the *functional* performance of the CMS product.

Performance assessments of the functional behaviour of the CMS systems and sub-systems involve on one hand, *calculations* to establish a *"target*

[42] A CMMI (Capacity Maturity Model Integration) certification initiative was ongoing at CMS-Co. during our data collection campaign.

performance" of the product and on the other hand, *simulations* about "if and how" the product meets the target behaviour and performance.

In order to perform system-level trade-offs analysis, engineers model the expected behaviour of the future *product in use*. By defining the *intended* usage of the future product without immediately referring to its existing physical components, engineers are able to work iteratively on *"what-if?"* scenarios.

The *static* data model described above is submitted to an important "trial of strength" concerning its capacity to integrate iterative and highly *dynamic* relationships across disciplines.

This means that the *static logical* links must be able to also account for modelling devices supporting the *simulation* of the product performance through a multitude of tests informing specialized technical trade-offs.

To do so, CMS-Co needs to connect three dimensions of the concurrent engineering *frame of reference*. We follow hereafter the *three forms of equivalences* between collaborative engineering practices and multiple modelling devices contributing to enhancing the reliability of risk assessments concerning the CMS product development performance.

Equivalences between "modelled behaviour" and "physical structures"/ The first dimension of the Concurrent engineering referential concerns modelling of the functional architecture. The PLM vendor introduces the concept of *Model Based Systems Engineering (MBSE)* based on SysML modelling language to establish traceable links between static and dynamic taxonomies characterizing the CMS product attributes.

Through the MBSE approach, CMS-Co. and software vendor teams formalize four components of a *sub-system in use*: (1) the *structure* of sub-systems is represented by a map of links indicating how information is shared between its physical components. This map also includes the type of physical interfaces used and all applicable messages (e.g. turn signal on, send message, etc.). Subsequently, the sub-system *behaviour* is represented though sequences of interactions indicating when messages are being sent and when the so called, "state base" is determined. For example, behaviours such as

"Alert loss of signal" will be represented by a sequence of interactions such as ["Detect loss of signal" – "Signal loss" – "Modulate signal sensor"]. The modelled *behaviour* can be allocated to the physical *structure* - associated to both, corresponding *Requirements* (e.g. text describing "the system shall send an alert in case of…") and to values calculated within specialised applications (e.g. advanced calculations represented by *Parametric diagrams).*

Through this trail of connections, Engineers can strengthen the *frame of reference* of the blueprinting process as they are able now to attach the *static* (logical) data model to a more cohesive representation of the *product in use*.

The *dynamic* behaviour can be allocated to physical *structural* elements, associated to textual *requirements* and linked to *parametric* simulations. Consequently, discipline specific design and simulation results, can be traced to requirements showing that a requirement is "verified by…" some value visible at cross-disciplinary level.

Equivalences between the "generic" product architecture and its "variation points" / The second dimension to be connected is product variability modelling. The PLM vendor introduces the concept of *Product Line Engineering (PLE)* aimed at promoting "architected re-use" of existing CMS sub-systems.[43] PLE models are product architecture templates that combine "Product instances" to mapped "Variation points" - the latter formalise "constraints" generated by sub-systems interdependencies. In the mid- long term, engineers would access a library of previously developed and tested *"CMS Architectured Models"* (a combination of validated product architecture templates joined to all possible executable *scenarios* – called the "*150% model"*). Consequently, future CMS Programs will be able to access common product models of all available *component variations* that could be re-used during the concept design phase. The discipline specific engineer is led to use "preferred" components listed in a library of solutions. There is no obligation – adhocracy is still the dominant model. However, the engineer is requested to explain his/her decision leading to a new longer, costlier development vs. the reuse of an existing validated solution. The blueprinting

[43] PLE methodology is built on recent standards described by ISO 26550:2013 Software & Systems Engineering – Reference Model for Product Line Engineering & Management

process establishes that this library is defined and maintained by domain experts and can be accessed by all relevant stakeholders. So the library strengthens the relationship between technical “re-use policies” and cross-disciplinary decision making processes.

The PLM platform strengthens the *frame of reference* of the blueprinting process as the representation of “what needs to be known/shared” is not primarily focused on the *technical content* (attributes of the components delivering the functional performance). It is rather built upon a mapping of socio-technical interdependencies (the “variation points” expressing the nodes accounting for potential interactions across discipline specific sub-systems).

Equivalences between product behaviour and economic costs / The third dimension of the Concurrent engineering referential concerns mediations leading to the inclusion of modelling devices used to assess the *economic* impact of *concurrent* engineering. The modelling approach recommended by the PLM vendor reverses prevailing practices at CMS-Co.

Dominant practices build cost assessments from the *bottom* (collection of costs of components and investment need for new manufacturing facilities) *up* (cross-disciplinary consolidation of product & process costs). Within this bottom-up approach, program managers depend on the calculations executed by each discipline. The software vendor introduces additional models of the optimal cost structure calculated on the basis of historicized economic data - including compiled financial data about both, the cost of CMS product’s components and the associated industrial process investments.

We present hereafter how the PLM blueprinting process seeks to change this situation by transforming the mediations between dominant engineering practices and more interoperable modelling software applications.

4.4.4. PLM mediations form semantic equivalences across modelling devices

The dominant engineering practices at CMS-Co are structured by "traceability matrices" managed manually within complex spreadsheets. These matrices are not able to account for the increasing number of interdependencies across CMS sub-systems.

Our interviews and workshops during the blueprinting process reveals that the lack of reliability of *traceability matrices* generates an increasing lack of control over risk assessments involving multiple disciplines. Tensions are exacerbated by increasing conflicts about product "release readiness" particularly visible at the CCB (Change & Control Board) meetings. Program managers complain about the fact that flaws in product performance assessments are discovered "too late" and corrective actions are costly and ineffective.

Throughout the PLM blueprinting process, Program managers put forward operational arguments to enforce a top-down approach of Systems Engineering (SE). Until then, the Systems Engineering initiative had been confined to a methodological framework enforced by a small number of engineering experts and consultants. The blueprinting initiative contributes to open the methodological "black-box".

This is enabled by the fact that the prescribed PLM mediations expand the definition of the CMS product and create a more comprehensive representation of the product performance. The Use Cases related to MBSE and PLE topics described above, combine economic and technical criteria: requirement topics such as *"cost reduction through controlled product variability", "control schedule over-runs to be validated by test campaigns"* express the interactions between technical and economic dimensions of the performance of the future CMS product.

As a result, Program managers working at cross-disciplinary level, are able to encourage specialized engineers to account for the impact of their proposed technical modification against the overall System Architecture.

Discipline specific technical assessments become commensurable activities inscribed within the overall Systems Engineering framework.

4.4.5. PLM mediations scale-up equivalences to secure "what if…" scenarios

Following the trail of connections described above we understand better how *traceability matrices* defining "what information needs to be known/shared" are reconfigured through the three major sequences.

- Through a first sequence, modelling devices capture technical communality and rationalize components variability within *"architectured product families"* at Systems level.
- The second sequence defines computational links between the captured technical variability and the functional performance of the product in use.
- The third sequence links discipline specific design data and the overall financial impacts of elements such as enforcement of technical re-use policies, reliability, quality, time-to-market schedule and cost.

These three sequences move disciplinary "what if…" scenarios to cross-disciplinary level and attach them to a shared cross-disciplinary "impact analysis" framework to assess the multiple (adhocratic) technical modifications.

In other words, the PLM platform mediates tangible equivalences between the three sequences and modifies "what information needs to be shared": what is shared is the collective capacity to *trace* and *interpret* the changes in the local, disciplinary "what if…" assessments. It therefore strengthens the traceability of discontinuous interdependencies.

4.4.6. PLM mediations move product modelling to Systems Architecture level

The new *frame of reference* enacts *“what needs to be known/shared”* and also defines *“when & where sharing takes place”*.

From now on, sharing takes place through a series of commensurable equivalences leading to a scaled-up and more abstract "Systems Architecture" level. This means that “what-if” scenarios may articulate *top-down* concurrent engineering practices and *bottom-up* CMS performance assessment practices.

This becomes possible as the PLM platform enacts equivalences between:

- models of the optimal *product performance* measured against customer requirements – e.g. the description of the expected behaviour of the product in use (based on the MBSE approach);
- models of the optimal *re-use trade-off* measured against a map of product family commonality & variation - including its configuration logic and rules (based on the PLE approach);
- models of the optimal *cost structure* of a product measured against the historicised economic data.

The blueprint of the PLM platform articulates the *static* and *dynamic* views of interdependencies. The static data model (described above in Trail #1) is strengthened by the enactment of the two types of modelling software applications within the PLM platform: dynamic links between models of functional performance (technical criteria) and models accounting for the economic impact of engineering trade-offs.

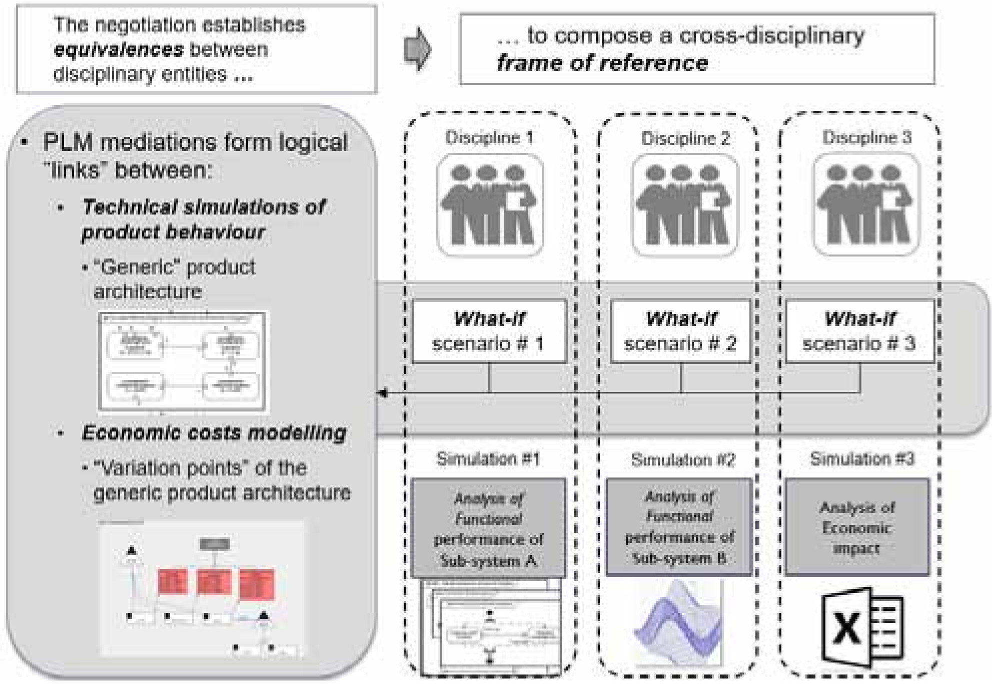

Figure n° 10 / PLM mediations move product
modelling to Systems Architecture level

In summary, Trail of connections #2 sketched a cross-disciplinary modelling approach of the *functional product in use*. As new forms of commensurability are established at cross-disciplinary level, we observed that the PLM blueprinting process tends to strengthens Program managers' roles as they are from now on equipped with tangible accounts of the impact of inefficient cross-disciplinary collaboration.

Consequences/ (1) Modelling software applications bring together heterogeneous and discontinuous risk assessment procedures and (2) Technical and economic criteria are assembled in consistent cross-disciplinary accounts about the CMS product. So the technical – previously "black-boxed" - view of the required functional performance of the CMS product can be *accounted for* and *interpreted against* an extended and more reliable cost analysis of its overall "product lifecycle."

We will see below that the next trail of connections prolongs connections accounting for product *"release readiness."* The PLM blueprinting process continues to assemble disciplinary practices and specialised software applications that may contribute to changing the dominant patterns of concurrent engineering.

4.5. TRAIL # 3 / Articulating persistent and transient accounts of the CMS product

The third trail of connections is about the collective capabilities to assess *at one point in time* the validity of cross-disciplinary *accounts* of the CMS product. Have all relevant specialised tests been taken into account? Are there still significant evolutions being made in a sub-component developed by a sub-contractor? These are typical questions raised within industrial R&D organisations dominated by adhocratic concurrent engineering practices.

During the early phases of the CMS concept design phase, all options about the functional product architecture are not yet "*frozen.*" Teams need to sometimes introduce *ad hoc* solutions to cope with *unforeseen* events. Each discipline tends to put forward its own requirements according to local constraints. Tensions emerge between the need to preserve *loosely coupled* iterations during early phases of the "elicitation process". [44] Nevertheless, engineers need to enforce throughout the subsequent phases of the elicitation process, "top-down" hierarchical configuration management methods.

[44] *"Within the context of ISO/IEC 15288, requirements are specifically mentioned in two of the technical processes, and are drivers for many of the system life cycle processes. Depending on the system development model, requirements capture may be done nominally once near the beginning of the development cycle, or as for agile methods, be a continuous activity. The reason for eliciting requirements is the same, understand the needs of the stakeholders well enough to support the architecture design process. One of the biggest challenges in this activity is the identification of the set of stakeholders from whom requirements should be elicited. Customers and eventual end-users are relatively easy to identify, but regulatory agencies, and other interested parties that may reap the consequences of the system-of-interest should also be sought out and heard."* International Council on Systems Engineering INCOSE Systems Engineering Handbook v. 3; June 2006

This trail of connections describes how the PLM blueprinting process copes with conflicting frames of reference guiding iterative collaborative engineering practices. The strength of the frame of reference performed by the PLM platform depends on its capacity to reframe the way CMS-Co teams articulate "top-down" requirements definition and "bottom-up" confirmations.

4.5.1. The need to improve traceability of product "release readiness"

How to secure cross-disciplinary information sharing and cope with the rather adhocratic collaborative environment? How to support *consistent traceability* across discipline boundaries?

These questions are expressed by CMS-Co teams as a required functional feature of the PLM platform, aimed at improving tracking capabilities of *"product release readiness"*.

The PLM blueprinting process addresses these questions by introducing three types of software applications aimed at expanding the scope of commensurable equivalences conveyed by the "data model" described above: the "multilevel product structure", "baseline" templates and "check-in / check-out" templates.

1/ The "multilevel product structure" establishes hierarchical equivalences between all attributes of a product "Part" / The first artefact is a model establishing "parent-child" relationships between main components of the CMS product - Parts/Assemblies are hierarchically associated to qualifying attributes (number, name, version, state, etc.) and usage contexts (including substitute parts, serialized parts, etc.).

The software vendor proposes a *common commensurable referential* (the "part structure" presented below) to account for the configured CMS product.

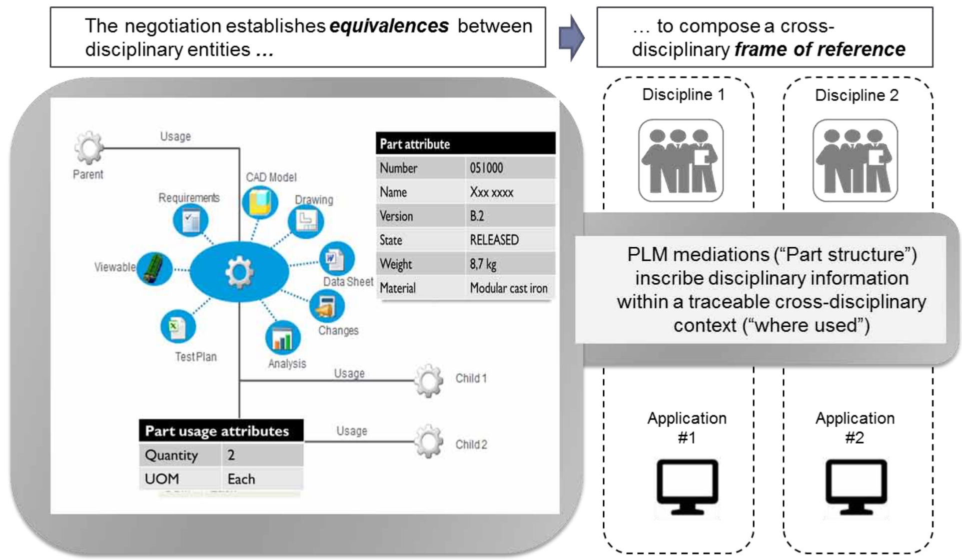

Figure n° 11/ Role played by the representation of a "Part structure"

We have mentioned before that throughout the design and engineering processes, engineers need to constantly iterate to verify the consistency of a particular item (system, sub-system, component, piece of code, etc.). Iterations concern on one hand, the (external) customer requirements and, on the other hand, the functional and physical constraints of the (internal) industrial context. Through this representation, the PLM platform mediations establish equivalences between a (logical) *"object"* and series of computational *"links"* to the actual CMS product attributes.

The Figure 12 below shows how the framework proposed by the software vendor establishes logical "links" between:

- the CMS "product" and the ways it is *described* ("Described by…" links associated to document, drawings, 3D data, ECAD data, Software data),
- the *context* within which it is used ("Used by…" links),
- the *interdependencies* across assemblies ("Derived by…" links), etc.

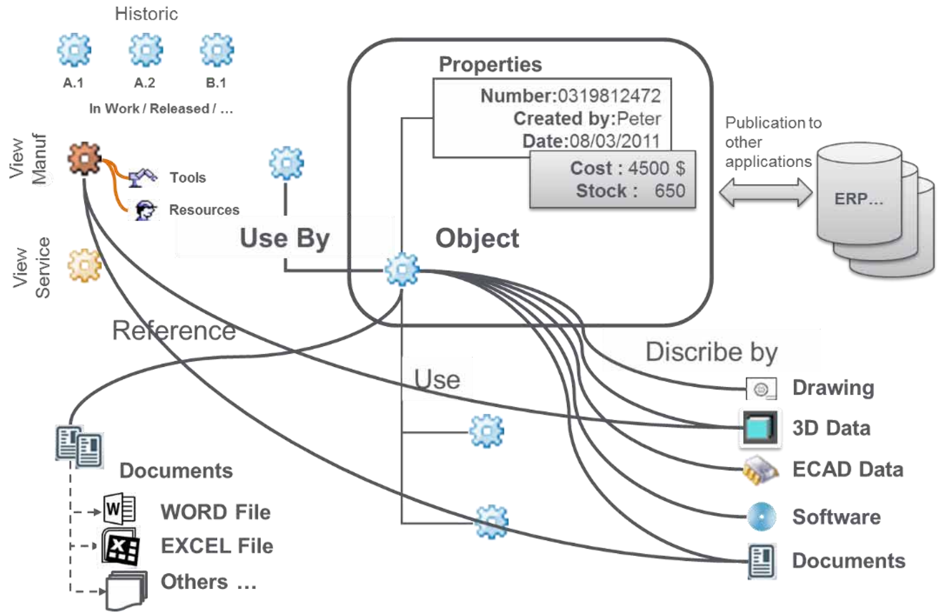

Figure n° 12/ Example of representation of an "Object" centric "Multilevel Product Structure"

As the overall CMS product information is associated to a common "part structure", the software vendor engages in assembling other "discipline specific" information. Links are established between a Part/Assembly of the CMS Product and all associated documents, models, and data spread across multiple discipline specific specialised applications.

The information produced by the main disciplines (e.g. mechanical, electrical, software, product documentation) can be assembled in a common representation of a "Multi-level Product Structure" (figure n° 13 below).

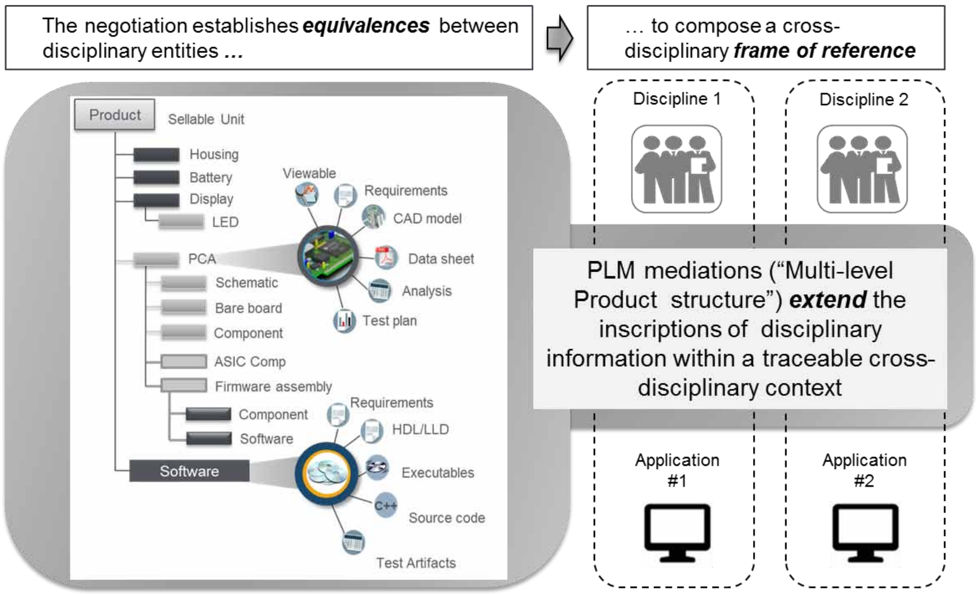

Figure n° 13 / Role played by the "Multilevel Product Structure"

Through the "Multilevel Product Structure", discipline specific teams may define and manage their Parts and Assemblies, while the PLM platform *automatically* creates and edits the associated updates of the corresponding links to the product attributes.

2/ "Baseline" templates establish equivalences at one point in time / The second artefact is a formalised workflow linking discipline specific modifications to the common *account* of the CMS product. All disciplines (mechanical, electrical, software), share the same digital cross-disciplinary *"change management template"*. Baselines provide commensurable/calculable accounts to trace the modifications that may or may not, impact the product "release readiness." Discontinuities and interdependencies are revealed/enacted through:

- a formalised process (a series of actions that produce something or that lead to a particular result);
- a traceable account of the Product (the end result of a process);
- the associated resources (consumable or person which supplies support);
- the specific techniques (a method of accomplishing a desired aim by using knowledge, skill and tools);
- and associated tool (something used to perform an activity or complete an action).

The baseline template contributes to frame and enact a *persistent* evaluation, review, approval and change implementation process. Change history, electronic signatures, and audit trails are automatically captured and notifications are sent to affected parties of change effectivity. Persistency of "release readiness" data is guaranteed by the fact that PLM platform capabilities capture and associate the revision and iteration history of affected digital product information with each change. It preserves nevertheless some flexibility within a persistent adhocratic logic.

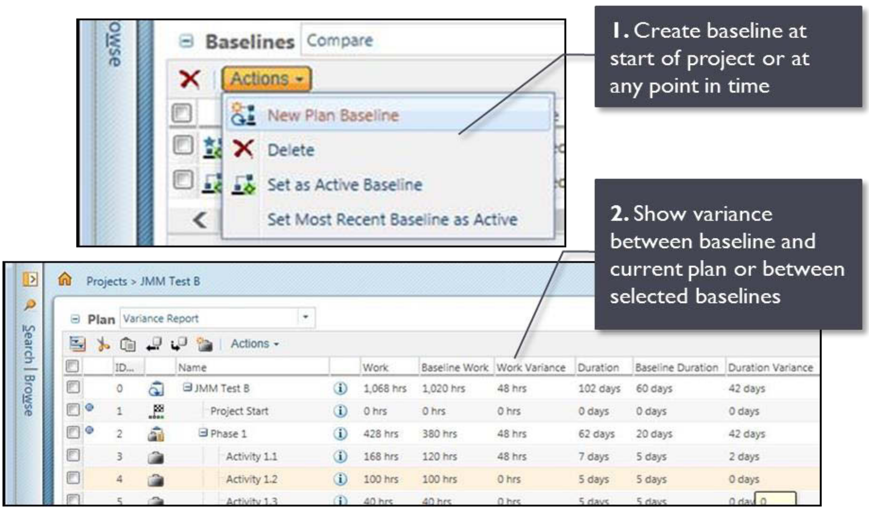

Figure n° 14 / Role played by the "Baselines"

For example, teams may adapt routing workflows according to change severity. An adaptable *workflow* (computed by a flexible organisational rule) is associated to the "Object" representing the Part and its Attributes. This can be done without interfering with the actual (highly adhocratic) testing practices embedded in a test bench at discipline level.

Product attributes can be automatically consolidated *at one point in time*. A particular part of an assembly can be traced through hierarchically defined rules – and each component state can be qualified as being "as-planned", "as-designed", as-maintained", etc. As a result, teams can bring together a *timeline* (the product lifecycle) and an organisational *context* facilitating the interpretation of the product "release readiness": the context is represented by the multi-level product structure and the timeline is accounted for through "baselines" of the *same* "multilevel product structure".

This second artefact organises rule-based relationships between the CMS product and its configurations in the various disciplinary contexts. Engineers from different disciplines can filter a product structure and obtain baselines of the relevant sub-assembly as the product design progresses.

The templates derive their strength from the fact that a Baseline conveys *effectivity dates* for each component (time or lot-based). In so doing, it provides rule-based configurability for the CMS product "release readiness". They can therefore *compare* "Multi-level Components Lists" by filtering the selected version of the part structure to match it with the latest version.

By cross-referencing the "Multilevel Product Structure" and a "Baseline", discipline specific modifications of the product components are *automatically* inscribed in a cross-disciplinary consolidated account of the product "release readiness". As such, it introduces shared capabilities to manage discontinuities that strengthens the proposed frame of reference.

3/ "Check-in/check-out" templates establish equivalences between highly structured and loosely-coupled engineering practices / The third artefact is aimed at containing the risk of inconsistency between "waterfall" or sequential engineering processes and more "agile", iterative development cycles characterising the development processes of software components.

Workflow templates described above are designed for very large CMS-Co programs where dominant disciplines (electric and mechanical) depend on heavy fixed cost investments. Product changes are not so frequent during the design of hardware components. Hardware engineers are compelled to use more structured change tracking processes encompassing hierarchical versioning principles and sophisticated product configuration rules. That is not the case for software driven processes subject to a rapid pace of product modifications. The tension between diverse paces of change generates inconsistencies penalising the "Verification & Validation" of product "release readiness". Sub-sequent "impact analysis" across disciplinary boundaries become less reliable and error prone.

The "check-out/check-in" mechanism is introduced to strengthen this unstable relationship between the rapid software code changes and the overall slower product development process. The potential disruption of the rapidly evolving "work-in-progress" code corresponding to discipline specific software configuration taxonomy, is contained through a distinct however interoperable artefact: the "change package."

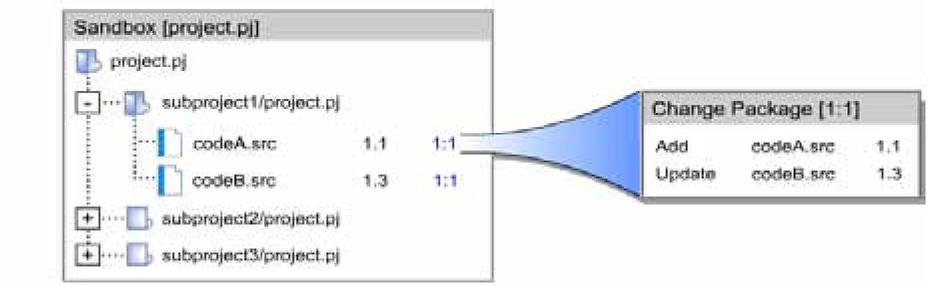

Figure n° 15 / PLM mediations articulate non-persistent practices ("sandbox") and persistent traceable "objects" ("Change Package")

The *"Change package"* template enables the isolation of subsets of code development (a practice called "branching"). The lead developer "checks-out" a subset of information to be shared and modified within a specific group of developers and then "checks-in" back to a development environment – the latter contains its own "version control system" adapted to the rapid pace of developments iterations (software build, packaging and testing). When the development iteration is verified and validated, the code is "checked-in" back to a common PLM referential. We observe that here too, new forms of managed discontinuities of the proposed *frame of reference* ensure better controlled integration of software specific "release readiness" data to a common account of the CMS product.

4.5.2. PLM mediations enact the inconsistencies about product validation practices

We have seen above how the PLM platform inscribes local modifications of the overall CMS components in a cross-discipline "object" centric representation of the overall CMS product. Consequently, technical modifications done by each specialised discipline can be *accounted for* at cross-disciplinary level.

The PLM platform also creates mechanisms to reveal the potential *consequences* generated by local modifications on the overall CMS product representation. The mechanism is called a "Suspect link" that represents potential inconsistencies between baselines of product "release readiness".

The "Suspect link" *enacts discontinuities* between the product validation practices. It *reveals* automatically the variations generated by a technical modification realised by one specialised engineer. "Suspect links" can be searched, be computed against, dynamically generated, and flagged as suspect when something changes.

Consequently, Change *propagation* is made visible through *tagging mechanisms*. These automatic mechanisms provide visual access to affected parts, untraced requirements and test failures. When a discipline specific technical modification of the CMS product occurs, the PLM platform *automatically flags* the relationships between the product "release readiness" that is documented by the "Multilevel Product Structure" and the subsequent accounts that are positioned downstream. The engineer may trace links to all upstream design software applications (Requirements, Designs, Models) and, then interpret if and when the linked downstream software applications may need to be updated.

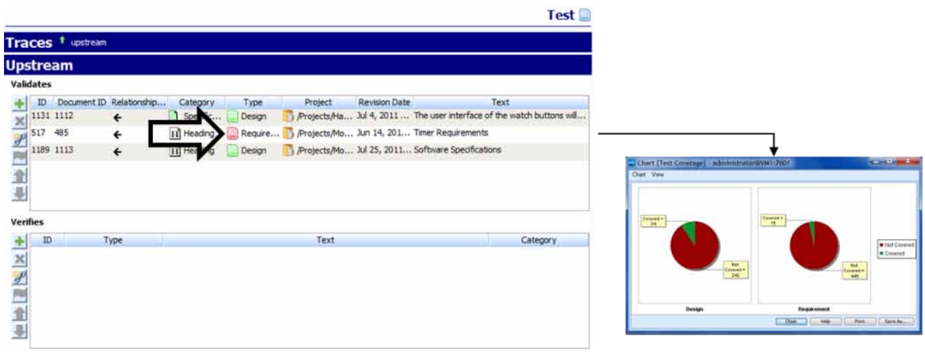

Figure n° 16 / PLM dashboards enact
compiled traces of inconsistencies ("suspect links")

The mock-up of the PLM platform enacts how engineering teams can rely on the stable persistent links to the "Multilevel Product Structure," and also *view* inconsistencies that may *potentially* impact "release readiness."

"Suspect links" are at the same time, part of a *stable* referential (e.g. the "Multilevel Product Structure") while also being inscribed in *evolving* validation contexts. Commensurable equivalences between the potentially conflicting dimensions of CMS-Co validation practices are inscribed in the common *frame of reference*.

This extension of the formal, persistent "Object-Oriented" (O-O) modelling capabilities to manage the product "change management" referential provides all CMS stakeholders with access to contextualised information about product "release readiness." [45] O-O modelling capabilities convey the *universal* characteristics of the product that are the result of functional capabilities supporting *persistent* "objects" - such as, for example, "baselines" assembling information under persistent rule-based "change management" templates.

In this sense, "suspect links" distribute cognitive capabilities to act across discipline boundaries. Discipline engineers can both perceive CMS product "release readiness" inconsistencies while being (automatically) inscribed in a scaled-up account of the product lifecycle. The capacity to enact discontinuities of product "release readiness" also strengthens peer driven interpretations – the Proof-of-concept demonstrates how peers across disciplines may qualify (semantically) the *relative* importance of such and such technical change. Information about "release readiness" may also be consistently shared across disciplines without blocking the dominant discontinuous interactions and the iterative "balancing act" mentioned above.

4.5.3. PLM mediations scale-up a measurable account of product "release readiness"

Through this third component of the trail of connections, both teams succeed in articulating the *static* representation of the cross-disciplinary collaboration (the data model described in Trail #1) with a more *dynamic* representation of the CMS product. We described the attempts to include the constant *changes* in CMS product accounts. At the core of these attempts are PLM mediations that increase the *visibility* of the *frame of reference* supporting the validation of the product "release readiness" while instituting forms of discontinuities that strengthen the emerging *frame of reference*.

Putting it differently, the PLM blueprint defines a *frame of reference* that extends the way the validity of product attributes is measured against. At the

[45] As we will see below, the ICT platform may play a role bringing together modelling artefacts concerning the traceability of the numerous discontinuities of the industrial product – primarily, qualifying the finalized, specific and localised characteristics of (1) Problem report (description of the need for change, duration, schedules, assignments) (2) risks management of interdependent workflows (e.g. Engineering Change Requests) (3) effectivity dates (Engineering Change Notice).

beginning of the PLM blueprinting process, there are no consistent capabilities to manage commensurability across specialised applications. Managing traceability of constant modifications of the accounts of the CMS product across discipline boundaries depends on highly adhocratic practices. As the PLM blueprint shapes-up and the Proof-of-Concept evolves, the vendor team is able to reframe "what information needs to be known/shared" to account for the validity of product "release readiness".

The figure below outlines the fact that the information that needs to be shared is in the (logical) "links," rather than in the actual description of the changes introduced in "requirement B.1" of a Power Supply Specification.

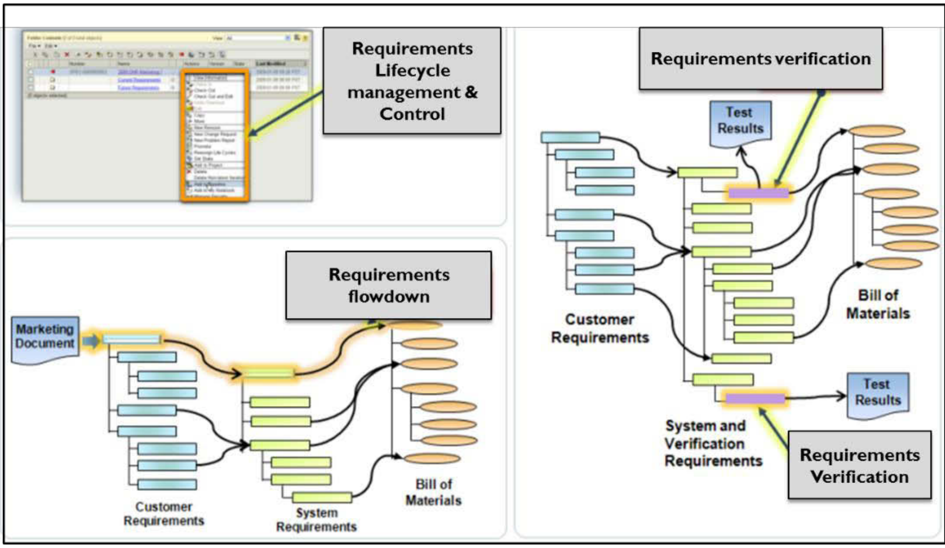

Figure n° 17 / PLM mediations compose traceable "links" enabling associativity across disciplinary boundaries

The more commensurable frame of reference attaches the account of the CMS product “release readiness” to:

- “object” centric software applications modelling the cross-disciplinary control of “change propagation” comprising more fine-grained “Change and configuration management” capabilities,
- “logical links” between hierarchical, “top-down” control and adhocratic peer-control comprising access to *visual evidence* facilitating *cross-disciplinary validation* of the information about product “release readiness”,
- “baselines” organising the way equivalent accounts about product “release readiness” are *enacted* within various organisational contexts.

  Connections between these three artefacts generate the following movements that strengthen and expand the third trail of connections.

The first movement *reduces the complexity* of validation practices dominated by adhocratic collaboration patterns. The PLM mediations strengthen syntactic equivalences forming commensurable relationships between validated product information and potential inconsistencies revealing non-aligned validation practices. This is achieved through syntactic equivalences between the abstracted cross-disciplinary “Multilayer Product Structure” (numbering structure, “where used” information, etc.) and the software applications ensuring traceability of technical changes.

The second movement *enables visibility* of the potential inconsistencies between hierarchic and adhocratic validation practices of product “release readiness”. Tagging mechanisms described above make visible the potentially contradictory aspects of cross-disciplinary impact analysis. PLM mediations are strengthened by the fact that CMS-Co teams have *visual access* to *evolving* forms of cross-disciplinary validation of product “release readiness” within the discontinuous “product lifecycle”.

Both movements contribute to scaling-up to cross-disciplinary level, the commensurable and calculable account of product “release readiness”.

4.5.4. PLM mediations contextualise product validation practices

We have described the PLM mediations leading to a more consistent synchronisation of persistent and discontinuous changes within a single account of product "release readiness".

The PLM platform brings together in a same account of product "release readiness" both persistent and transient components of CMS-Co validation practices. This trail of connections brings together the centralised representation of the CMS product and the required software applications to support peer awareness at cross-disciplinary level.

CMS-Co and software teams can confront their views and discover, through the PLM Proof-of-Concept, alternative ways to compose a meaningful organisational context that enables the interpretation of the product "release readiness" at different points in time.

We have observed that "suspect links tags" play a key role in stabilising the controversies. They demonstrate how collective capabilities can enact the synchronised and commensurable discontinuities between diverse paces of technical change across disciplines. *Technical* traceability throughout "allocation" and "flow-down" phases can be enforced and *organisational* slack and loosely coupled iterations are made visible across discipline boundaries.

Through the visualisation of "suspect links", semantic logic can be framed and enacted across disciplines.

Consequently, the account of product "release readiness" is expanded as it includes the potential *risks* generated by discipline specific changes to the CMS components. Risks can be calculated by qualifying the state or condition that may cause incompleteness or loss of CMS functionality.

The PLM mediations between syntactic (descriptive) modelling software applications and the semantic (demonstrative) validation practices create a virtual *context* for cross-disciplinary cooperation and arrangements within the hierarchy driven taxonomy. Contextualisation is achieved by including *in a same PLM platform* two frames of reference: the (static) "data model" supporting syntactic interoperability across existing applications and the (dynamic) modelling software applications supporting semantic interpretations of product "release readiness". Through the combination of these two frames or reference, engineers have structured access to the *"best of both worlds":* the hierarchical, abstracted, "Object" centric representation and also the contextualised information enabling adhocratic improvements of the CMS product.

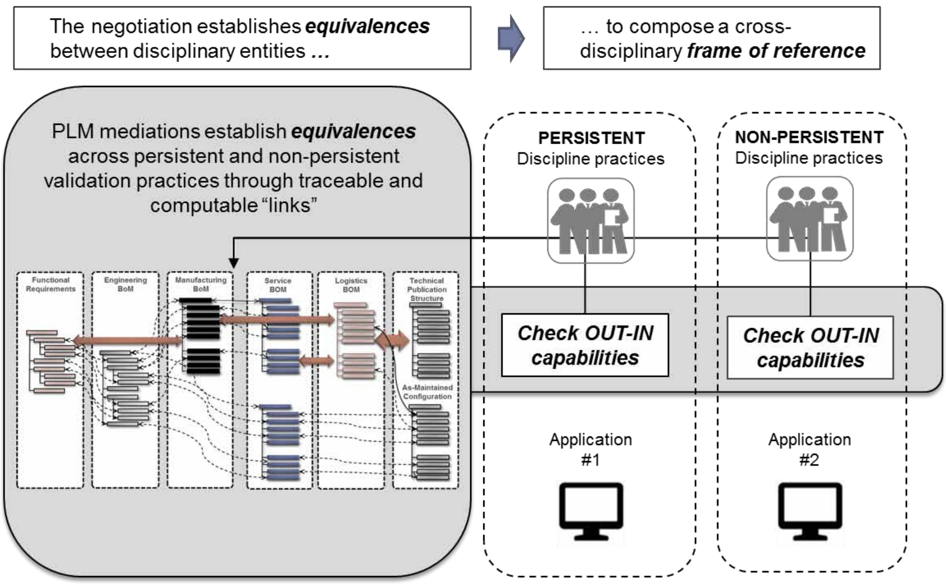

Figure n° 18/ PLM mediations compose "links" across associative O-O "objects"

In summary, Trail of connections #3 brought together interoperable modelling software applications to enhance cross-disciplinary *traceability* of product "release readiness". At the end of this third trail of connections, computational links ensure traceability across disciplinary boundaries. The cross-disciplinary account about CMS product "release readiness" includes the diversity of discipline specific interpretive practices attesting its "readiness for release".

- Consequences: the strength of the PLM blueprint is increased as the proposed *frame of reference* assembles:
- discontinuous paces of discipline specific changes of CMS product components,
- traceability at various levels of granularity of product "release readiness"– CMS system, sub-systems, assemblies, components, parts and parts attributes.
- visible relationship between persistency of formalised processes and transiency of local adhocratic validation practices.

We will see hereafter even though interpretations about the validity of the state of the CMS product can be framed, traced and synchronised across disciplinary boundaries there are still open questions about the associated accountability patterns.

4.6. TRAIL # 4 / Communication protocols produce layered visibility about complex interdependencies

The fourth trail of connections between the PLM platform and concurrent engineering practices, assembles organisational protocols defining the roles and responsibilities of risk mitigation.

4.6.1. The need to secure risk mitigation protocols across disciplinary boundaries

The workshops about risk mitigation express the need to improve the speed and the accuracy of "impact analysis" across disciplinary boundaries. Both speed and accuracy are considered as prerequisites to secure complex distributed technical trade-offs. The software vendor tries to canalise these requirements towards a dialog about the benefits of a working environment (expressed in terms of "user interface") where discipline specific engineers could combine both *access to "work-in-progress" information* and more reliable *hierarchical* navigation principles.

At this phase, the PLM blueprinting process brings forward two topics: the need to improve the *early access* to information about *CMS product integrity* and the need to *create dashboards* for the consolidation of product "release readiness" information.

4.6.2. PLM mediations create a user interface to organise early access to "work-in-progress" information

The Use Cases about "user interfaces" and "access rights" generate controversies about how PLM mediations make visible a more holistic *user experience.* Through the mock-up of the PLM platform, the software vendor attaches a new component to the proposed frame of reference.

This is done through the characterisation of the future "user." Is he/she a member of a "discipline," sharing documents (*content* about *"what the product will be"*) through "point-to-point" connections between disciplinary software applications? Or is he/she a "contributor" to a series of interdependent tasks (the product development *process* defining *"what the product will be"*) inscribed in a consistent interoperable infrastructure?

The graphical characteristics of the proposed user interface introduce tangible visualisation capabilities that enable *continuous* reviews of *evolving* accounts of product "release readiness". This means that the same baselined information about "release readiness" may be accessed across software, hardware and mechanical disciplines without implying any information duplication. After going through an authentication protocol provided by the PLM platform, an engineer is able to navigate to all objects residing in all integrated applications. The user interface enables the access to heterogeneous authoring applications based on specialised modelling notations.

From this point onwards, *technical* interoperability is more closely associated to *organisational* concurrent engineering. Each role may navigate the "links" between "objects" (upstream and downstream) and check which product parts and/or functions are affected by a change request.

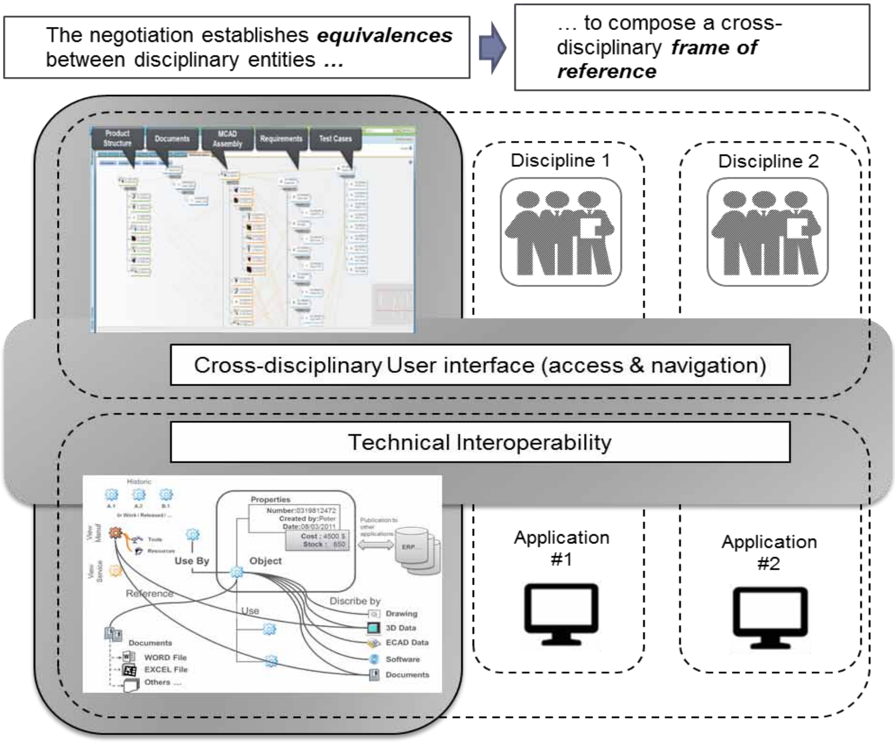

Figure n° 19 / Common user interface enables cross-disciplinary access and navigation to evolving information about product "release readiness"

The outcome of this trail of connections is the capacity to assemble different components leading to more accurate "impact analysis" of a change in the product. Changes become *visible* across disciplines through a role based user interface bringing together different "views" of product "release readiness":

- Document *view* for context based authoring (engineers are able to understand the context where design data & documentation is produced).
- List *view* for efficient categorization, sorting and filtering (engineers filter and establish a "baseline" to trace and control "change & configuration" management).

- Tree *view* for hierarchical decomposition (engineers may move or "drill down" from the "Part View" to associated drawings, Parts list, Parts structure and eventually execute geometry measures in the 3D authoring tool).
- Detail *view* for attribute association (engineers may comment and give feedback through mark-up & annotations (a practice called "redlining").

- This type of mediation adds an additional component to the movement through which the PLM platform alters *what information must be known/shared:* we observe that the focus is put less on sharing the actual ("validated") information about product "release readiness." What counts is the collective capabilities mediated by the PLM capabilities to ensure *access* to evolving ("work-in-progress") information about the CMS product "release readiness."

4.6.3. PLM mediations enact interdependent roles & responsibilities about product integrity

The second movement defines *where* sharing takes place through the creation of dashboards assembling heterogeneous information about the CMS product as it evolves through the design and engineering processes. Dashboards benefit from the existence of persistent links across disciplinary boundaries. They convey a complementary *material* equivalence between *integrity* of information and *persistency* of visual evidence about product "release readiness".

The visual equivalences previously introduced by the third trail of connections, are strengthened by the capacity to consolidate in *dashboards* the information about product "release readiness".

Dashboards simplify accounts of the complex information processing operating "behind the scenes". They provide a more structured access to the evolving synthesis of *persistent* links - obtained as we have seen, through tagging mechanisms performed by "suspect links".

Dashboards also *scale-up* the information conveyed by the various levels of traceability of CMS product "release readiness". Traceability about product accounts "states", "release levels", etc. is performed by means of automatic triggering mechanisms.

Dashboards simplify and scale-up accounts of interdependencies and potential inconsistencies generated by the *propagation* of changes in product accounts. Interdependencies become automatically visible to all relevant discipline engineers.

Accordingly, the way accountability patterns are presented is also altered. The dominant accountability model at CMS-Co is structured around *"heavy–weight"* program managers (Wheelwright and Clark 1992). They are responsible for risk mitigation devices – particularly "impact analysis" templates used throughout the "stage-gate" management process. The blueprinting process outlines new *"heterarchical"* [46] forms of accountability (Stark 2009; Beunza & Stark 2004) as, from this point forward, responsibilities about risk mitigation are visible to *all* disciplines members.

As dashboards enact a more reliable account of the "product lifecycle," responsibility for cross-disciplinary consistency is no longer the prerogative of program managers. The proposed user interface ensuring new forms of navigation enables accessing information *when needed*. "Views" and "Dashboard" are available at all times. The resulting holistic *account* of the product throughout its lifecycle enhances control over interdependent cross-disciplinary trade-offs. We observe the extension of the account as it incorporates system requirements, design, analysis, verification and validation activities.

The framework for sharing and creating knowledge is expanded to support and perform a more comprehensive representation of roles and responsibilities concerning risk mitigation operations aimed at securing the

[46] Heterarchy *"represents a new mode of organizing that is neither market nor hierarchy: whereas hierarchies involve relations of dependence and market involves relations of independence, heterarchies involve relations of interdependence."* It is an *"organizational form of distributed intelligence in which units are laterally accountable according to diverse principles of evaluation"*. (Stark, 2009, p. 19)

CMS product integrity. In this extended representation of the CMS product integrity, disciplinary accounts of the product are linked to each other at cross-disciplinary level – as a result, the associated risk mitigation roles and responsibilities become tacitly and more and more, explicitly (dashboards…) synchronised across disciplinary boundaries.

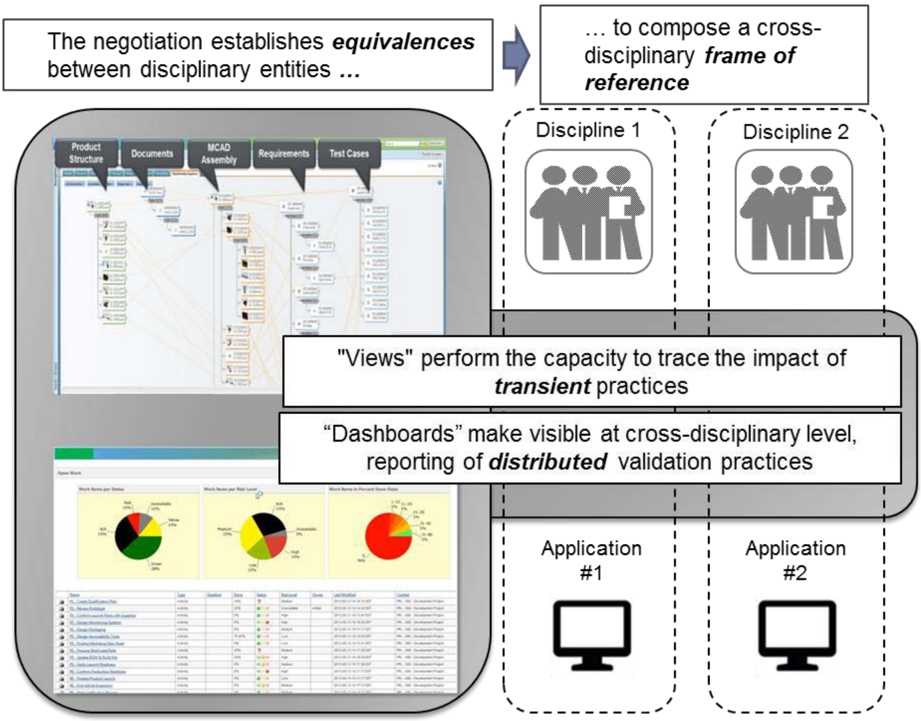

Figure n° 20/ PLM mediations make visible cross-disciplinary accountability

In summary, Trail of connections #4 describes the emergence of *visible* cross-disciplinary accountability practices enabled by, on one hand, "Views" that perform the capacity to trace the impact of transient practices across loosely coupled collaborative settings. On the other hand, "Dashboards" perform collective capabilities to enact synchronised validation practices.

Consequences/ Accountability protocols & dashboards generate layered visibility about interdependent roles and responsibilities across disciplinary boundaries. Hence, the qualification of risks is secured by more reliable communication protocols and information sharing can take place within wider discontinuous, distributed organisational settings.

4.7. What do PLM mediations do?

The dialogue around the overall coherence of the PLM platform is driven by the need to create a solution that both develops the technical interoperability between discipline specific applications while bringing together distributed disciplinary practices.

As the PLM mediations compose the new frame of reference, disciplinary practices and software applications are progressively *moved* to a cross-disciplinary level.

In this sense, the four trails of connections organise a simplified and extended account of the "product lifecycle" [47] and composes operational "links" between:

- *technical notations* and related specialised *taxonomies* used to account for attributes of the CMS product;
- *technical and economic models* used to assess and account for potential risks associated to the CMS product performance;
- *persistent and non-persistent accounts* about the validity of the CMS product "release readiness";
- *communication protocols* generated by a "multi-tier" client-server architecture leading to the capacity to account for accountability practices vis-à-vis the account of the "CMS product lifecycle".

The figure below summarises the main equivalences through which *accountability* about product integrity becomes *commensurable, calculable and observable* across disciplinary boundaries.

[47] The account composes a "*chain of reference"* (Latour, 2005) modifying the morphology of the "interobjective" (Latour 1996) relationships between disciplinary entities.

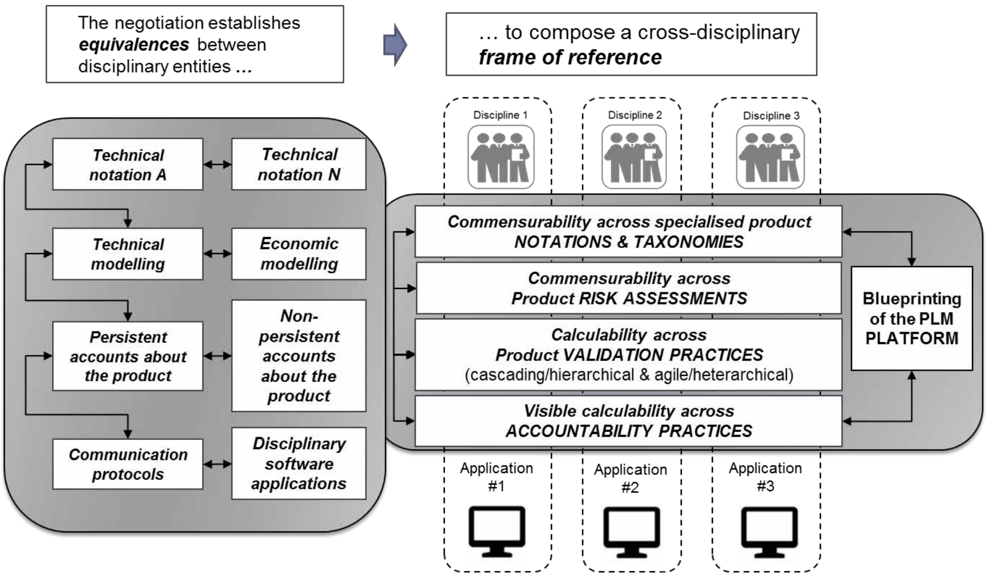

Figure n° 21/ PLM mediations organise a simplified and extended account of the "product lifecycle"

4.8. How PLM mediations work?

The PLM blueprinting process takes a different course as the software vendor introduces a complementary discussion about the need to define the "multi-tier" client-server architecture. [48] This is achieved through a middleware that streamlines application interfacing and secure cross-application communication. [49]

Instead of connecting applications through a series of more or less standard adaptors, the proposed three-tier architecture enables more reliable messaging

[48] The Multi-Tier Architecture is composed of a "client tier" (web browser, mobile devices, etc.), an Application tier (Web server, business applications, file vaults) and a Database tier (Database servers, LDAP).

[49] For a more detailed description of the role played by a middleware and the "Enterprise Service Bus" see the paragraph *ESB Architecture* in http://en.wikipedia.org/wiki/Enterprise_service_bus

services across specialized applications. The proposed IS architecture is based on an "Enterprise Service BUS" structured by a middleware.

The middleware simplifies and extend client-server architecture through the introduction of communication protocols [50] that are both common to all major disciplines and are also persistent across discipline boundaries. These *communication protocols* expand the cross-disciplinary capabilities in two directions. [51]

First, *routing* capabilities support unidirectional data flows guaranteeing correlations and commensurability across heterogeneous information. Data processing is limited to the mapping of one way (lexical) equivalences enabling capabilities such as:

- Authentication & authorization management (role based access rights);
- Create, Search, Request services;
- Explore / Navigate / Administer / Visualize information about "release readiness";
- Controlled access to trusted documentation (Policies, Methods templates and tools);

  Second, *synchronisation* capabilities support bidirectional data flows enabling more complex coordination operations (e.g. pattern matching). Data processing works through associative links. Resulting equivalences enable (semantic) *interpretations* of the impact of inconsistencies across disciplines – examples of capabilities are:

- Cross-discipline Requirements Management (Baselining, track requirements interdependencies);

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[50] Particularly the development of a new set of routines, protocols, and tools to build the necessary "Application Program Interfaces" (APIs) called *RESTful* APIs.

[51] There are various standardization bodies working towards more stable standards for middleware technology. See for example, OSLC (http://open-services.net/), "Codex of PLM Openness" (http://www.prostep.org/en/cpo.html), or standards such as STEP / ISO 10303 (standard for the computer-interpretable representation and exchange of product manufacturing information.).

- Cross-discipline configuration management and Change Impact Analysis based on multiple effectivities navigation and Configurable links;
- Cross-discipline design reviews (mobilizing software applications sur as Master geometry, Space allocation, Functional DMU).

Through these *routing* and *synchronizing* protocols, the middleware inscribes a new form of cross-disciplinary mediation that scales-up accounts of the product integrity to a cross-disciplinary level. It acts as a “knower” (Law & Singleton 2005) that materialises the collective capabilities that *hold together* the *loosely coupled* practices within a *shared hierarchical* account of the evolving CMS product *lifecycle*.

The cross-disciplinary middleware performs the technical principles put forward by material “multi-tier” client-server architecture. It consequently defines and organises *what* information needs to be known/shared across disciplinary boundaries. It also, organises *when and where* knowing takes place by *expanding* and *contextualising* the materialised accounts about interdependencies/discontinuities and potential inconsistencies of product “release readiness”. Finally, it makes visible the *accountability patterns* by equipping cross-disciplinary roles with cognitive capacities to assign and make known – at cross-disciplinary level – disciplinary judgements impacting risk mitigation agencies.

Risk mitigation processes are no longer based on *ex post* descriptions of product integrity managed by program managers. The cross-disciplinary account of “product release readiness” attaches - through O-O “links” to a network of “objects” - main traceable, calculable and persistent disciplinary agencies that secure CMS product lifecycle management.

Consequently, inconsistencies/discontinuities over the constant evolutions of the “product lifecycle” are automatically framed and up-dated. Differences in pace of change management practices occurring between electric, software and hardware related disciplines are summed up (*“encapsulated”*) through more reliable workflows.

Records of requests for change from one discipline are automatically kept as they are transformed into work items for the discipline that will accomplish the subsequent activity. Tasks may also be automatically assigned to various other teams so that they can pursue the development activity.

4.9. Revisiting our initial propositions

We have seen in the introduction to this chapter, that one of the major weaknesses of the CMS-Co Systems Engineering initiative is generated by the lack of collective capabilities to calculate the impact of the *discontinuous* propagation of technical and economic modifications introduced by each individual discipline. The lack of visibility and control over cross-disciplinary inconsistencies/discontinuities puts at risk the capacity to trace product “release readiness”.

The rather formal Systems Engineering framework doesn’t have an operational impact on the actual cross-disciplinary traceability of CMS product “release readiness”. The high-level justifications about the business benefits of concurrent engineering have no grasp of current adhocratic practices.

We observed that the proposed *frame of reference* defined during the blueprinting process tries to circumvent these obstacles. At the final steps of the fourth trail of connections, the PLM blueprint expresses a re-configured *frame of reference* where the methodological recommendations about the implementation of concurrent engineering are part of an extended account of “product release readiness” consistently embedded in the cross-disciplinary middleware – the “enterprise service BUS” (figure below).

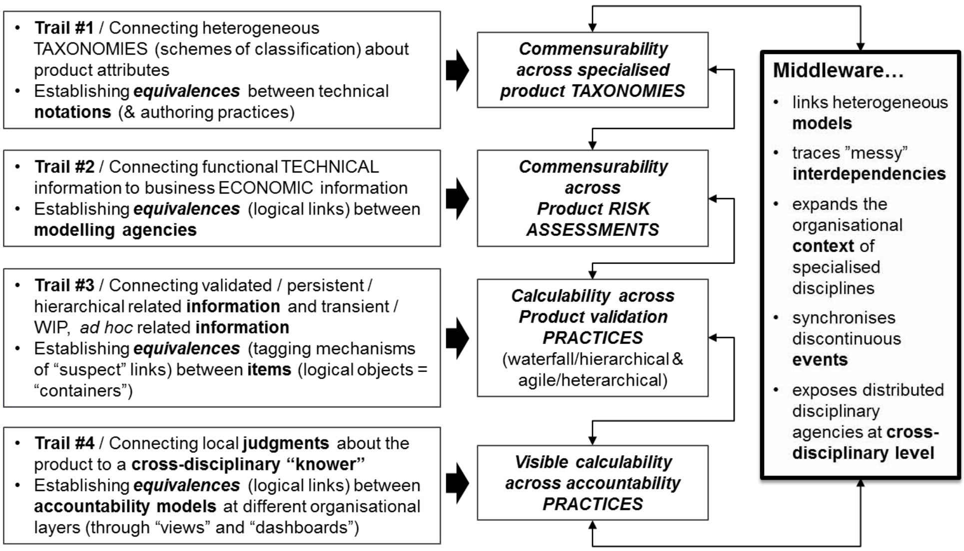

Figure n° 22/ The role of the "Enterprise Service BUS" (middleware)

A compromise is achieved through which the "*heterarchic*" *forms of organisational accountability prescribed by concurrent engineering methods, are (re)distributed through technical capabilities materialised by a "multi-tier" client-server architecture.*

In this final section, we discuss how the empirical evidence presented above allows us to better understand how PLM mediations perform an organizing role across engineering disciplines. To do so we will go back to our research question - *how does the blueprinting process of a PLM platform assemble the disciplinary agencies accounting for a new product across organisational boundaries* - and review the following three propositions:

- Proposition 1/ The blueprinting process alters the way PLM mediations define what information needs to be known/shared across disciplines.
- Proposition 2/ The blueprinting process alters the way PLM mediations define when & where information sharing takes place.

- Proposition 3/ The blueprinting process alters the way PLM mediations define accountability across organisational boundaries.

We propose to revisit these propositions in view of the four trails of connections structuring our Case Study findings.

Proposition 1/ The blueprinting process alters the way PLM mediations define *what information needs to be known/shared* across disciplines.

Starting from the Use cases presented in Request-For-Quotation, we described how the various "trails of connections" transform initial CMS-Co approach. In the beginning of the negotiations the blueprinting approach was focused on the creation of a single instance that could collect and manage across discipline boundaries, *all* information composing the "auditable accounts" of CMS product. In this initial phase, the definition of a cross-disciplinary referential is conceived as a CMS entity that *substitutes for* or *supplements* local knowing practices – cross-disciplinarily is defined as a centralisation process driven by the replacement/consolidation of existing applications.

The blueprinting process is at first engaged on the basis of required functional attributes of the PLM platform aimed at sharing documents across organisational silos. The organisational model accounting for the industrial products across organisational boundaries, is structured around folders. The consistency of the model is given by the capabilities enabling *"users"* to access a *"folder."* The latter is viewed not only as a common vault but also as a common structured referential – or, a "*single source of truth.*" (primarily, a relational database).

Progressively, the blueprinting process leads to the reinterpretation of initial requirements stated by the *Request for Proposal* issued by CMS-Co teams. Instead of creating this hypothetical *"single source of truth"* the final blueprint of the PLM platform expresses an alternative form of account of the CMS product. Instead of sharing information about the product, engineering teams share the collective capabilities to access, analyse and compute the *attributes of logical objects accounting for product attributes.*

Through this first movement, the PLM platform inscribes local, discipline specific practices and specialised software applications, in a common cross-disciplinary referential (the data model structured around the "Multilevel Product Structure"). The PLM platform mediates the elaboration of more abstract and comprehensive cross-disciplinary accounts of the Combat Management System.

<table>
<tr><td colspan="2">The exploration of Proposition #1 shows that the blueprinting negotiations lead to a transformation of the morphology of concurrent engineering as they define a single cross-disciplinary Data model.</td></tr>
<tr><td>PLM mediations enable top-down persistency (tightly coupled coordination)</td><td>- persistency secured through the compositions of an abstract account of relationships between heterogeneous engineering software applications;

- O-O modelling principles perform a static account of equivalences between disciplinary modelling software applications

- O-O modelling "objects" ensure commensurability across CMS product related taxonomies.</td></tr>
<tr><td>PLM mediations preserve bottom-up transiency (loosely coupled cooperation)</td><td>- Transiency is preserved as O-O modelling "encapsulates" and abstracts specialised modelling notations & practices without imposing the merger of disciplinary modelling practices/taxonomies.</td></tr>
</table>

Gradually, the objective of the PLM platform is no more focused on the *content to be shared* but on the definition of collective capabilities enabled by interoperable *virtual containers*. As the blueprinting initiative evolves through the subsequent trails of connections, the PLM platform performs the logical and dynamic connections across local *knowing* practices and enacts an alternative, layered, contextualised *frame of reference*.

Proposition 2/ The blueprinting process alters the way PLM mediations define when & where information sharing takes place.

PLM mediations define *when & where sharing takes place* through the enactment of more abstract, traceable and scalable accounts of an emerging industrial product across organisational boundaries.

The exploration of Proposition #2 shows that the negotiations transform the morphology of concurrent engineering as they enact traceable "links" between "objects" linked through logical relationships.	
PLM mediations enable top-down *persistency* (tightly coupled coordination)	- Computable, logical "links" trace modelling software applications and associated engineering practices from requirements definition down to the product usage – for example, a link states that: ["Object" is "Satisfied by…"]. - The logical *"links"* guarantee traceability and calculability across discontinuous product descriptions;
PLM mediations preserve bottom-up *transiency* (loosely coupled cooperation)	- The calculable traceability *contains and confine* ("encapsulate") "loosely coupled" interpretations about changes of product integrity. - Transient practices are traced but preserved: the logical *"links"* assemble and trace hierarchic (top-down / "waterfall") practices and transient (iterative / "agile") practices in one same traceable account of the product "release readiness. "

The PLM vendor succeeds in redefining how the PLM platform may put under control the complex and intricate network of changes in the accounts of the Combat Management System. The mock-up of the future PLM platform demonstrates an operational way to simplify representations of complex relationships leading to a common account of the new product across disciplinary boundaries.

At the core of this process are the collective capabilities that make visible the interdependencies/ discontinuities at cross-disciplinary level. We have emphasized that this is possible because the PLM vendor sets up a parallel negotiation about the "multi-tier" architecture through which, a middleware enables the *repurposing* of local taxonomies. *So, instead of sharing documents, CMS engineering teams share the capacity to access, analyse and trace logical links connecting "containers" ("encapsulating"* disciplinary content). Discipline specific taxonomies are now inscribed in traceable equivalences supported by *"links"* between *"persistent objects"* across organisational contexts. This stabilised account of the *"CMS product lifecycle"* may be represented and traced across disciplinary boundaries.

Proposition 3/ The blueprinting process alters the way PLM mediations define accountability across organisational boundaries.

In this new context, PLM mediations perform the redefinition of accountability patterns across disciplines. The cross-disciplinary "knower" equipped with capabilities to act and validate commensurable product "release readiness" across organisational boundaries, institutes preferred courses of action through which specialised engineers become compelled to take into account what other disciplines may do to the "product lifecycle."

The exploration of Proposition #3 shows that negotiations characterise PLM mediations that perform an organizing role by bundling calculative agencies to judgements across organizational boundaries	
PLM mediations enable top-down *persistency* (tightly coupled coordination)	- The introduction of a middleware conveying powerful communication protocols, provokes the layered visibility about complex interdependencies. Communication protocols move the "User experience" to the cross-disciplinary portal – and transform therefore, the morphology of relationships. - Visibility at cross-disciplinary level of disciplinary judgements and practices, redefines who "owns" product integrity. Increased visibility of accountability patterns combines "object" centric (lexical) accounts and capacity to interpret (semantic) inconsistencies generated by heterogeneous validation practices.
PLM mediations preserve bottom-up *transiency* (loosely coupled cooperation)	- As a result, "open conversations" between disciplinary engineers are preserved – even though they become visible, and are continuously, under the scrutiny of "peers" (through "views" and "dashboards") - Visible calculability of product "release readiness" is therefore assembled to (enacted) *heterarchic* accountability models.

4.10. Summary of case study #1 and progression in the argumentation

We have brought empirical evidence revealing in what manner, through the four trails of connections, the PLM platform becomes an operational *"metrological chain"* (Latour;2005) spanning across specialized disciplinary domains.

We pointed out in the Case Study's introduction that concurrent engineering processes face a paradox: engineers must be able to both, implement *tightly coupled coordination* processes across disciplines as well as create the organisational conditions for *loosely coupled forms of cooperation* between disciplines.

We have shown that PLM mediations compose a cross-disciplinary *frame of reference* that enables both the *extension* (scale-up disciplinary practices to cross-disciplinary level) and the *enactment of discontinuities between* these two potentially divergent trends. The *frame of reference enacts* organisational discontinuities and makes technical interdependencies *visible.* The consistency of the novel frame of reference is given through calculable forms of traceability.

We observed that the introduction of a middleware supporting a new SI architecture is a key component – the middleware enables secured interoperability across specialised applications and strengthens the associativity across disciplinary engineering practices.

CHAPTER 5 / CASE STUDY # 2 - ACCOUNTING FOR "PREDICTABLE PRODUCT SERVICEABILITY"

This chapter presents the results of a second qualitative case study concerning the negotiation about a PLM platform aimed at articulating the engineering and maintenance services of a biotechnology product used for micro-biology *in vitro* diagnostics for the medical and industrial sectors.

The chapter contributes to the academic debates around the understanding of the role played by PLM platform in articulating the engineering of a complex product, and its use by the final customers.

We structure the presentation of the empirical findings into five "trails of connections" revealing how the negotiation articulates, on one hand, engineering issues concerning the connection and data collections of the biotech machine being used by the end-customers and on the other hand, the associated maintenance services.

5.1. Emerging competitive landscape of "Internet-of-Things"

The biotechnology company studied in this case is engaged in a major evolution of its business model aimed at introducing new ways to concurrently sell machines, trace service operations and learn from predictive maintenance and troubleshooting practices. The blueprinting initiative of novel PLM platform is a component of this wider strategy aimed at implementing a new "servitization" offering. [52] The latter consists in providing the biotech product integrated into "bundles" of maintenance services capable of generating continuously new sources revenue throughout the product lifecycle.

The new strategy implemented by the biotechnology company - referred to hereafter as Diagna [53] - requires collective capabilities to enhance the *predictability of maintenance services* that will be offered through *"smart, connected products"* (Porter & Heppelmann 2014) – in our case, *in vitro* diagnostics machines used by laboratories and hospitals.

Designing, engineering and servicing such products, calls for concurrent engineering processes across various organisations. The information about the product and its related services must be *assembled* under a consistent and scalable account of the *serviced product lifecycle* - including, information about the more or less structured patterns of use of product by the final customer. This requires bringing together engineers with different skills and collective capabilities to mobilize heterogeneous knowledge domains to improve the *predictability of maintenance services.*

Challenges emerge as serviced products are more or less "loosely coupled" to complex maintenance practices. Indeed, the company does not have sufficient control over the way its own services teams track and support the machines used by the laboratories and hospitals.

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[52] Terms such as "servitization" (Vandermerwe & Rada 1988; Lightfoot et al. 2013), "open service innovation" (Chesbrough 2003; Chesbrough 2011), refer to a business models shift in which a service offer is added or integrated to the product throughout its lifecycle.

[53] For confidentiality reasons we have changed the name of the company. It is one of the major European players in the market of *in vitro* infectious disease diagnostics systems.

As we observed in Case study #1 above, the PLM blueprinting process is also caught within a paradox consisting in the need to support simultaneously the two dimensions described in the table below.

Tightly coupled coordination across disciplines – structured by strict management rules and regulatory policies.	*Highly standardized formal* cross-disciplinary validation processes imposed by the fact that biotechnology products must comply to healthcare related standards (for example, user authentication of *in vitro* analysis and data transfer constraints[54]). Connections to machines in use must comply to strict confidentiality and security rules.
Loosely coupled cooperation between engineering, support services and customers.	*Adhocracy:* maintenance practices deployed by Field Services Engineers (FSE) are characterised by a wide diversity of informal relationships with final customers (hospitals and laboratories).

Table n° 10 / Combining conflicting requirements of concurrent engineering

We will show how throughout the negotiation about the required PLM platform, teams from Diagna and the software vendor define a new *frame of reference* that may enable the *synchronisation* between these two potentially divergent trends.

[54] The blueprinting process was heavily impacted by specific rules enforced in the USA concerning Health Information Privacy standards such as the *Health Insurance Portability and Accountability Act* – HIPAA.

5.2. Leverage relationships between a product and its related services

Diagna and the software vendor providing the software package engage in a dialogue structured, in its initial phase, by controversies concerning on one hand, the *technical configuration of the technology* and on the other hand, the *organisation of scenarios of use* that should be set-up during the actual deployment phase. [55]

We study the incremental shifts going from the analysis of a legacy PLM platform – where the focus is put mainly on *remote monitoring services* - to a more complex model recommended by the software provider, aimed at instituting an expanded set of relationships with the final customers through PLM capabilities.

We have mentioned that Diagna encounter many challenges when trying to leverage the relationships with the final customer to enable a more accurate predictive service model.

First, the complexity of cross-disciplinary relationships: there is a need to enable and control cross-disciplinary account of the servicing processes supporting the new product within an organization that is characterised by a very high degree of decentralization. Local Support Services teams do not always comply with corporate policies. During the interviews, we observed a wide diversity of Support Services related practices such as engineering of repair procedures, writing technical bulletins, managing spare parts, coping with standards about Maintenance, Repair and Overhaul (MRO) legal rules, etc.

Second, le complexity of dominant product engineering processes: there is a need to rationalise the way Engineering teams develop their products so that Services teams can more easily define maintenance policies to *predict* the technical reliability of the *in vitro* diagnostics machines.

[55] The case study does not address the implementation phase that was engaged subsequently and is still ongoing. So strictly speaking, we don't analyse the actual use of technology but the blueprinting process that defines the way the (future) use of the ICT platform is defined.

5.3. The need to build an account about the *serviceable product* across organisational boundaries

Diagna's i*n vitro* infectious disease diagnostics systems are used in both clinical and industrial microbiology domains. Its worldwide presence in this market was achieved mainly through acquisitions of leading providers of technology in clinical and industrial microbiology.

The business model that contributed to the firm's historical development was based on designing and selling "products" that are used for diagnosing infectious diseases and providing medical test results for cardiovascular emergencies and cancer screening and monitoring. The profitability is achieved by providing complex machines for *in vitro* biological testing, coupled to the supply of the corresponding reagents required to detect, identify and quantify agents that cause diseases. So the rapid and sustainable growth of the company was based on the expansion of the *number* of machines sold coupled to high *margins* in selling the reagents for long periods of time.

The business model that drove high profitability is being challenged more and more by the fact that revenues decrease as reagents play a less important role in the new generation of testing technology. Testing technology used for diagnosing infectious diseases and for cardiovascular emergencies and cancer screening and monitoring is rapidly changing.

5.3.1. Engaging in the initial learning curve

The company is engaged in finding a new growth strategy. The search of new growth drivers is characterized by the creation of offers linking the product and the reagents to the maintenance and support services.

The first phases of the development of the new offering consists in organising the deployment of Diagna's *serviced products*. Dominant engineering processes are not well coupled to the emerging "Servitization" concepts based on sophisticated maintenance offerings defined by marketing teams.

Servitization marketing principles are at first, deployed through formal business plans to all local subsidiaries that are in charge of the actual service engagement model with hospitals and laboratories.

Local sales teams decide ultimately *"if, how & when"* the *servitization* business model is actually deployed locally.

Local Service Support teams struggle to comply to prescriptions from Corporate marketing teams. During the workshops aimed at qualifying the requirements of the future PLM platform, Service Support representatives affirm that the prescribed "Servitization Sales policy" is not in accordance with the local market specificities. More generally, local service teams lack appropriate skill sets. In this respect, there is a substantial variety of situations. In mature markets, there is an established relationship between the Field Service Engineers (FSE) in charge of the support of relatively small subset of local hospitals and laboratories. The FSEs are somewhat autonomous in organising their maintenance tasks following the individual analysis of the "log files" from the machines which they are responsible for. This approach generates an organisational model that is highly dependent on frequent visits coupled to a rather *ad hoc*, reactive, customized approach that conflicts with Corporate driven servitization policies.

5.3.2. Assembling knowledge about the use of the industrial product

In the course of the initial phases of the PLM blueprinting process, the emerging *servitization* offering is perceived as being incompatible with the commercial and technical imperatives of the dominant customer relationship patterns. In contrast, in comparatively smaller and emerging markets, the FSE activity is highly structured and tasks are more formalised.

Engineering teams lead the design and deployment of a PLM platform that is aimed at establishing a more consistent link between the product and its final usage. Engineering teams face new challenges as the actual development of connectivity features requires relatively new skill sets – particularly on the design of the underlying data model that supports information transfer across organisational boundaries.

The purpose of the blueprinting process is to define *how* the PLM platform could establish a more reliable relationship between the development of a machine for *in vitro* diagnostics and the *usage* of the product by the final customers.

Controversies emerge around the best way to account for the *serviced product condition.*

The figure below summarises the three main components of the negotiation generated by the introduction of the target PLM architecture:

1. PLM mediations must capture information about the real-time performance of the "smart and connected" *in vitro* diagnostics machine (machine in use).

2. PLM mediations must capture information about the reliability of Digna's product support and maintenance practices;

3. PLM mediations must capture information about the usage of the already deployed *in vitro* diagnostics machines and the consistency of the healthcare professional's practices (diagnostics operations performed by hospitals and laboratories).

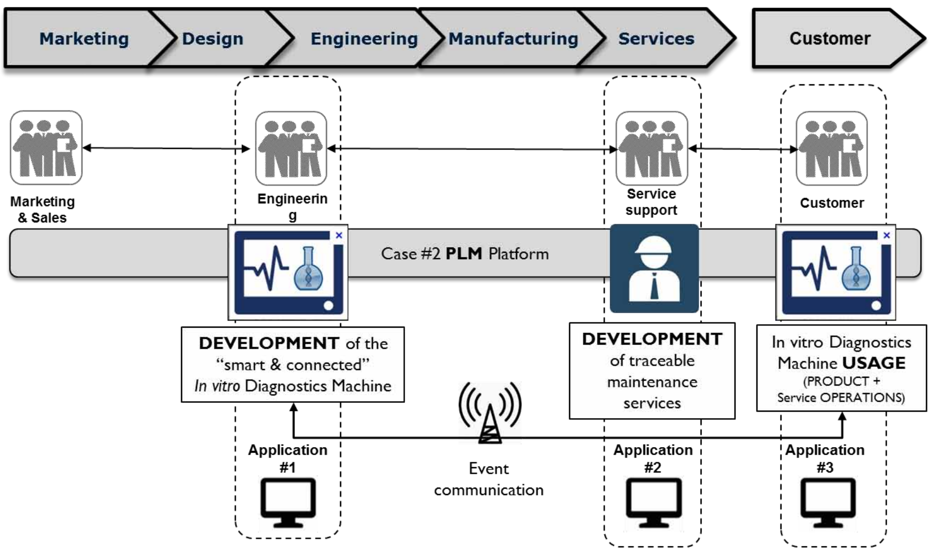

Fig. n° 23/ Scope of the PLM blueprinting negotiation

5.3.3. Data collection is structured around anticipations of Scenarios of use of the PLM platform

We have already described the qualitative research approach in the chapter about research methodology. We recall nevertheless the main steps of our data collection approach for Case Study # 2.

Empirical data is collected through the negotiation between a biotechnology company and a software provider. We study how the convergence between organising and technology is enacted through the negotiation between the two firms during the blueprinting phase of the new software platform.

The case study takes place before the actual implementation of the PLM platform is realised – empirical data is collected during the *blueprinting* process of a PLM software package[56].

[56] The software package is described here: http://www.thingworx.com/platform/

The data collection protocol is structured around sequences through which *anticipations of the future use* of the information system are incrementally revealed, discussed, formalised and validated. The data collection process lasted approximately five months. It consisted in collecting primary documents about servitization marketing policy coupled to the participant observation within workshops and semi-structured interviews with engineers. We followed the negotiations around the "use cases" defining the future PLM platform and its envisaged use within hospitals and laboratories.

During workshops involving both Diagna and the software vendor teams, we observed the convergence between the "demand" (functional requirements of the future IoT platform) and the "offer" (Use cases expressing scenarios of use conveyed by the software vendor offering). A "Proof-of-concept" or mock-up of the PLM platform is used to articulate this confrontation between "offer" and "demand."

The Proof-of-concept demonstrates the capacity of the PLM platforms to support the following three types of capabilities.

CONNECTIVITY LAYER / Secure agents and middleware and support hybrid networks	
The *demand* expressed by Diagna	The *offer* proposed by the software vendor
Use cases concern:	*Scenarios of use* focus on:
- Connectivity of remote devices (*in vitro* diagnostics machines operating in laboratories and hospitals) and transfer machine and sensor data into the cloud. - Asset connectivity protocols between the	- capabilities to *connect* the sold product to a database through an "agent": leveraging the agent technology and connectivity services to rapidly and flexibly connect to any wired or wireless asset via third-party device clouds, direct network connections, open APIs or edge devices. - capabilities to *monitor* the condition of the product at the EDGE: providing secured real-time bidirectional communication with devices;

healthcare device and the cloud, where data is structured and subsequently transferred to relevant stakeholders.	- capabilities to *exploit* any data available on the machine even after release; - capabilities to Monitor Product Operation / Use (manage main internet message protocols and formats); - capabilities to allow high *security coverage* and *security features* concerning user identity management: ensuring compliance with policy management for access control, logging, and auditing of interactions with connected products and assets (particularly healthcare related security standards and protocols).
DEVICE AND DATA MANAGEMENT LAYER / Process information flows	
The *demand* expressed by Diagna	The *offer* proposed by the software vendor
Use cases concern:	Scenarios of use focus on:
- Securely process and collect machine and sensor data; - Data and Event management aimed at establishing a material relationship that is coupled to the Service Level Agreement & warranty policy.	- capabilities to *manage "agent" lifecycle*: rapidly integrate "agent" with enterprise data from business systems, time series data from connected things, and unstructured feedback from people to rapidly respond to changing business requirements and uncover actionable insights. - capabilities to *interact in real-time* with connected products to perform remote service activities including machine adjustments, software updates, and self-tests to avoid downtime and eliminate need for on-site service calls. - capabilities to *analyse and benchmark product performance* and usage data collected through remote connectivity with sensor-equipped products or systems to inform and improve product requirements

	definition, prioritization of features, options and variants, market segmentation, life cycle costs, and supply chain coordination and planning; - capabilities to *capture (apparently unpredictable) events* into a traceable sequence of tasks: monitor connected product operating characteristics and combine with thresholds, trends, and analytics to move from reactive to proactive maintenance; - capabilities to *codify local "maintenance tasks"* into a cross-disciplinary servicing process: automatically trigger service events based on pre-emptive connected product alerts, diagnose issues, determine the best service response and dispatch technicians based on SLA entitlements and resource availability; - capabilities to *enable remote diagnostics* and service: continuously analyse field data collected through remote connectivity with sensor-equipped products or systems to improve root cause analysis and corrective actions, product quality, reliability and safety, preventive maintenance, and service; - capabilities to *create a scoring table* to trace optimization opportunities of the connected product performance.
APPLICATION DEVELOPMENT ENVIRONEMENT / Enable "agile" development principles	
The *demand* expressed by Diagna	The *offer* proposed by the software vendor
Use cases concern:	*Scenarios of use* focus on:
	- capabilities to *establish rules, business logic, and algorithms* that analyse and correlate unstructured, time-series, and

- The definition of the IoT applications development environment; - An environment that enables a graphical "mashup" of data from heterogeneous "objects"; - An environment that supports data analytics reporting capabilities.	transactional data to optimize business processes and discover new opportunities and insights that answer Diagna's business questions; - capabilities to *collect and analyse product usage, condition, and consumable data* to anticipate customer needs, automatically trigger alerts for cross-sell and up-sell opportunities, forecast future purchases, and create new consumable resupply models. - capabilities to *interact with connected products* to identify and diagnose product issues remotely to eliminate unnecessary service calls and improve first time fix rate. - capabilities to *process and manage healthcare related data* and to collect & maximize the number of data points in an analysis. - capabilities to *enable customer (hospitals and laboratories) to monitor and track the usage* and performance of their Diagna products or benchmark with anonymized peers to optimize the value they extract.
- Application development	- *Scenarios of use focus on "agile" IoT Application Development* - capabilities to *develop Apps* independently form connected *in vitro* diagnostics machines: leveraging an IoT platform with a model-based application development environment to reduce the time, cost, and risk required to build and maintain innovative connected applications that differentiate products and services and provide a competitive edge for Diagna's servitization business model.

5.4. Trails of connections reveal the composition of a cross-disciplinary "frame of reference"

We have explained in Chapter 5, why we adopt a methodological framework structured around the concept of "trails of connections" (Nicolini 2009) revealing the way equivalences are established between disciplinary practices and software applications.

We will describe now how the PLM blueprinting negotiation is structured around four *trails of connection* will ultimately assemble a novel cross-disciplinary *frame of reference* supporting the servitization related business requirements.

We will follow through these trails connections, how Diagna and the software vendor builds progressively the operational *"links"* to account for the "serviced product lifecycle:"

- the technical condition of the "smart, connected product" in use (alerts monitoring);
- the organisational practices ensuring repeatable diagnostics and traceable ways to repair and overhaul product condition – including connections to planning and execution of maintenance operations executed by Field services engineers;
- contractual accountability including servitization business goals and responsibilities involving judgements about the way final customers interact with Field services engineers.

The figure below outlines the research design aimed at exploring our research question – *How does the blueprinting process of a PLM platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?* - to the five trials of connections:

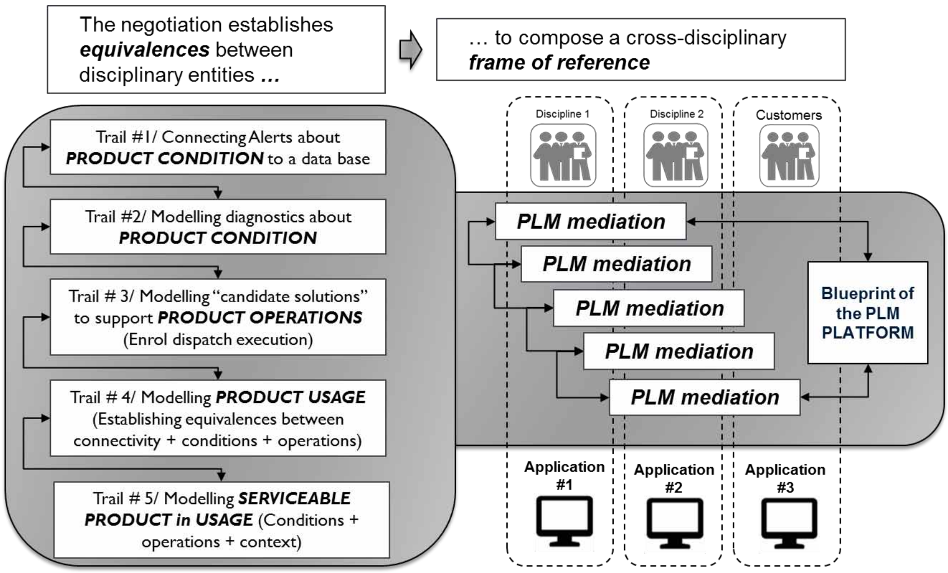

Fig n° 24 / Research framework of Case #2

We describe in the subsequent sections how - through these five trails of connections - both teams from Diagna and software vendor reach an agreement about how a novel *frame of reference* could enact accounts of the product combining not only engineering, services practices and associated software applications – but also include information about the final *usage* of the *in vitro* diagnostic machines.

5.5. TRAIL #1/ Producing equivalences between metrics of continuous asset monitoring

A first trail of connections concerns the relationships between the machine *in use* and Diagna's Services teams.

5.5.1. PLM mediations perform real time remote monitoring

By placing a software "agent" embedded in the diagnostic machine, Diagna's teams are able to monitor the actual *condition of the product* at the customer site. The embedded agent captures information about its actual conditions of the machine in use and establishes a continuous real-time flow of *alerts* describing the *condition* of the in-vitro diagnostic machine. The Agent enables a continuous monitoring of a number of sensors collecting data about the machine condition and sending alerts when this condition is altered by technical malfunctioning. When a failure occurs, the Call Centre is informed automatically. *"Alerts"* are sent to services teams when an issue is identified at the customer site. An initial diagnostic about the identified issue is established through the analysis of the "*log files*" that trace the performance of the machine *before* the failure occurred. Local Services teams deploy a *"work order"* that is communicated to a pre-appointed Field Service Engineer (FSE).

The envisaged scenario of use of the PLM platform establish an initial connection to troubleshooting practices performed by services teams. Diagna engineering teams are able to connect information about recurring machine failures and information about the associated ad hoc Field Service Engineers (FSE) practices – particularly about the number and the effectiveness of FSE visits.

The continuous pervasive *"link"* established between the *"alert codes"* accounting for the condition of the machine *in use,* and the ensuing *troubleshooting procedure* executed by the Field Services Engineers*,* modifies the role of the Call Centre team. Consequently, the human interventions by the Call Centre actions become subordinated to the *remote monitoring* capabilities inscribed in the PLM platform.

At this stage, PLM mediations introduce a first modification of relationships between engineering and services teams. Instead of owning and managing the *notifications* about machine failures, services team interventions are a supplement to the actions generated by the embedded software agent defined by engineering teams. We observe that the PLM platform mediations engage a first redefinition of *what information needs to be known/shared* across organisational boundaries: the focus moves from transmitting *discrete* information about the *product failure* (dispatch tickets), to processing a flow of ubiquitous "data points" about the *product in use*.

"Alert codes" accountings for the actual (real-time) conditions of the "As-maintained" machines are attached to, and can be compared to the *a priori* characterisation of the "As-designed" machine kept by the engineering teams.

The figure below describes the extension of the connections exerted by the embedded agent. Engineering agencies (practices and software applications become digitally connected to the *in vitro* diagnostics machine.

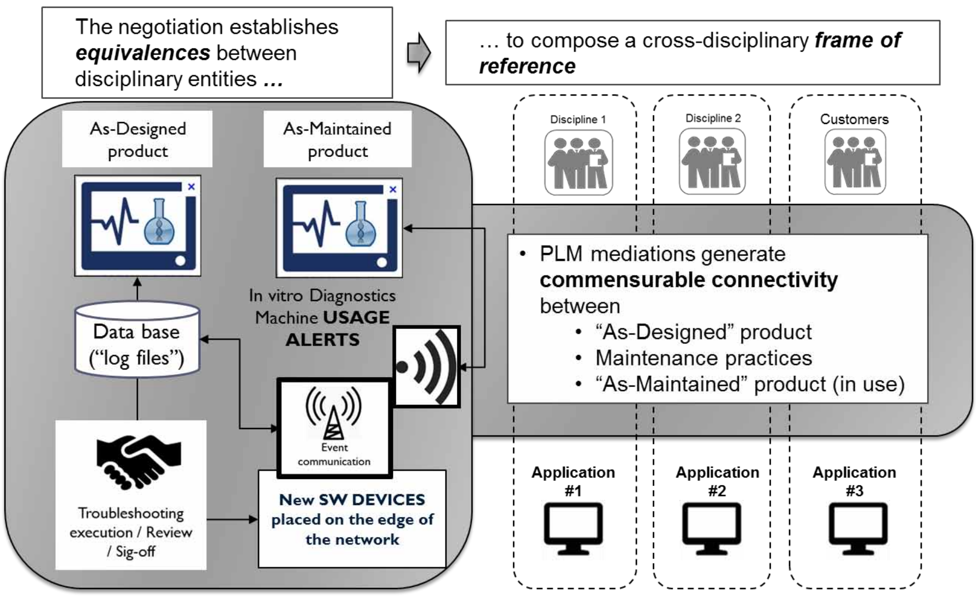

Fig. n° 25/ PLM mediations generate commensurable connectivity

In summary, Trail # 1 addresses Scenarios of use that demonstrate that account for the *condition* of the *"As-maintained"* product in use, can be continually linked to the account of the *"As-designed"* product located at the Engineering application.

Consequences/ PLM mediations compose "logical" accounts of the traceable "problem alerts," materially embody a first alteration of the relationships between Diagna and its customers. The embedded "agent" accomplish a first step towards the composition of boundary spanning "*calculative agencies*" (Callon 2005; Muniesa et al. 2007; Callon & Muniesa 2005).

5.6. TRAIL #2/ Producing equivalences between "failure" modelling devices

The initial phases of the project were focused primarily on technical connectivity capabilities supporting remote monitoring of the product in-use.

Discussions during the blueprinting phase reveal that Diagna needs to address more structural organisational impacts generated by the introduction of the embedded software in the diagnostic machine.

5.6.1. The need to improve efficiency of troubleshooting execution

The second trail composes links between technical connectivity and the organisation of the troubleshooting execution. Connections are established between on one side, a *modelling device* of recurring failure alerts, and on the other side, two organizational mechanisms: technician *dispatch processes* and *diagnostic practices* deployed on site, by the FSEs.

The PLM platform leads Service support teams to focus is on the *"root causes"* of services execution inconsistencies that generate the relatively high number of recurring visits by FSEs to their customers. Topics addressed revolve around two main operational factors: first, sales teams claim a lack of a clear *"value proposition"* to support their commercial campaigns targeted to hospitals and laboratories. The lack of sales material to support the offer of connected products results in limited business development of the servitization related revenue. Corporate marketing team asserts that *"strictly speaking, the remote monitoring capabilities enabled by PLM platform are not yet sold. Local Sales forces tend to give it for free in order to sell the diagnostic machines"*.

Moreover, local Service teams require proper skills to manage the increase in the inbound information flow generated by the PLM platform. Many local teams sustain that they face many problems due to the lack of local FSE skills: *"There* are *no trained resources to support connectivity issues. This generates wrong diagnostic results, inefficient spare parts management and finally ad hoc service procedures"*.

5.6.2. PLM mediations formalise accounts of *candidate solutions* to repair connected machines

During the blueprinting workshops, experts from different departments systematically analyse the way FSEs manage incidents and formalise a sample of *"problem alerts"* to constitute a simplified repertoire of *"formal solutions"*. The sample formalized by the experts is logically organized into categories called *"domain model."* One of Diagna's main product lines is selected to illustrate within the mock-up environment, the envisaged capabilities inscribing *"candidate solutions"* in the future PLM platform. Each domain represents a key aspect of the way support requests about Diagna's products are currently issued (e.g. request type, product, symptom, error message, etc.). Domain modelling coupled to advanced search methodologies outline a first version of the future repertoire of *candidate solutions* containing *"typical"* information that a maintenance expert needs in order to quickly and accurately solve the machine failure.

The set of predefined *candidate solutions* is incrementally detached from contingent *on-site issue resolution.* The way Field Technicians use terms to refer to the recurring issues and submit support requests to the Call Centres, becomes increasingly normalised. [57]

The need for a new organisational role is also identified: a group of troubleshooting experts assigned to complete a collection of generic, standardized terms that describe most frequent issues identified within machines *in use.* Rules about troubleshooting content creation are written

[57] Main concepts mobilized are: "Free Text Search" (natural language processing, synonyms, clarification questions, matching rules, patterns), "Guided Search" (dynamic guide, static decision tree), "Advanced Search" (attributes types, weights, filters), Sensory Search (images, sounds, videos), "Attachment Search" and "Federated Search".

from an end-user ‘symptom’ perspective. The various information sources used for troubleshooting are also restructured to address inconsistencies about problem solving procedures and question descriptions.

The initial repertoire of incidents can be regularly improved by a *real-time* flow of failure code alerts. Progressively links are established between *local*, *ad hoc* diagnostics practices and *generic*, *formalised* tables of recurring failure codes alerts. The local technician dispatch is henceforth inscribed in a wider, cross-disciplinary *“ontology”:* a data model where diagnostics practices are linked to a standardised set of *predictable* candidate solutions.

As a result, the PLM blueprinting process raises controversies about how to build links between

- the ways FSEs learn from past failures,
- the way recurrent patterns may support detecting future anomalies,
- the way a cross-disciplinary *“ontology”* captures various *“types of failure modes”*.

The mock-up of the PLM platform is enriched with complementary maintenance related capabilities to address these controversies. The software vendor organises new demonstrations to characterise how the PLM platform supports a continuous process where *candidate solutions* are coupled to real-time operating conditions derived from sensors data points.

By the end of this phase of the blueprinting process, the scenarios of use are (re)defined as follows:

- The *“agent”* within the connected product *in use* detects the error codes corresponding to abnormal conditions;
- The selected error codes and conditions are connected to a remote PLM platform containing the repertoire of *“candidate solutions”;*
- The PLM platform is configured to automatically identify one or more *candidate solutions* and recommend service response for each error code or condition;

Results of the automatic analysis triggers a required remote service procedure that will – if necessary – prompt an additional diagnostic through a technician dispatch or a customer specific action;
In parallel, the PLM platform initiates a workflow tracing the impact of the recommended service response in all other interoperable interrelated service systems (CRM ticket, Spare parts inventory, Warranty management, Regulatory compliance tracking). The figure bellow presents the extending trail of connections.

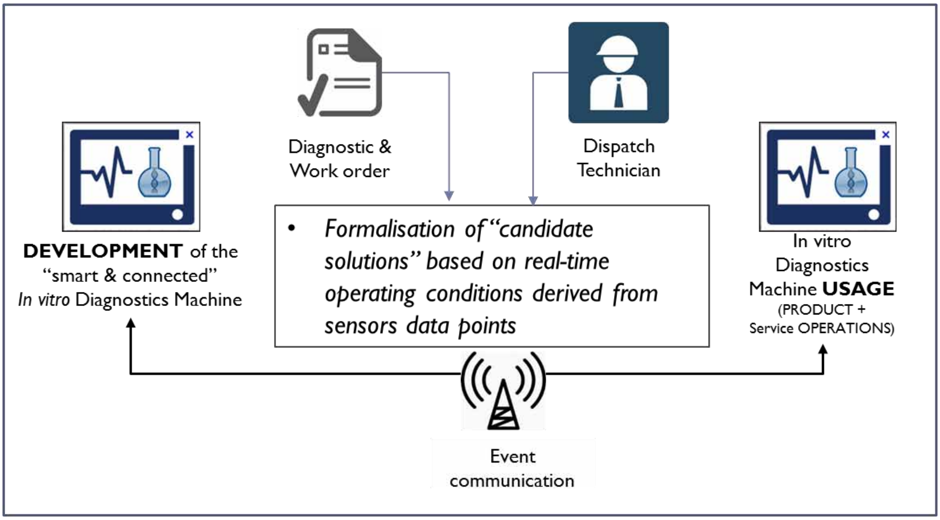

Fig. n° 26/ Scope of "candidate solutions" definition

5.6.3. PLM mediations build relationships between "candidate solutions" and "problem solving" algorithms

An important transformation in current practices is introduced as the blueprinting approach reverses the temporal perspective of the analysis of failure code alerts. This occurs as *"candidate solutions"* are linked to *"predictive problem solving"* algorithms that may guide the FSE's search for information about the root-causes of the detected failure. Instead of just mobilising their own local experiences and knowledge to analyse the information about an incident occurred in the past, Service teams are requested to engage their work from a set of pre-diagnostic *"candidate solutions"* documented in the PLM platform – this information if coupled to scoring tables that trace the diversity of optimization opportunities of the connected product in-use.

In this new Scenario of use represented through the mock-up of the PLM platform, Diagna's maintenance experts, can envisage new ways to represent and model information about "*failure modes"*. When faced by a failure code alert, the Call Centre activates a pre-defined set of *"candidate solutions."*

From then on, the scenario of use defines a process where FSEs are accountable for *preventing* failures.

Rather than reacting to alerts, the maintenance approach encompassing the extended list of *candidate solutions,* is connected to the embedded software agents supporting *remote issue resolution* capabilities. Through the mediation of this embedded agent the PLM platform generates the capability to *access* huge amounts of data about error codes and machine performance data. Local Customer Support teams can *access* both historical and real time data about the operating conditions of a *particular* machine and compare its performance with regard to *all* Diagna's machines belonging to the *generic* product line. Remote monitoring capabilities generate systematic comparison between a *particular* machine in the context of its usage, with regard to *generic* ratios describing the product line performance. FSEs are responsible for contacting customers to provide guidance on product/system performance, for recommending eventually a change in operating methods and scheduling proactive service calls to avoid product/system failures.

In summary we observe through this trail of connections, how PLM performs an organizing role by redefining organisational accountability of the troubleshooting processes.

Up until then, the technician dispatch *follows* an alert. The Call Centre issues a *"dispatch ticket"* and the technician engages in a diagnostic phase that will lead most frequently to at least one visit to the customer site to make a diagnosis and eventually solve the problem.

The PLM platform introduces a different approach by putting forward on one hand, *remote service capabilities* and one the other hand, *predictive maintenance modelling devices*.

The figure below describes the second component contributing to the extension of connections between the product and the product in use:

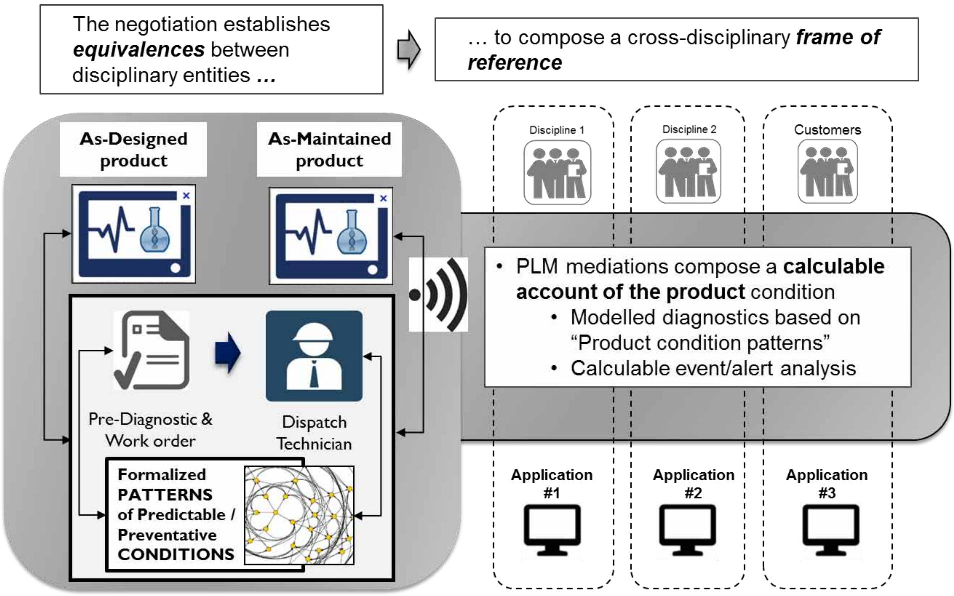

Fig. n° 27/ PLM mediations compose a calculable account of the product condition

In summary, Trail # 2 addresses Scenarios of use that detach local, *ad hoc* maintenance operations and inscribe them within an equivalent set/repertoire of standardized "candidate responses."

Consequence: "product failure" diagnostics processes are materially linked to *observable and predictable agencies* (e.g. the standardised list of *"problem* *alerts*") that establish tangible relationships between Corporate marketing policies (servitization sales targets) and day-to-day FSE practices.

5.7. TRAIL # 3 / Producing equivalences between *candidate solutions* and *execution planning* software applications

Through the first two trails of connections we described how local FSEs practices are inscribed within a more predictive account of maintenance procedures. As *locally embedded* failure/alerts are detected through remote monitoring capabilities, the *generic* repertoire of *"candidate solutions"* guides the *specific* work of the FSEs.

5.7.1. The need to reinforce troubleshooting planning capabilities

The new scenarios of use proposed by the software vendor, ensure that the servitization framework is attached to a consistent *"end-to-end"* account of the maintenance processes. However, during the subsequent workshops, Diagna's maintenance experts point to persistent open questions about the predictability of service *execution*. Even though troubleshooting processes can be *"front-loaded"* with more formalised diagnostics procedures, there are still uncertainties about the way servitization is linked to actual service *execution*.

The third trail of connections addresses the way the PLM mediations not only insure connectivity to *"alerts"* expressing a condition of the product (*what is the ongoing problem*?); mediations also take into account *"links"* to future operations (*how problems will be solved?*).

The modelling effort of maintenance execution is addressed through two main sequences: reparability analysis and service execution planning.

A first negotiation is engaged around ways to formalise *ex-ante* serviceability analysis. Generally, this dimension is rather less important in the current product design process. The lack of structured feed-back from maintenance execution phases incites Engineering teams to underestimate its importance during the early phases of the product design. Reparability policy is more often defined at the end of the product development process, just before the product launch. A member of the service engineering team remarks that the PLM platforms open opportunities to *"connect some more dots and adopt a different way of working…we need to address serviceability at the forefront of the product design process"*.

A second negotiation topic emerges during the blueprinting process, around the introduction of predictive scheduling policies in the planning procedures of local Service teams. The improvement in product connectedness creates *access* not only to information about the product *in use* and its failures. The PLM platform creates also interoperability with regard to other information sources that reveals product flaws and the lack of reliability of certain critical components.[58] *Ad hoc* repair tasks can be therefore inscribed in a wider framework about *"machine reparability"*. As a result, a *specific failure/alert* becomes part of an account about repetitive and *"no-fault-found"* service claims.

The frame of reference is expanded as the *specific* local failure is placed in the context of a *generic* service quality policy.

5.7.2. PLM mediations generate real time feedback loops

The capacity to capture sensor-based equipment data and automatically identify trends that could impact performance, contributes to reverse the way maintenance planning is conceived. Stand-alone maintenance planning applications are progressively assembled to applications capable of identifying failure trends.

Maintenance plans are designed to take into account feedback loops from real-time product performance data so that part of the ticketing process may be automatically delegated to the PLM platform through:

[58] Particularly Diagna's stand-alone quality management data bases – such as FMEA (Failure mode and effects analysis) applications.

- automated interventions: repair activities can in simple cases, be executed remotely through automated service order: service tasks are executed without FSEs interventions (ex. error code expressing the condition of the product triggers an automated (*Over-The-Air* – OTA) upgrade of firmware to solve the problem);
- semi-automated intervention: if a remote repair is not possible, troubleshooting activity can be prepared up-front through a pre-diagnostic of the problem encountered locally. The remote monitoring system alerts triggers a request for a pre-diagnostic and propose a selection of *"candidate solutions"* to the FSE.

At this stage, the blueprint results assert that knowledge about the way the customer uses the product, shall be captured to generate real time predictions about the operating in vitro diagnostics. Accordingly, the prescribed maintenance schedules may be constantly up-dated to prevent predicted failures.

5.7.3. PLM mediations define *when & where* service execution is managed

The automatic ticketing process described above establishes operational *equivalences* between on one side, the Engineering *analytical* knowledge defining what is the reparability analysis and on the other side, the Services *contextualised* knowledge of the actual product *in use.*

As a result, the PLM platform *moves* the static account of the product that needs to be repaired (a list of candidate solutions) to its inscription in FSEs daily practices.

Yet again, the PLM platform contributes to the reversing the temporal approach of dominant local troubleshooting practices. Until then, dominant organizing principles were defined locally by Service experts. Local FSEs were accountable for both, the organisation of their day-to-day work, and the execution of their predominantly *ad hoc* tasks. The whole process was characterized by a relatively low traceability.

The PLM platform acts by assembling predictable *candidate solutions* to more reliable service *execution planning* capabilities. The alterations introduced by traceability capabilities, create an opportunity for the engineering team to integrate local service knowledge into more *generic* reparability analysis. Local FSEs become even more enrolled in the "smart, connected product" devices through the predefined *candidate solutions*. They also become inscribed in a *generic* serviceability policy through a tightly controlled service planning device.

The figure below describes the third trail, contributing to the extension of connections between the product and the product in use.

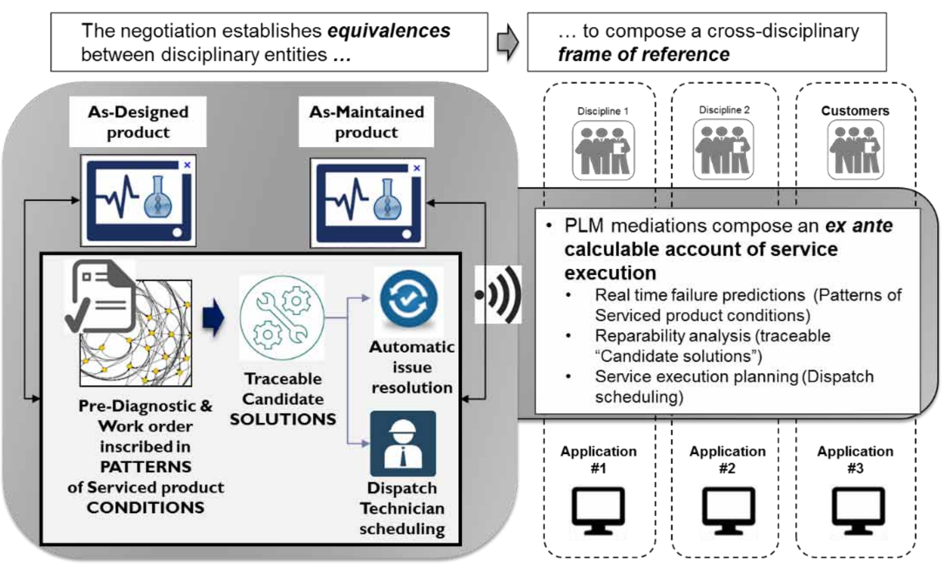

Fig. n° 28/ PLM mediations compose an *ex ante* calculable account of service execution

In summary, Trail # 3 addresses Scenarios of use that engage a first modification of the time horizon of FSEs practices.

Consequences/ *Ex-ante* account of the connected product and its associated maintenance policies can be materially linked to the way FSEs act within their specific working environments.

5.8. TRAIL # 4 / Producing equivalences between technical failures and economic calculation

The fourth trail of connections is related to PLM capabilities contributing to articulate on one side, technical information about troubleshooting and on the other side commercial profitability of Diagna's servitization offer.

The focal point of this fourth trail is the reliability of *"service level agreements"* (SLAs) between Diagna and their customers (hospitals and clinical or industrial laboratories).

5.8.1. The need to integrate economic calculability

"Service level agreements" (SLAs) are contractual agreements setting-up commitments with regard to the quality and the reliability of the various aspects of maintenance services.

An SLA aggregates heterogeneous knowledge about:

- *commercial* commitments related metrics such as warranty costs;
- *technical* performance related metrics such as asset downtime levels – e.g. mean-time-between-failures (MTBF);
- *organisational* efficiency related metrics such as repeatability of troubleshooting routines within Call centres – e.g. dispatch avoidance or first-time-fix rates, labour utilization in point of service;
- *logistics* related metrics such as inventory levels – e.g. spare parts rotation.

- The PLM platform mediates the "calculability" (Callon and Muniesa, 2005) of the economic impact of technical failures. The enhanced interoperability between software applications processing the various types of information, creates operational software applications to measure the impact of a machine failure on overall profitability of the servitization offering.

- For example, inventory data may be automatically linked to service orders:

- required spare parts can be identified and ordered appropriately;
- mapping of spare parts location can be optimized to insure reduced capital expenditure;
- resources/technician allocation and scheduling can be optimised – including the allocation of relevant documentation (repair methods, diagnostics procedures, etc.).

As a result, the blueprinting process enacts more accurate comparisons between expected performance and real performance.

5.8.2. The PLM mediations account for compliance to Service Level Agreements

Compliance analysis is based on *"performance matrices"* where field service events are compiled and traced with regard to SLAs goals. Through the PLM platform, performance matrices incorporate real-time information about the actual organisational context where customers are using Diagna's products. As we mentioned above, the embedded software "agent" produces more accurate information about the way laboratory technicians use the final *in vitro* diagnostics device. PLM capabilities would therefore, transform the way compliance to contractual commitments contained in the SLAs are measured and interpreted. Warranty policies and service entitlements can be described more precisely as they integrate *"usage patterns"* of connected products. Even though there are at this stage, still many organisational uncertainties, getting access to information about the actual use of the product, (potentially) enables Diagna to point out that a *particular* failure of the machine is due to an incorrect manipulation of a *generic* work-instruction by the customer.

The fourth trail of connections also establishes traceable relationships between different chronological dimensions:

- *Ex-ante* serviceability policies guiding the negotiations about the contractual *"Service Level Agreements",*
- *Real-time* error codes and machine data expressing the usage and the failure conditions of the specific machine - including the up-dated information following the action that restored the asset to a proper condition;
- *Ex-post* service execution practices are documented through *"performance matrices,"* including increasingly predictable machine failure patterns.

  Accordingly, the temporal dimension of the SLAs interpretation can then be reversed: the compliance with regard to SLA commitments is not only accounted for by referring to quality of the maintenance process and the assignment of responsibilities about *"what happened*" (past events). Compliance can also be measured with respect to *"what may happen"* to the in vitro diagnostics machines (probability of failures occurring in the future).

The figure below describes the forth component contributing to the extension of the trails of connections between software applications accounting for the *product,* and software applications accounting for the *product in use*.

We can see how the reliability of the Service Level Agreements (SLA) can be performed by a more accurate calculability of technical failures associated to visible judgments about the usage of the machine.

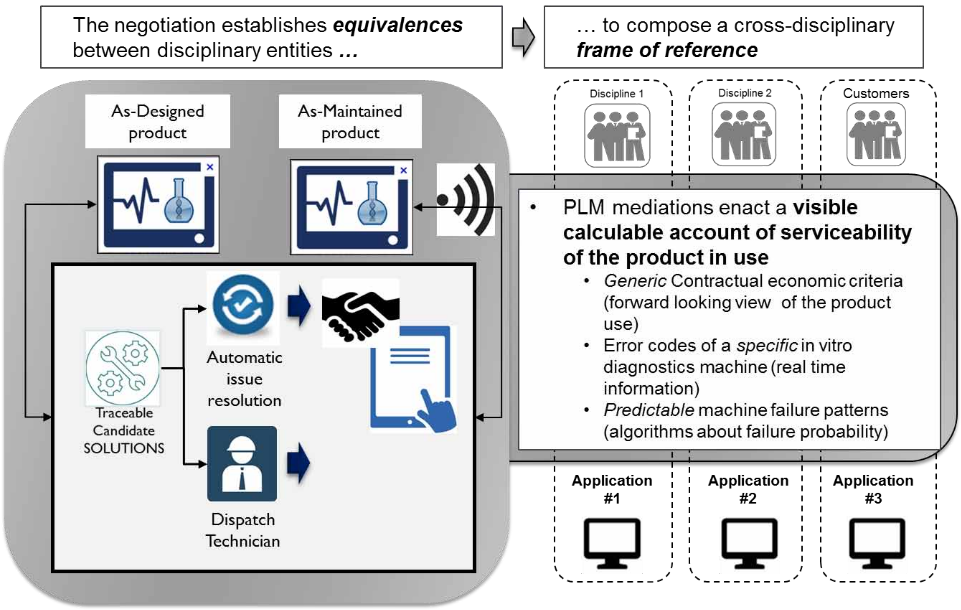

Fig. n° 29/ PLM mediations enact a visible calculable account of serviceability of the product in use

In summary, Trail # 4 addresses Scenarios of use where dashboards perform traceable equivalences between apparently unpredictable *"Events"* (a product failure), list of *"candidate responses"* (routinized solutions to product failures) and the economic criteria composing *"Service Level Agreements"*.

Consequence: ex-ante account of the industrial product and its associated maintenance policy, can be materially linked to the contractual engagement model prescribed by Diagna's marketing policies (servitization).

5.9. TRAIL #5/ Organising role exerted by modelling connectivity between the product and a serviceable product in use

The fifth trail of connections, is related to PLM capabilities contributing to define a *material* framework, to mediate discontinuous relationships between two types of accounts about the product: the *generic* product and a *specific* product *in use* by the final customers.

We will describe hereafter how all temporal dimensions become visible through a "mashup" - one of the key components of the "Internet-of-Things" (IoT) platform that describes, materialises and performs the multiple discontinuous but nonetheless, traceable layers of information sharing across organisational boundaries from Engineering, Sales and Services to the final customer.

5.9.1. The PLM mediations bring together heterogeneous modelling devices

In the early phases of the PLM blueprinting process, Diagna's IT landscape is characterised by a large number of heterogeneous software applications and a lack of interoperable standards to manage corresponding interfaces.

The focal point of this trail is the definition of a more consistent IT architecture that mediates contradictory organisational developments generated by the deployment of the servitization offering: on one hand, there is a need to *leverage* the generative capacity and the diversity of *what is to be shared and known* through local troubleshooting practices. On the other hand, there is a need to *simplify, standardize* and *control* the way these heterogeneous and discontinuous information sources are processed.

The software vendor introduces new software design and development procedures to address this tension.

Primarily, Object-Oriented (O-O) modelling contributes to simplify the specification of software requirements about serviceability related data processing. We come across the same modelling approach described in Case Study #1 above. Modelling is accomplished by "encapsulating" programming elements in more abstract, logical "objects" that share a common structure and a common behaviour.

This creates a common foundation to describe the different aspects of the material connections between the product definition and the product in use. Developers can then model relationships by defining *"links"* that establish bi-directional associations between *"objects."* The Object-Oriented (O-O) modelling produces a more abridged, layered, logical account of the multiple *"links"* that assemble different connectivity related topics. Building on O-O programming principles, the blueprinting approach moves to a more abstract account of the relationships between (1) the product attributes, (2) the monitoring of the product in use and (3) the computation capabilities required to leverage the collected data generated by remote monitoring.

The two main consequences are the following.

The O-O modelling addresses the need to reframe the way data gathering is accounted for/ A connected product in the medical devices environment must comply with a large number of security related standards – particularly concerning user authentication of *in vitro* analysis and data transfer constraints. In the proposed model, a "middleware gateway" supports the controversial transition between the initial step through which the *"embedded agent"* collects patient related data and the subsequent steps when this data is encrypted and processed. This capability generates a consolidated view of the use of the connected machine.[59]

The O-O modelling addresses the need to standardize the connectivity protocols/ The *"middleware gateway"* plays a role not only in anonymizing "data points" generated by the "embedded agent", but also in simplifying the way interfaces between legacy software applications are accounted for. As a result, the gateway creates new resources to bypass the impact of regulatory compliance. The introduction of a new set of protocols (based on

[59] Controversies about users' authentication related issues created critical organisational challenges which almost stopped the project and generated supplementary delays due to the need to significantly redefine the IS architecture. Servitization related capabilities introduce new constraints for Engineering teams: first, the design of the monitoring device generates more complex verification & validation procedures that structure the medical devices industry (rigid FDA rules). Second, each time the monitoring device is up-graded with new functionalities, the verification & validation process must be redeployed to assess its regulatory compliance. This generates an increase in project risks and design costs.

Representational State Transfer (REST) standards and RESTFull APIs) mediates the *discontinuity* between technical and organizational issues. Consequently, we observed a relative stabilisation of the controversies about network performance issues (processing huge data flows generated by the embedded "agent") and security constraints (management of authentication of user ID imposed by healthcare laws).

5.9.2. PLM mediates the way software applications development is executed

Remote monitoring of the product in use generates many questions. What can be done with the collected data? Which are the priority "use cases" that must be addressed first? How to move beyond "connectivity" and (re)define new revenue generation models? [60] The need to swiftly process the large amount of data gathered and the instability of the technical requirements, calls for an alternative software development approach.

An innovative software development environment is created within the PLM platform to increase the pace and the flexibility of the application development process. It consists in a *"mashup builder"* that captures, through a *"drag and drop"* [61] graphical representation, the *"links"* between data/content (*what needs to be known/shared*) and the corresponding web services (*how and when sharing takes place*).

The *"mashup builder"* enables developers and subject matter experts to rapidly create applications, real-time dashboards, mobile UI and analytics capabilities that could help stabilising the controversies mentioned above.

This means that the PLM platform not only connects *existing* applications but also enables the development of *new* applications that process information coming from the sensors. Here too, the PLM platform adds capabilities to account for discontinuities between heterogeneous software applications. It

[60] For example, charge price premium for consolidated data, expand market with pay-per-usage offering, new revenue streams from expanded maintenance services portfolio.
[61] Without therefore the need for advanced coding expertise.

“encapsulates” older legacy software applications, while developing the capacity to flexibly develop new applications adapted to the relatively low maturity use cases about servitization.

5.9.3. Modelling the logical relationships across legacy software applications

We have followed through this fifth trail of connections how the PLM platform models the logical relationships, while enabling technical interoperability across legacy software applications.

By combining Object-Oriented modelling principles, connectivity standards and a more flexible application development environment, the platform is able to describe, simplify and enact traceable *“links”* between the product and the product in use. So, the resulting IT architecture accounts not only for “data” (log files containing data points about the product condition) but accounts as well for “persistent links” between “objects” (enacting the discontinuities between the As-Designed *product* and the As-Maintained *product in use*).

Trail # 5 addresses scenarios of use enabling engineering teams to take in account serviceability related risks by creating a cloud based IS architecture.

The cloud based architecture assemble and perform a material referential that:

- preserves the diversity of *what is to be known and shared* about the products *in use* in local laboratories (main requirement to solve confidentiality and security constraints);
- enacts a continuum of commensurable tasks through real-time *dashboards* reflecting what the final customer *does* and *will predictably do* with the connected product;
- encapsulates complex discontinuous relationships between specialized accounts tracing potential failures of the product *in use*.

Consequence/ Towards the end of the blueprinting process, the *servitization* business model can be accounted for and operationally attached to a *connected serviceable product* (encompassing “always-on” connectivity conditions + diagnostic operations + service execution context + contractual standards about actual use).

The figure below describes the PLM mediations that compose the collective capabilities to process, compute and enact an account including both, the *in vitro* diagnostic *product* and its *use* in the customer context.

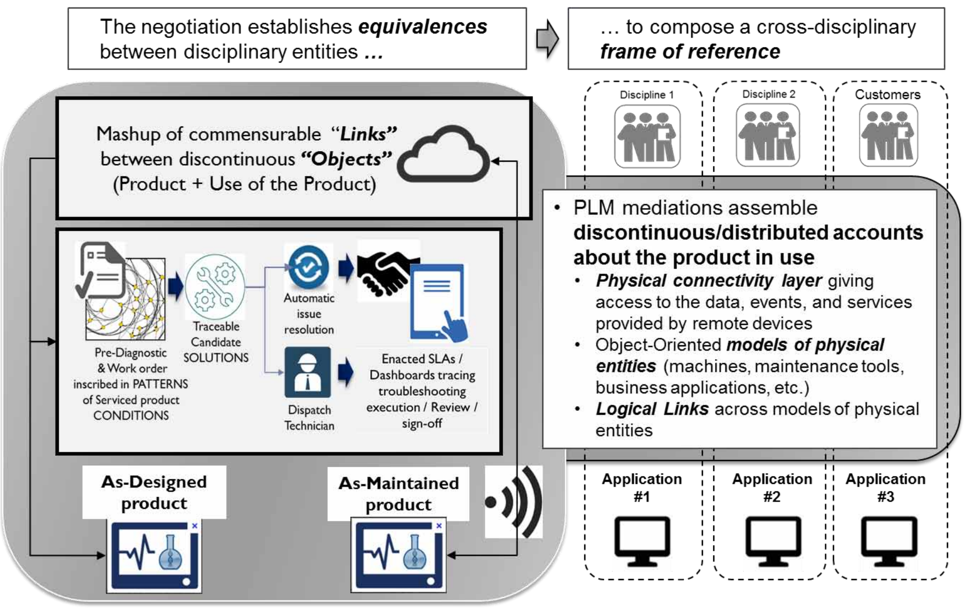

Fig n° 30/ PLM mediations assemble discontinuous/distributed accounts about the product in use

5.10. Revisiting our initial propositions

We argued that the blueprinting process of the PLM platform reveals how PLM software applications perform a role in organizing the discontinuity of modelling agencies across disciplinary boundaries.

In this final section, we are now able to revisit our research question about *how does the blueprinting process of a PLM platform assemble the* *disciplinary agencies accounting for a new product across organisational boundaries.*

We present hereafter alterations of our research propositions in view of the four trails of connections structuring the case study findings.

Proposition 1/ The blueprinting process alters the way PLM mediations define *what information needs to be known/shared* across disciplines

In view of that we observed, we can better understand how the focus of negotiations about *what needs to be known/shared* move from the product *attributes* to the *relationships* between the actual products in use.

At the end of the blueprinting process, the focus is less on sharing content (documents describing attributes about evolving conditions of the product), but rather on containers (logical object-oriented models) encapsulating information about the usage of the product.

The software vendor team achieves this by introducing Object-Oriented modelling through which *"standard relational objects"* are capable of aggregating heterogeneous and discontinuous knowledge about both, the product attributes and the associated services delivered to the product in use.

Moreover, Object-Oriented modelling detaches the account about *"product serviceability*" from local service deployment contingencies. The resulting ontology is defined by logical *"links"* between calculable engineering and maintenance actions securing product reliability.

Primarily, "Objet-Oriented" (O-O) data model performs, the assemblage of *what is to be known/shared* (the "data model" focused on extended remote monitoring capabilities).

Second, O-O data model creates more flexible cognitive capabilities to enact a *"network of links between actions"* (i.e. dash-boarding executed through the mashup environment). In this sense, it simplifies interfacing challenges.

Third, O-O data model contributes to the disambiguation of heterogeneous practices contributing therefore to their calculability (supported by the introduction of pre-defined “candidate solutions” to execute “traceable tasks”).

<table>
<tr><td colspan="2">The exploration of Proposition #1 shows that negotiations about PLM mediations lead to a transformation of the morphology of relationships by composing a data model that performs “real-time” commensurability between Diagna’s product designed by the Engineering teams, and the products in use at the distributed laboratories and hospitals.</td></tr>
<tr><td>- PLM mediations enable top-down persistency (tightly coupled coordination)</td><td>- The data model detaches locally embedded accounts of the product condition and moves them to an account of the “Predictable Product Serviceability.”
- The main component of the new forms of persistency of product condition across organisational boundaries, is performed by the “agent” placed in the “As-Maintained” products. The “always-on” monitoring of the product in use can be linked to the “As-designed” definition of the product.
- This new capability (commensurable connectivity) transforms the morphology of disciplinary relations and the associated task-partitioning between all organisational entities involved in the “servitization” initiative.</td></tr>
<tr><td>- PLM mediations preserve bottom-up transiency (loosely coupled cooperation)</td><td>- The commensurable connectivity preserves transiency as it moves the accounts about actual (“As-Maintained”) machines being used, to the more abstract, generic (As-Designed”) machine – but creates nevertheless new capabilities to trace the specificities/singularities of the events (machine failures…) embedded in local contexts.</td></tr>
</table>

Proposition 2/ The blueprinting process alters the way PLM mediations define when & where information sharing takes place.

Empirical results describe the trails of connections between practices through which a new temporal horizon of the servitization calculation is performed.

At the end of the blueprinting process, *the PLM mediations transform the way concurrent engineering agencies enact and account for the new industrial products across organisational boundaries.*

The way to establish a common account for machine failure patterns were organised by a reference to events that occurred in the past. In the new PLM blueprint, knowledge sharing is enacted through calculable product serviceability framed in the *future perfect continuous* verb tense: collaborative service tasks duration is accounted for in such a way that current product performance patterns (cause) are predictably generating product failures (potential effect).

The enhanced calculability generated by the PLM platform frames *predictable* conditions of both the connected machine performance patterns and also the usage patterns of these machines by Diagna's customers.

The enactment of more predictable, abstract, traceable and scalable accounts of the product in use transforms the way Service Level Agreements (SLAs) are contracted and cross-boundary information sharing is managed. Contracts do not depend anymore on abstract, decontextualized accounts of the servitization business model.

<table>
<tr><td colspan="2">The exploration of Proposition #2 shows that negotiations about the PLM mediations alter where and when information sharing takes place by composing accounts about the predictability of services related agencies.</td></tr>
<tr><td>- PLM mediations enable top-down persistency (tightly coupled coordination)</td><td>- Persistency relies on the mediations contributing to frame the predictability of the product condition and of the associated servicing agencies – this achieved through the account of the “predictable product serviceability.”
- Information sharing about the in vitro diagnostic machines may occur continuously (conveyed by “always-on” monitoring of predictable conditions) and pervasively (supported by commensurable cloud-based connectivity).</td></tr>
<tr><td>- PLM mediations preserve bottom-up transiency (loosely coupled cooperation)</td><td>- Even though PLM mediations compose a persistent model of the predictability of product conditions and the associated maintenance and service procedures, they preserve the distinctions between modelling agencies such as:

- real time tracking of the product failure (agents installed in the actual machines in use enabling “always-on” alerts),
- ex ante economic calculations (contractual Service Level Agreements),
- ex post performance of maintenance practices at the point of service (hospitals and laboratories).
- The capacity to connect and nevertheless preserve the discontinuity between these three modelling agencies, strengthens the reliability of contractual standards (SLAs) of the “connected product in use.”</td></tr>
</table>

Proposition 3/ The blueprinting process alters the way PLM mediations define accountability across organisational boundaries.

Our *Third Proposition* stated that the blueprinting negotiations alter the way accountability is characterised across organisational boundaries and transform the relationships between the biotechnology company and its customers.

We observed that the assemblage of logical and material links stabilises new forms of discontinuity between organisational entities (engineering, services, customers) that give the new boundary spanning "frame of reference" its overall coherence.

The resulting strengthened accounts of the "predictable product serviceability" enable more reliable judgements taking into account the relationships between on one hand, the way connected machines are engineered and serviced by Diagna, and on the other hand, the way they are used by the final customer.

John Law (2000:349) affirms that material objects hold distributed agency patterns together. We described above how the embedded software agent acts (behind the scenes…) connecting persistent traceable *"links"*.

Existing equivalence tables that were embedded in stand-alone spreadsheets and manual practices, are *extended* by the mediations exerted by the PLM platform. In this sense, the PLM platform plays a role of a material *knower* enacting and performing stabilised accountability patterns. This stabilises the more complex forms of service support practices of the product in-use required by the "servitization" strategy.

<table>
<tr><td colspan="2">The exploration of Proposition #3 shows that shows that negotiations lead the characterisation of a “boundary spanning knower” equipped with the cognitive and normative capabilities to act and organise “predictable product serviceability” across organisational boundaries.</td></tr>
<tr><td>- PLM mediations enable top-down persistency (tightly coupled coordination)</td><td>- Persistency is secured by the account of the “predictable product serviceability.”
- It extends and synchronises the “messy” discontinuous interactions with end-customers to proactively plan and execute maintenance tasks
- It acts on behalf of Engineering, Sales & Marketing and Service support teams.
- It deprives FSEs of their self-reliance as they become inscribed in the account about the serviceable product lifecycle. Consequently, “local” troubleshooting practices are gradually enrolled into the persistent servitization business model.
- The resulting accountability model brings together all relevant judgements guiding contractual engagements about the way servicing of the product in-use is provided.</td></tr>
<tr><td>- PLM mediations preserve bottom-up transiency (loosely coupled cooperation)</td><td>- Transiency is preserved through dashboards describing SLA related accountability.
- Dashboards (mashups of heterogeneous data and web services ensuring real-time connectivity to data about product condition and usage) include the (transient) event driven troubleshooting patterns execution.
- Dashboards carry technical traceability of root causes of product failures to boundary spanning SLAs. Root-causes can be “peer reviewed” and the local specificities of a technical failure may therefore be taken into account in the boundary-spanning judgements of its economic impact.
- In other words, Dashboards rely on novel technical traceability capabilities to enact the distributed (“heterarchic) character of the organisational accountability model 1required by the servitization strategy.</td></tr>
</table>

5.11. Summary of case study #2 and progression in the argumentation

Through the analysis of the blueprinting phase of a PLM platform, we have shown how it composes a *common account* of the “predictable product serviceability” that includes persistent and transient agencies that characterise concurrent engineering relationships.

We followed the path going from Use Cases (required collective capabilities “demanded” by Diagna) to the final composition of a commensurable, distributed account of the *serviceable product in-use*. We have also observed that questions emerge as designing biotechnology machines includes progressively more normative and technical constraints due to both product connectivity and uncertainties about product reparability. The improved commensurability and calculability of discontinuous interactions and the extension of the scope of *what needs to be shared* about the product, appears as a condition to inscribe all accountable parties in one shared account about the *predictable serviceability* of the product in use.

The PLM platform becomes a holder (“container”) and a dynamic vehicle (“O-O objects”) to account for the lifecycle of “smart, connected products” across organisational boundaries. Consequently, sales and marketing teams can engage in the deployment of the servitization offering. The PLM platform performs the *extension* of the temporal horizon of the account through the attachment of its predictive use by the final customer. The *calculability* of the servitization goals is defined not with regard to *past* product failures, but rather with regard to *predictable conditions* of the serviceable product in use.

We have described how, at the core of this process, is the composition of a frame of reference capable of bringing together diverse *“calculative agencies”* forming a scalable account of the product lifecycle - including, information about the more or less structured patterns of use of product by the final customer.

In this sense, we have progressed on our attempt to better understand how PLM mediations play an organising role by composing *logical* and *material links* between the (persistent) account of *product definition* and the (transient) account of the *product in use.*

CHAPTER 6 / CONCLUSION

This chapter presents a summary of empirical and theoretical contributions.

We start with a presentation of the relevance of the empirical data as we review the three propositions supporting our research question.

We present our theoretical contribution by discussing the specificities of the *"socio-technical agencement"* (Callon 2008) studied in this dissertation – particularly, how its calculative agencies compose a "heterarchic" frame of reference that includes both conflicting components of the concurrent engineering (persistency and transiency).

We conclude with a presentation of our findings limitations.

6.1. Empirical contribution to the study of ICT mediations in organising concurrent engineering

The aim of this dissertation is to contribute to the academic debates about the role played by ICT mediations in organising complex and *"messy discontinuities"* (Law 2003) that characterise concurrent engineering organisational settings. We have built our argumentation around the analysis of the blueprinting process leading to the composition of a frame of reference accounting for the emerging industrial product.

Both case studies reveal the trails of connections that extend and stabilise a frame of reference that:

- concatenates the organisational roles of (human and non-human) entities in charge of modelling devices and moves them from discipline level to the cross-disciplinary platform;
- coalesces and combines unstable (adhocratic) ways of accounting for, and validating attributes of the product as they evolve throughout its lifecycle;
- attaches technical and economic accounts about the product to a wider number of organisational entities – such as the future and actual (real time) use of the product by final customers;
- institutionalises visible forms of accountability – such as dashboards of *"suspect links"* expressing potential inconsistencies between the product components.

Through this frame of reference, PLM mediations embed/inscribe distributed agencies (machine maintenance, use of products, etc.) into stabilised accounts about the *"product release readiness"* (case #1) and the *"predictable product serviceability"* (case #2).

In case #1, we have shown that CMS-Co faced challenges to consistently and timely account for "*product release reediness."* The outcomes of the negotiations produce a frame of reference that holds together all relevant disciplinary agencies that are responsible for the "*auditable*" validation of the CMS product attributes. This is done mainly by extending the context of the validation process. Calculable and semi-automated operations, replace and/or inscribe manual data consolidation procedures into scalable navigation capabilities (supported by a cross-disciplinary portal) and shared dashboards. Distributed agencies in charge of the validation of the technical and economical attributes of the new industrial product, can be stabilised as they become inscribed in the traceable account of the product lifecycle.

In case #2, we have shown that Diagna engaged in a new business strategy ("servitization") without having the necessary common frame of reference to account for the *"predictable product serviceability."* Negotiations leading to the definition of the novel frame of reference, consisted mainly in attaching the dominant engineering related agencies to those of Field Service Engineers (FSE) and laboratory and hospital teams (end-customers). The validation of the PLM mock-up, demonstrated that the traceable product account is endowed with more formalised, consistent – and *nevertheless discontinuous* maintenance and usage related agencies. This is done by adding the visible attributes of the connected product to real time accounts of traceable maintenance competences and usage protocols. The newly formalised maintenance protocols become attached to real time information flows about the use of the *"smart, connected machines."* In other words, PLM mediations create an organisational context to localise and stabilise the relationships between formally anticipated maintenance practices by the FSEs, and the increasingly predictable practices by laboratories and hospitals.

We have pointed out that both concurrent engineering initiatives analysed in the case studies struggled to bring together *discontinuous* relationships between *loosely coupled agencies* (transient, *adhocratic* forms of agencies) and *tightly coupled agencies* (persistent and traceable forms of agencies). [62] Both industrial companies put forward functional requirements for the PLM platform expressing the need to cope with the *"messy"* cut-offs generated by the *"iteration and balancing process that works both 'top-down'* (…) *and 'bottom-up'."* (Hamelin et al. 2010: 76).

Our research question explored how the blueprinting process of PLM platforms assembles the multiple mediations accounting for the product

[62] Or *"Open ended conversations"* (Lester and Piore 2004) characterised by interpretation and creation of new knowledge about the product and its related services.

lifecycle across organisational boundaries. We brought empirical evidence about the way these mediations compose a more comprehensive and scalable account of the product lifecycle across organisational boundaries.

Our main empirical contribution concerns the way the negotiations about the PLM mediations bring together *heterogeneous*, *discontinuous* and *distributed* forms of agencies within a common, cross-disciplinary referential. The latter brings about commensurable/abstract, traceable/calculable and visible *equivalences* between all the main entities composing the cross-disciplinary *account* of the industrial product and services lifecycle. We have described in the two case studies, the composition of a *chain of reference* (Latour 2005) that is able to bring together, on one hand, heterogeneous software applications used to model the industrial product, on the other hand, discontinuous engineering practices mobilising disciplinary software applications, as well as distributed judgements accounting for the product's consistency and integrity.

We present hereafter a summary of the three main components of the *cross-disciplinary chain of reference* for different forms of agencies *"that don't quite fit,"* (Law 2003)*,* from design and engineering phases down to servicing phases.

6.1.1. PLM mediations organise commensurability across heterogeneous agencies

The initial PLM "Request-for-quotation" issued by the two industrial companies defined requirements of the PLM blueprint as a means to enforce a *unified referential* of the industrial product to be used by all relevant disciplines.

Case study	Industrial companies request a software platform to produce a *unified referential …*
Case #1/ Defence company (CMS Co)	… enabling a transient account of the *"product release readiness,"* …validating a persistent account of an *"auditable product."*
Case #2/ Biotech company (Diagna)	... enabling a transient account of the use of *"smart, connected products,"* …validating a persistent account of the *"predictable product serviceability."*

Table n° 11/ Composing a unified referential

We followed the trails of connections showing how the blueprinting process forming such a unified referential, depends on a series of mediations that establish a complex balance between the *transient* and the *persistent* dimensions of the industrial product account.

A key component of this emerging network, is the data model based on Object-Oriented (O-O) modelling principles. The O-O Data model formalises a scalable referential that establishes *equivalences* across *heterogeneous* modelling software applications. The network of cross-disciplinary O-O containers bundles the numerous disciplinary "*documents*" (text documents, requirements templates, SysML models, 3D data, quality simulations, spreadsheets, etc.). The data model adds sets of collective capabilities that significantly modify the relationships between disciplinary entities (human and non-human). Local, specialised disciplinary entities are accordingly moved to a cross-disciplinary level. The added ICT capabilities *move/abstract* local, discipline specific modelling software applications away from their particular organisational contexts, and redefine *what information needs to be shared/known* across disciplines (Proposition #1).

The negotiations leading to a final PLM blueprint, compose a *chain of reference* (Latour 2005) that connects heterogeneous modelling devices without amalgamating disciplinary "*things that don't quite fit"* (Law 2003) into a single cross-disciplinary taxonomy. "What needs to be shared" is no longer the actual discipline specific *"documents"* (content), but the information about the way they become *"attached to…"* logical *"objects"* (containers). In other words, by *adding commensurability to heterogeneous modelling agencies*, the data model establishes the necessary equivalences between heterogeneous engineering practices and software applications across disciplinary boundaries - while nevertheless preserving, their disciplinary specificities.

6.1.2. PLM mediations perform calculability across discontinuous agencies

We have also presented empirical evidence of how PLM mediations not only *bring together,* but also *persistently trace "messy"* (Law 2007) relationships between engineering disciplines. Our research reveals that this occurs as PLM mediations compose and perform *calculable links* between *transient* disciplinary cooperation agencies and *persistent*, cross-disciplinary coordination agencies. PLM mediations synchronise these two dimensions through *"Object-Oriented Links"* that perform equivalences across discontinuous agencies. For example, the added collective capabilities inscribe local, discipline specific reporting devices (spreadsheets, correspondence matrices, stage-gate planning templates, etc.), within traceable, calculable (logical) *"links"* between cross-disciplinary "containers". Algorithms may therefore, perform visible accounts of organisational inconsistencies *("suspect links*"). Reporting methodologies - such as, manually operated "stage-gate" templates - become inscribed in, and traced by, automatic workflows. Calculations are also operated/computed at the level of (logical) *"links"* between *"containers"* - rather than at the "*content*" level.

By adding the capabilities to *perform consistent traceability of discontinuous forms of agencies across disciplinary boundaries,* PLM mediations introduce:

- a continuous *timeline* to determine *when* knowledge can be shared: the blueprint demonstrates that information sharing about the industrial product can be done *continuously*;
- a pervasive *context* to determine *where* information can be shared: information sharing takes place within *calculable "O-O links"* that enact the *traceable* relationships between, on one hand, adhocratic practices (dominated by transient engineering practices) and on the other hand, hierarchic processes (enforced by persistent logical "objects").

Our heuristic model enables us to capture the *consequences* [63] of such an assemblage of transient and persistent agencies. We observed that PLM mediations recompose *where information sharing takes place* (Proposition #2). Previously, cross-disciplinary information sharing took place mainly at project milestones called "stage-gates" where documents (content) are presented, discussed and up-dated by all involved parties. Object-Oriented traceable "links" form calculable equivalences between discontinuous agencies. Consequently, information sharing may take place *ubiquitously* through *persistent, logical "links"* that account for information integrity across organisational boundaries.

Moreover, PLM mediations also define *when information sharing* takes place (Proposition #2). Traceability *"links"* are continually visible throughout the product development process. Instead of sharing information at consecutive milestones (i.e. at "*stage gates*"), all involved disciplines may access, *continuously and pervasively*, the relevant "*views*" accounting for the evolving product lifecycle – for example, *"suspect link tags"* can be traced across disciplinary boundaries, "*baselines*" can be compiled, propagation of "*Parts change and configuration management*" can be calculated, predictable judgements about disciplines performance are accessible on cross-disciplinary dashboards – all this occurs independently from specialised, locally embedded, disciplinary agencies.

[63] See Nicolini (2009) on *"zooming-out"* trails of connections.

In summary, the negotiations define a novel frame of reference that establishes *when & where information sharing takes place* across disciplines (Proposition #2). Consequently, discontinuous disciplinary information sharing practices may continue to exist despite the fact that (loosely and tightly coupled) engineering agencies become part of a traceable and calculable account of the product lifecycle.

6.1.3. PLM mediations assign accountability across distributed agencies

We have seen that the blueprinting process assembles mediations that alter dominant accountability patterns. Distributed forms of judgments about the evolving product become possible as accountability patterns become visible across disciplinary boundaries.

We have shown that this is possible as *observable chains of reference* generate *equivalences* between roles & responsibilities distributed across disciplinary boundaries. The case studies described how PLM mediations enact visible forms of peer-to-peer judgments. Accountability is persistently and ubiquitously accessible to all involved disciplines developing the new product across disciplinary boundaries.

Increased visibility of distributed forms of accountability transforms the ways roles are formalised and responsibilities are assigned.

The PLM mediations:

- assign local validation responsibilities to cross-disciplinary software applications – mainly by the cross-disciplinary *user interface* and associated dashboards and reporting capabilities;
- ensure that discipline specific organisational roles are held accountable for the entirety of the *cross-disciplinary* product lifecycle;
- compose a scalable organisational *context* where agency responds – concurrently and automatically - to two organisational logics: engineers (humans) and software applications (non-humans) account for both, inductive engineering methods (loosely coupled peer

reviews, bottom-up joint enquiries that create new knowledge about the product) and deductive engineering methods (rule based, top-down management processes that insure knowledge persistency and integrity);

- enable scalability of accountability models: the product may be seamlessly analysed and validated at different organisational levels – at local disciplinary simulations (within relatively small engineering teams), at cross-disciplinary level (within projects or programs), and, eventually within the customer organisation using the product (across very large ecosystems).

Accountability is recomposed as dashboards reveal inconsistencies *in real time* and hold engineers accountable for events (such as machine failures) that may occur in the future. The PLM mediations convey visual evidence (dashboards compiling information about the use of monitored products) about what will (potentially) happen.

Therefore, while cross-disciplinary roles (project and program managers) become equipped with more reliable calculative capabilities to proactively manage risks, *distributiveness* of disciplinary judgements can still be preserved. PLM mediations preserve important forms of slack required for engineering information sharing and creation. The latter cannot be fully formalised within transactional routinized procedures.

Instead of hopelessly trying to put adhocracy under the control of transactional procedures, the PLM mediations contribute to enact interdependencies between transient and persistent agencies. Primarily, PLM mediations reconfigure disciplinary organisational contexts to enable "*open-ended conversations*" (Lester and Piore 2004) about the product lifecycle. The extended PLM narrative also redistributes agency by allocating accountability from local, disciplinary contexts to cross-disciplinary level. The collective capabilities required to validate the product attributes locally (within the disciplinary boundaries) become part of a lengthier narrative that situates/inscribes information sharing and creation in an extended frame of reference acting across organisations boundaries.

In summary, we can say that our empirical contribution has brought evidence of how PLM mediations *actively organise* concurrent engineering. Firstly, mediations abstract disciplinary notations and categorisation while preserving specificities of disciplinary taxonomies and modelling practices. Secondly, PLM mediations enforce transversal traceability and calculability of product information while preserving forms of adhocratic slack indispensable for complex engineering cooperation. Thirdly, PLM mediations make visible discipline specific judgements about the product, while ensuring flexible peer-to-peer forms of cross-disciplinary accountability.

The figure below shows that this becomes possible as long as the PLM platform compose an organisational compromise between *persistent* and *transient "calculative agencies"* (Callon & Muniesa 2005). However, we must emphasise that "*socio-technical agencements"* studied in both case studies are relatively unstable as they are still confined to the scope of the blueprinting initiatives.

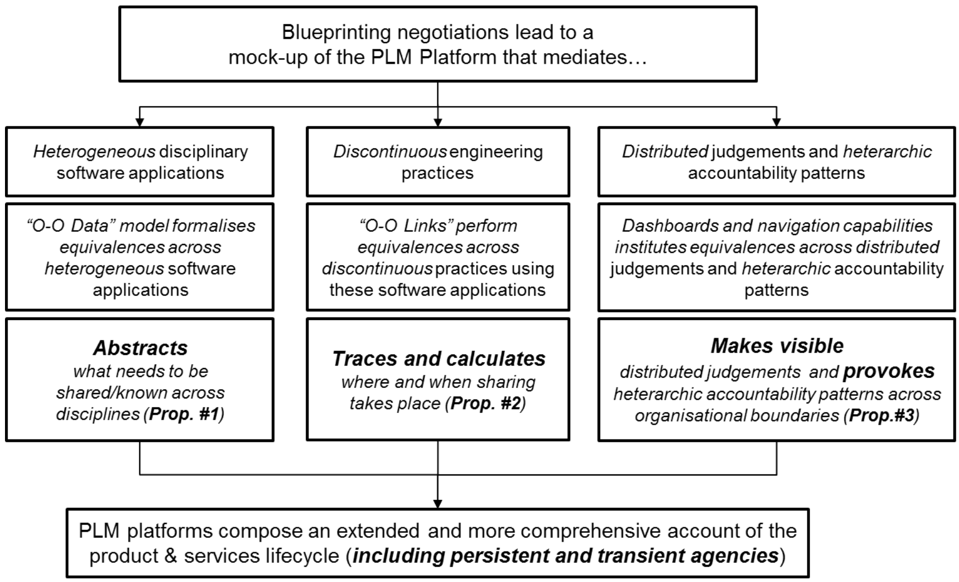

Fig. n° 31/ How PLM mediations alter our three Research Propositions

6.2. Theoretical contribution

We mentioned throughout this dissertation that concurrent engineering practices are constantly confronted to the need to simultaneously address the following conflicting trade-offs: engineers need to secure tightly coupled coordination (i.e. enforce *persistent* engineering agencies through the "waterfall" model) and also enable loosely coupled cooperation (i.e. facilitate *transient* engineering agencies through "agile" models).

In the previous sections outlining our empirical contribution, we have highlighted findings that draw attention to how distributed engineering and servicing agencies become equipped with PLM mediations that help engineers in coping with both disciplinary discontinuity and distributiveness. We would like to outline some concluding remarks on the theoretical developments that could improve our understanding of the role played by ICT in organising a *continuum* between *transient*, *non-coherent*, [64] and *persistent* instances of ordering.

6.2.1. A heuristic shift to capture the relationship between "what is known about" & "knower"

We have seen that ICT contributes to various *"techniques of staging the world"* (Latour 1996). It does so by assembling, on one hand, an *object* (something known about) – in our case, an irreconcilable representation of a constantly evolving product and its use by end-customers - and a *subject* (something or someone that does the knowing – i.e. the "knower").

The *practice turn* in the Organisations and Management literature bring forward the organising role of ICT by focusing on the *subject* (something or someone that does the knowing). Authors study the organisational hurdles and cognitive limitations affecting *subjects* sharing and creating information across disciplinary boundaries – in this heuristic perspective, ICT

[64] Law (2003) pointed out that *"organisations precisely work because they are non-coherent."* (Law 2000; Law & Singleton 2000; Mol 2003)

compensates for *cognitive* limitations of the *"knower"* (Gherardi 2009; Nicolini 2011).

The *material turn* in the Organisations and Management literature investigates how the materiality of the *object* (something known about) influences the subject's practices – in this perspective, focus of the enquiry is put on how ICT structures and is structured by the practices of the "*knower*" (Orlikowski 2007; Leonardi 2013; de Vaujany et al. 2015).

We have seen that Actor Network Theory proposes a heuristic shift by considering that what is *known about* is – concurrently! - composed, enacted and institutionalised with the *knower.* In this heuristic perspective ICT devices perform *relationships* composing *"collective hybrids"* (Latour 2005) or *"socio-technical agencements"*(Callon 2008) and (Callon & Muniesa 2005; Callon et al. 2007; Muniesa 2014). Building on ANT's *"interobjective"* heuristic model, our theoretical contribution highlights how PLM mediations coalesce and perform novel "*techniques of staging the world"* that bring together *"things that don't quite fit"* (Law 2003).

6.2.2. Organising discontinuity while enforcing calculability

Our dissertation brings new insights on how these "*techniques of staging the world"* are performed by ICT mediations – we have shown how the latter play an increasing role in organising agency *discontinuity,* while simultaneously enforcing cross-disciplinary *commensurability* and *calculability.*

Our contribution highlights how the blueprinting process of PLM platforms compose a chain of reference that accounts for both, consistent/persistent/traceable agencies <u>and</u> less-coherent, distributed and discontinuous agencies. This is achieved as PLM mediations compose an account of the industrial product lifecycle that frames, traces and enacts a *continuum* between *discontinuous, distributed, heterarchic* [65] and nevertheless:

- *commensurable* quantitative calculations about the technical and economic attributes of the product,
- *calculable* judgements concerning the performance and the use of the industrial product,
- *visible* accountability patterns organising these highly distributed and interdependent judgements.

Persistency and transiency are conveyed by PLM mediations autonomously vis-à-vis all involved disciplinary practices. Therefore, the descriptive dimension of the account institutionalises the calculable forms of traceability that enable both, the enforcement of *persistency* (coordination, tightly coupled coordination) and the preservation of *discontinuity* ("open conversations," slack and loosely coupled cooperation). We have mentioned above how ICT mediations abstract [66] and detach local, one-off practices based on engineers' previous disciplinary experiences from disciplinary contexts. Disciplinary agencies become part of a (1) commensurable, (2) traceable, and (3) visible account of the product lifecycle.

6.2.3. Making cross-disciplinary inconsistencies observable

Our dissertation brings also new insights about the role played by ICT mediations in organising forms of agency *distributiveness* while enforcing *heterarchic* accountability within complex concurrent engineering contexts.

This implies enacting the demonstrative dimension of the account – i.e. enacting a *narrative* about the product lifecycle. The observable narrative dimension of the product lifecycle "*provokes*" (Muniesa 2014) the relationships between both, the messy judgments about product integrity, and

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[65] As we mentioned above, "*heterarchies involve relations of interdependence (...) in which units are laterally accountable according to diverse principles of evaluation*" (Stark, 2009: 19).

[66] *"Abstraction, or rather to abstract, is an action, an action of transformation and displacement, as in 'to extract' or 'to draw away' suggested by its etymology: abs (away), trahere (tract). To a large extent, to abstract something is to transport it into a formal, calculative space"* (Muniesa 2014 :40).

the persistent, visible accountability patterns involving all disciplines. In other words, the account/*narrative* about the product lifecycle coalesces, on one hand, the (static, logic) frame of reference that represents *what information needs to be shared and known*, and on the other hand, a (dynamic, instantiated) chain of reference that represents the more unstable components of the "socio-technical *agencement"* (Callon 2008).

For example, PLM mediations indicate preferred courses of action that engineers will not necessarily follow.[67] Depending on the context of the project, discipline specific engineers may adopt customized technical solutions that are not compliant with cross-disciplinary recommendations. Nevertheless, the product lifecycle account represents the engineers' judgement. Engineers are tacitly and/or explicitly held accountable for potential inconsistencies of the product account generated by their actions. The contextually situated occurrence leading to the fact that an engineer did not adopt the "preferred course of action" is traced by the PLM platform (for example, through "suspect links", dashboards, etc.).

The novel *"techniques of staging the world"* introduced by the PLM mediations compose a narrative that brings together, on one hand, the "messy," iterative *transiency* of disciplinary engineering judgments and, on the other hand, more formalised, top-down *persistent* cross-disciplinary traceable validation of local judgements. In this sense it performs a "calculative space" that *"establishes a continuum between judgments and quantitative (or numeric) calculation (...) The calculation does not take place only in human minds. It is distributed among humans and non-humans"* (Callon & Muniesa 2005: 16).

We propose to formalise (metaphorically) such a process by stating that PLM mediations bring together a "compass" and a "map." The compass corresponds to the demonstrative *narrative* dimension accounting for unstable heterogeneity, distributiveness and discontinuity. The "map"

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[67] In this regard, "Product Lifecycle Management" Platforms differ from "Enterprise Resource planning" (ERP) platforms. The latter, enforce transactional routines that don't leave any space for adhocratic adjustments.

corresponds to the descriptive *bookkeeping* component accounting for stabilising consistency, persistency, traceability. [68]

We can sum up the approach by saying that the *continuum* composed by PLM mediations, attaches a compass (the *narrative* enacting agency distributiveness and the corresponding potential risks) to a map (the consistent, persistent, traceable *bookkeeping* dimension). The assemblage of the compass (narrative) and the map (bookkeeping) can be formalised as follows:

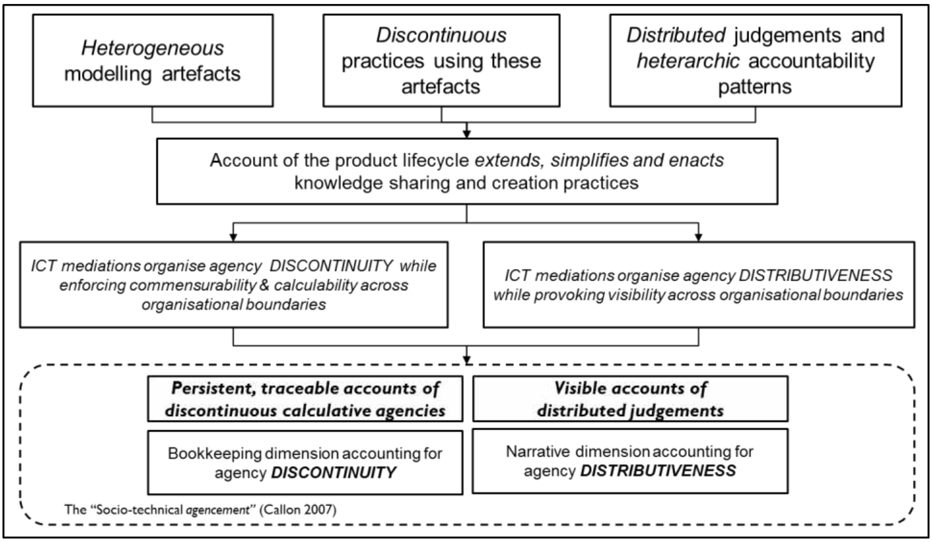

Fig. n° 32/ Organising by producing an observable continuum between discontinuity and distributiveness

6.3. Limitations

We have observed that the composition of the necessary observable links between *compass* and *maps* is achieved mainly by *technical* capabilities – in particular, the O-O modelling principles coupled to novel scalable communication protocols (the mashup, routing and synchronisation

[68] As we have mentioned before, the term *account, "simultaneously connotes bookkeeping and narration"* (Stark 2000: 5). See also (Suchman 1987) and (Beunza et al. 2006).

capabilities conveyed by the middleware supporting the "multi-tier" client-server architecture).

The non-coherent *"things that don't quite fit"* and the *organisational* interdependencies are "black-boxed" by the *technical* IS architecture. In this sense, the PLM platform institutes forms of accountability that address the "engineering paradox" described above. The blueprint demonstrates that the *organisation of heterarchic agencies* can be technically implemented through *material "O-O links."*

However, upon completion of the blueprinting phase, there are many open controversies about the organisational consequences of the stabilisation of the oppositions characterising concurrent engineering processes.

The narrative leading to the enforcement of a visible lateral accountability across disciplinary boundaries was not fully stabilised during the blueprinting phase. Uncertainties about the sustainability of the results achieved within a limited period of time concern, most of all, the movement going from the current *adhocratic* organisation to a stabilised *heterarchic* organisational model. Many topics falling under the redefinition of organisational roles and responsibilities were to be addressed during the subsequent implementation phase. In other words, the PLM narrative leading to the enforcement of extended, visible lateral accountability across disciplinary boundaries is not fully stabilised during the limited time span of the blueprinting process.

6.3.1. Limitations generated by the scope of the dissertation

The blueprinting initiatives studied in this dissertation lasted for about six months. It is a limited timeframe with regard to the subsequent large scale implementation and the actual use of the PLM platform.

A first limitation of the dissertation is the impossibility to establish longitudinal perspective of a process that could better assess the consequences of the implementation of the PLM mediations on actual engineering practices.

Moreover, blueprinting activities are contained within a relatively small IT and procurement driven departments isolated from the overall company perimeter. Even though the blueprint of the PLM platform was based on actual engineering information provided by the industrial companies, its manipulation occurred in a development server – called a "sandbox" - that doesn't take into account the interdependencies generated by its future use within the extended enterprise context. We were not able to collect information about actual changes in engineering practices related to the introduction of PLM platform.

6.3.2. Limitations linked to the case study approach

The "generalisability" of the case study results is constrained by the following question: *can research findings be applicable to other concurrent engineering contexts?*

During the blueprinting process, the software vendor demonstrates that numerous heterogeneous software applications and distributed engineering practices can be accounted for *technically*, through a more *persistent* representation of the "product lifecycle." *Technical* connectivity insures cross-boundary commensurability between modelling software applications. Calculations are located in the algorithmic "objects" instead of being placed at procedural/project management level. So, *organisational* accountability patterns can be *technically* characterised across disciplinary boundaries. Even though such reviews are proven to be technically feasible, its generalisation can be quite organisationally disruptive.

To assert that *findings could be applicable to other concurrent engineering contexts,* we would need to establish – through a longitudinal perspective – that organisational uncertainties can be met by industrial companies. There are still many uncertainties about the inscription of all accountable parties in one shared narrative. The two industrial organisations are not yet ready to make widely visible responsibilities about risk mitigation to *all* discipline members. The most fragile link of the emerging chain of reference concerns the definition of the heterarchic validation model. The organisational capabilities defined and enacted during the blueprinting process, are rather "loosely attached" to the wider controversies generated by broader concurrent engineering initiatives. The stabilisation of these controversies implies that peer review control is not only observable by all disciplines involved, but also consistently and sustainably organised.

6.3.3. Limitations generated by the data collection and coding process

We have already described above the particular conditions through which the empirical data was collected (confidentiality constraints limiting disclosure of collected data, no possibility to record interviews and workshops, etc.). If our full immersion on the PLM project generates benefits due to the intensive, long-term field involvement, it also creates limits about results "falsifiability" of the data analysis.

We addressed this limitation - inherent to the participant observation stance - by providing a detailed description of the qualitative research procedures that we have mobilised (Yin 2011: 79). We have established the "triangulation" between different sources of information concerning the PLM "demand" and the PLM "offer" (presented in annex 2). The validity of the inductive qualitative analysis can also be assessed through the details of the data coding protocol (presented in annex 3).

Finally, we can say that the PLM blueprint remains confined to a relatively small organisational perimeter. Its "generification" (Pollock et al. 2007) implies that more attachments are deployed between the blueprint of the PLM platform and the ongoing organisational transformation of the two industrial organisations in the case studies. This involves different *"techniques of staging the world"* and constitutes, most certainly, an opportunity for a new research project about the *implementation* phase of the PLM platforms. We hope that this analysis brings nevertheless new insights that will contribute to theory development as well as possible recommendations for management practitioners.

7. Bibliographical References

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Annexes

Annex 1. Unit of analysis and data collection scope

Case study #1 / Qualitative data analysis is focused on the controversies about the composition of a new frame of reference supporting the description of the *"release readiness"* of an auditable product lifecycle.

Data collection lasted for about seven months organised as follows:

M 1	M 2	M 3	M4	M5	M6	M7
21 interviews	• 13 Workshops with Engineering and Service experts (&Program manager)			Demonstrations of the Mock-up ("Proof-of-Concept")		• Workshops & meetings
• Program managers • Engineering (mechanical, Electrical & electronic, Software) • IT	• Analysis of controversies about Use cases - Functional - Non-functional • IS Architecture • Technical infrastructure			• Explanation/extension about Scenarios of use of the ICT platform about: • "Requirements definition & management" • "Concept development" • Verification & Validation" • "Systems architecture and design" • "Platform design and variant generation" • "Mechanical, Electrical and software development"		• Validation of use cases with business and technical stakeholders

- **Primary unit of analysis**: Blueprinting of a PLM platform within an industrial discrete manufacturing company (manufacturing combat systems for the defence sector);
- **Secondary unit of analysis:** description of negotiations about how the PLM platform recompose the relationships between disciplinary practices and software applications within the following domains:
    - *Requirements definition and management*: translate the voice of customers into prioritized requirements, targets and constraints while establishing bi-directional traceability between requirements.
    - *Concept development:* based on customer needs and specifications, define alternate product concepts, investigate feasibility and select best candidates.
    - *Verification and validation:* verify and validate that designs meet requirements through digital or physical means progressing from components to assemblies, systems and products.

- *Systems architecture design*: develop the functional and physical architecture, model of the product, associated specifications and derived requirements.
- *Platform Design and Variant generation*: define and manage multiple product configurations to satisfy customer, regional and market-specific needs and accommodate design alternatives and improvements.
- *Detailed design*: based on initial product concepts and system architectures, develop a detailed product design that meets the requirements and is sufficiently documented for manufacturing (mobilising discipline specific applications: mechanical (MCAD), electric & electronic (ECAD), software related (Code generation).
- *Change and configuration management*: trace an orderly process for evolving a product from conception to retirement

Case study #2 / Qualitative data analysis is focused on the controversies about the composition of an account of "predictable product serviceability" of in vitro diagnostics machines in use.

Data collection lasted for about five months organised as follows:

M 1	M 2	M 3	M4	M5
• 13 Interviews	• 6 workshops		Demonstrations of the Mock-up ("Proof-of-Concept")	• Workshops & meetings
• Marketing & Sales, • Engineering • IT (engineering) • Support Service (maintenance)	• Analysis of controversies about Use cases - Functional - Non-functional • IS Architecture • Technical infrastructure		• Explanation/extension of scenarios of use of the ICT platform • "Product support analysis and planning" • "Service diagnostics and knowledge management" • "Service parts planning and pricing" • "Equipment monitoring and lifecycle management" • "Performance analysis and feedback"	• Validation of use cases with business and technical stakeholders

Primary unit of analysis: Blueprinting of a PLM platform within an industrial discrete manufacturing company (manufacturing biotechnology sector);

Secondary unit of analysis: description of negotiations about the deployment of predictive maintenance system based on "smart connected product" (real-time connectivity) within the following domains:

- *Smart, Connected Product Enablement:* leverage proven agent technology and connectivity services to easily and flexibly connect to any wired or wireless asset via third-party device clouds, direct network connections, open APIs or edge devices.
- *Verification and validation:* verify and validate that designs meet requirements through digital or physical means progressing from components to assemblies, systems and products.
- *Product support analysis and planning*: define the service activities and intervals necessary to meet the targeted operating performance of a product.
- *Service diagnostics and knowledge management*: diagnose service issues at contact centre, field service and via self-service, automate issue diagnosis and initiate best service responses with connected interactive diagnostics, coordinate and track diagnostics as issues transfer among technicians, partners, and service groups
- *Service parts information creation and delivery*: manage configuration-specific service parts content and automate change processes;
- *Performance analysis and feedback*: collect and evaluate historical product and service information to recommend continual product and service improvements
- *Business System Support*: Monitor critical end-user transactions through state of the art APM technology, apply service level agreements and establish performance benchmarks for continual improvement and historic reporting. Rapid root cause analysis through effective diagnostic capabilities and notifications on alerts minimizing the need to reproduce issues and ensuring high system availability.
- *Warranty & Performance based Contract Management:* automate claims processes to improve accuracy and administrative efficiency, reduce fraud and overpayments and enable early visibility into product quality issues

Annex 2. Documents expressing the "Demand" and the "Offer"

Empirical data is collected in the form of written documentation, graphical and video and audio material, technical descriptions of the PLM platform, generic documentation about IS infrastructure, training material, screen shots of user interface, etc.

The following Documents constitute the core of the empirical data

A.TI n°	Origine	Date	Document
P1	Generic	2012	Retour d'expérience des architectures produit (usage SysML/MBSE) / 16eme journée AFIS, Toulouse 2012
P2	Generic	2010	Magic Quadrant for Enterprise architecture tools / Gartner Research note G002074406, Oct 2010
P3	Generic	2010	Glossaire de base de l'ingénierie de systèmes
P4	Vendor	2014	Safety Manual- A guideline for using PLM related development
P5	Memo	2014	Position paper on "Extend the physical world"
P6	Generic	2013	Definition Simulation software for Cax
P7	Vendor	2014	Position paper on "Persistable objects"
P8	Vendor	2014	Product Lifecycle Management Software selection criteria
P9	Vendor	2014	Product Lifecycle Management and Product development process support - software selection criteria
P10	Generic	2013	Simulation numérique et cycle en V - application A1
P11	Vendor	2013	Requirements Lifecycle Management and control practices test cases
P12	Vendor	2014	Requirements Verification Practice test cases
P13	Generic	2010	Systems Engineering Handbook / INCOSE
P14	Generic	2000	Systems Engineering Handbook - SE PROCESS / INCOSE
P15	Generic	2013	"Achievable PLM" / Position paper
P16	Vendor	2014	Detailed Design Productivity Improvements of PLM platform
P17	Vendor	2014	A&D / Developing a Collaborative Environment B-Case template
P18	Generic	2012	Product Lifecycle collaborative environment - PoC adv. Business Scenarios
P19	Generic	2012	A&D / Requirements issues and PLM platforms
P20	Generic	2011	Collaborative engineering - key facts
P21	Generic	2011	Common operating process - concurrent engineering
P22	Generic	2011	Common operating process - collaborative simulation

P23	Generic	2011	Developing a Collab. Environment B-Case template (?)
P24	Vendor	2013	Response to RFQ (chapter 5)
P25	Vendor	2013	Response to RFQ (chapter 8)
P26	Vendor	2013	A&D Debreif PB Notes
P27	Vendor	2013	A&D RFQ - Oral questions
P28	Vendor	2013	A&D RFQ
P29	Vendor	2013	A&D PoC Business Scenarios
P30	Vendor	2013	A&D PoC Business Scenarios - issues to vendors
P31	Vendor	2013	A&D PoC Requirements issues 2
P32	Vendor	2013	A&D PoC RFP Kick Off
P33	Vendor	2013	A&D What is "concurrent engineering" / portal guidelines
P34	Generic	2014	Standards ISO 26262 Example from Automotive vertical (Polarion)
P35	Vendor	2014	Position presentation on SI architecture ("Better together" initiative)
P36	Customer	2014	Systems Engineering PoV / Presentation of vertical industry specificities
P37	Customer	2014	Interview Systems Engineering Expert Manager #1
P38	Customer	2014	Interview Systems Engineering manager # 4
P39	Customer	2014	Interview Systems Engineering manager # 3
P40	Customer	2014	Interview Systems Engineering manager # 2
P41	Customer	2014	Position paper on ALM.docx
P42	Customer	2014	Interview Systems Engineering Expert A4.pdf
P43	Customer	2014	Meeting minutes of Mock-up demonstration #1.docx
P44	Customer	2014	Meeting minutes of Mock-up demonstration #2.docx
P45	Customer	2014	Position paper.MBSE.2012.pdf
P46	Customer	2014	CMSCO-MOM_closure_meeting.pdf
P47	Customer	2014	CMSCO Business.case.inputs.pdf / presentation of results of PLM Blueprinting initiative to management team
P48	Customer	2014	CMSCO. CMS FULL PLM Format wvm et commentaires.wmv
P49	Customer	2014	CMSCO Interview CR A2.docx
P50	Customer	2014	CMSCO Interview EXPERT Architect outil nouvelle generation.docx
P51	Customer	2014	CMSCO Interview CR A1.docx
P52	Customer	2014	CMSCO Interview Service atelier logiciel.docx
P53	Customer	2014	CMSCO Interview Expert_software configuration management_ En.docx
P54	Customer	2014	CMSCO Interview EXPERT coordination project PLM.docx

P55	Customer	2014	CMSCO Interview EXPERT QC _En.docx
P56	Customer	2014	CMSCO Interview EXPERT Architect logiciel.docx
P57	Customer	2014	CMSCO Interview Pleinière_En.docx
P58	Customer	2014	CMSCO Interview EXPERT Outils de production.docx
P59	Customer	2014	CMSCO Mom; Kick off phase 1.pdf
P60	Customer	2013	CMSCO RFx CMS A1.pdf / "Demand" #1
P61	Customer	2013	CMSCO RFx _presentation_doors_sis.pdf /"Demand" for Requirements management
P62	Customer	2013	CMSCO RFx Requirements PLM.pdf
P63	Customer	2013	CMSCO RFx Exec Conf call May 17th.pdf
P64	Customer	2013	CMSCO Rfx Expression besoin PLM .pdf
P65	Customer	2013	CMSCO RFx MISEENOEUVREV2.0.pdf
P66	Customer	2013	CMSCO RFx Requirements Decomposition.docx
P67	Customer	2013	CMSCO Value Assessment/Phase0-A4.pdf
P68	Customer	2013	CMSCO.Value.Modeling.pdf
P69	Generic	2005	GENERIC Standards MODAF Jul 2005.pdf
P70	Customer	2013	CMSCO.Value.Modeling.Final.pdf
P71	Customer	2013	CMSCO.Phase0-Value.model.A2.pdf
P72	Vendor	2014	Model for "TraceableProductDataSharing_TestCase.pdf
P73	Vendor	2015	Standards "Enterprise Platform Architecture".pdf
P74	Customer	2014	Interview Expert on "Traçabilité du fait de deux Referentiels".pdf
P75	Customer	2014	CMSCO Format wvm A1.
P76	Vendor	2013	Presentation on "Middleware" (Ent. BUS).MP3
P77	Vendor	2014	Emerging Standards / Position on Middleware and SE.WAV
P78	Vendor	2014	Call with Expert on Configuration management.MP3
P79	Vendor	2014	Workshop on final PLM Demo.WAV
P80	Vendor	2014	Pre-Sales Marketing position paper on PLM
P81	Vendor	2014	Inputs on WIP on transition strategy.pdf
P82	Vendor	2014	Call with Pre-sales team.MP3
P83	Customer	2013	Diagna RFx ExecMeeting.pdf
P84	Customer	2013	DIagna Rfx Expression besoin PLM .pdf
P85	Customer	2014	DIagna RFx IoT specifications/Use cases.pdf
P86	Customer	2014	DIagna RFx Requirements Connectivity.docx
P87	Customer	2014	DIagna Value Assessment_ remote monitoring.pdf
P88	Customer	2014	DIagna.Value.Modeling.pdf

Annex 3. Coding protocol

Our heuristic model indicates that to increase in reality, PLM platform mediations must gain force over local, disciplinary mediations.

The analysis of the role played by PLM platform mediations is done through (1) inductive Analytic Memos to identify linkages among coded data and events & observed situations and (2) analysis of documents and structured analysis of verbatim from interview notes.

The coding approach follows/formalises how the blueprinting negotiation establishes equivalences between disciplinary entities … composing a cross-disciplinary frame of reference:

<table>
<tr><th>FROM …</th><th>…TO</th></tr>
<tr><td>FROM Non-interoperable modelling software applications</td><td>…TO abstracted modelling software applications inscribed in data model</td></tr>
<tr><td colspan="2">- NEGOCIATIONS concern the data model
Abstracting what information is known about (the new product)</td></tr>
<tr><td>FROM Ad hoc practices</td><td>…TO traceable/calculable practices</td></tr>
<tr><td colspan="2">- NEGOCIATIONS about how are disciplinary modelling software applications/practices causally and materially connected with other software applications/practices.
- Tracing where and when information sharing takes place
- Enacting traceability (“links” between “objects”)
- Linking discontinuous agencies</td></tr>
<tr><td>FROM Visible judgements</td><td>…TO visible accountability models</td></tr>
<tr><td colspan="2">- NEGOCIATIONS concern how to trace/inscribe is disciplinary judgements (and associated roles & responsibilities) in a cross-disciplinary accountability model?
- Moving “Verification & Validation” processes to the cross-disciplinary level;
- Composing the cross-disciplinary “knower” (“Views” and “Dashboards”) conveying “lateral accountability.”</td></tr>
</table>

***FROM** data file model*	*…**TO** federated multi-tier client-server model*
- NEGOCIATIONS concern how to enable cross-disciplinary navigation model and cross-disciplinary dash-boarding (communication protocols) - Designing the cross-disciplinary middleware ("Enterprise Service BUS")	

First order codes (Offer & Demand)

First order codes correspond to collective capabilities mediate the relationship between heterogeneous discipline specific entities. The following list of *first order codes* correspond to main PLM mediations composing the *relationships* between discipline *specific* practices and software applications.

1/ PLM Functional requirements (Demand)

We have extracted from the documents (listed in Annex 2) the main items composing the "Functional requirements" defining the PLM platform as expressed by the industrial companies. The following list accounting for the PLM DEMAND is used to compile the "first order codes"

Systems architecture - Web native architecture - Infrastructure - Interoperability - Integrations - User interface - Security - E-signature - Replication - System administration - Customization - Legacy Data Migration
Requirements Management

- Requirements capture - Requirements qualification - Requirements analysis - Requirements Verification & Validation - Requirements Management - Report generation - IT architecture & User Interface
Software Lifecycle management - Software Configuration Management - Software Change Management - Software Safety Classification - Software Development
Product Data management - Manage Product Documentation (including CAD Data Management) - Component Lifecycles - Search and Reuse - Design Reviews - Top-Down & Bottom-Up Planning - MCAD Data Management Requirements - ECAD Requirements
Engineering change management - Change Objects / Process - BOM Annotation - Effectivity - Reporting
Configuration management - View Versions - Serial Numbering - Product Structure Editing, History, and Compare - Effectivity - Baselines - BOM Management - Replacement Parts - Supersede Parts
Workflow systems - Workflow integration allows the workflow to interoperate with all business objects, their lifecycles, states, and access controls

- Advanced capabilities such as multiple parallel execution paths, looping and complex routing
- Available from a standard web browser
- Allow workflow administrators to define templates
- Capture history of each iteration of the template
- Automatically check for inconsistencies
- Allow for runtime resolution of roles
- Ability to define automated tasks such as check in, check out
- Define reviews that can be addressed to multiple users
- Voting
- Allow for nested process definitions
- Allow variables to be defined locally
- Define synchronization points in a process flow where the process will wait for an event to occur in another process
- Workflow definitions should be extensible so that they can handle unexpected requirements that surface
- Provide for an electronic signature
- Capture the user's name, role, purpose, comments, and time of completion of the task with the signature
- Provide multiple mechanisms for notifying users they have tasks to complete
- Allow for deadlines to be associated with tasks
- Provide for a way of delegating assignment of tasks temporarily or indefinitely
- Provide for a means of specifying points in a process where the user assigned to a task can add additional tasks to the workflow at runtime (ad hoc)
- Temporarily grant read and/or write privileges to specified business objects for the duration of that activity
- Performance of a running process should be independent of the number of activities defined in that process
- Provide for a graphical means of monitoring
- Control running processes including the ability to complete or terminate specific activities and complete or terminate the whole process
- Drive the timely publishing of pdf documents of record inclusive of signature history
- Follow different paths based on conditions or projects
- Offer role management
- Create user groups
- Provide the ability to change assignee during a workflow
- Provide management of feedback/annotations
- Allow the addition/removal of users
- Have the ability to create and change automated workflows based on business processes
- Offer WYSIWYG workflow editing

- Allow assignment of users to projects - Provide the ability to modify workflow lifecycle/status - Support finding, tracking and troubleshooting all workflow processes across the entire system in one view - Allow users to create templates for change notice objects and include them in workflow tasks - Provide utilities to identify any checked-out objects associated to a promotion request
Collaboration - Project setup - Project access - PDM interoperability - User functions - Administrative functions - Programs
Project management - Collaboration - Project planning - Third party integrations - Portfolio management - Program management
Visualisation - Visualization and Markups – MCAD - Visualization and Markups – ECAD - Interference check - Printing
Product intelligence - General reporting - Cost analytics
Release to manufacturing - Release to manufacturing - Ease of administration
Product information delivery - General support for specialised notations (XML, SGML, XSL (XSL-FO and XSLT), XML Schema, XPath, XInclude, DOM and other next generation Web standards for sharing data and content) - Design

- Creation - Management - Link management - Information structure management
IoT (Internet-of-Things) capabilities – *specific requirements limited to Case study #2*
- IoT Application Enablement - Applications development - Data analytics reporting - Data management - Platform - Portal - Device connectivity - IoT Connectivity and Communications - Agent Lifecycle Management - Data Processing - Data management - Software and Content Management - Application Services and Development Tools - Infrastructure and Cloud Services - Security

2/ Scenarios of use (Offer)

During the negotiations leading to the blueprint of the PLM platform, the software vendor present "Scenarios of use" that are demonstrated within the Mock-up ("Proof- The following list accounting for the PLM OFFER is used to compile the "first order codes" for Case study #1.

1/ Customer requirements management - Collaboratively author all requirements in a single environment that supports contextual representation in richly-formatted documents and hierarchical lists. - Relate and reuse 2D engineering concepts in 3D designs in order to shorten design cycles. - Manage and relate cross-discipline product information (e.g., mechanical, electrical, software, product documentation) in a single product structure. Establish a single, synchronized source of product data to capture the correct hardware and software product configuration.

- Create 3D models of all mechanical parts and assemblies to ensure design accuracy while reducing or eliminating the need for expensive physical prototypes. - Establish cost targets at the product, function, and/or component level. Provide program stakeholders with visibility into cost estimate status against the cost targets. - Share product related information (requirements, tests, and designs) with design and manufacturing partners to enable effective collaboration. Provide traceability to what was delivered, received, and accepted. - Automate the creation of key design configurations to analyse and validate. Rapidly visualize and identify design issues in a digital mock-up; track and resolve interferences. - Provide easy and timely access to latest design data to facilitate asynchronous design collaboration regardless of the data size or type. Encourage continuous feedback, and manage formal design review preparation, execution, and follow up. - Manage and control individual requirement definitions and specification approval throughout the lifecycle. - Establish traceability between customer needs, market requirements, and their associated technical specifications / designs. Ensure that all requirements are allocated to the product design. - Automate a requirements analysis and validation methodology for determining whether the stated requirements are unclear, incomplete, ambiguous, or contradictory, and track the resolution of these issues. - Automate requirements verification processes and seamlessly integrate testing tools into overall lifecycle management to streamline and reduce errors and oversights. - Manage and track the reuse and sharing of requirements across projects and products. Identify and report on the entire history of the reuse of requirements. - Collaboratively author all requirements in a single environment that supports contextual representation in richly-formatted documents and hierarchical lists
2/ Multi-CAD data management - Manage concurrent development of mechanical CAD designs, ensuring stakeholders have access to the latest information. - Manage concurrent development of printed circuit board CAD design and manufacturing data to ensure stakeholders have access to the latest information. - Collaborate with teams, suppliers, and partners regardless of their CAD systems to avoid recreation of non-native geometry. - Utilize PLM to streamline the exchange of incremental design changes between electrical and mechanical domains in PCB design to improve cross-discipline communication and decrease design-cycle time while managing the history of changes. - Support for proactive planning of software structure, elaboration, iterative and incremental development of software to minimize serialization of development activities. - Proactively plan and structure larger CAD assemblies to support team-based development without concurrency gridlock. Reuse and associate early product structures with CAD structures. - Support iterative and incremental approaches to software development that focus on delivery of working software, rather than work in progress. - Create 3D models of all mechanical parts and assemblies to ensure design accuracy while reducing or eliminating the need for expensive physical prototypes.

- Concurrently develop logical schematic, 3D cabling and piping design, as well as harness and piping manufacturing instructions.
- Enable collaboration on work-in-process design data. Share product information throughout enterprise in order to facilitate front-end ideation, concept development, and design refinement.
- Provide easy and timely access to latest design data to facilitate asynchronous design collaboration regardless of the data size or type. Enable continuous feedback, and manage formal design review preparation, execution, and follow up.
- Optimize system performance and workability of complex CAD assemblies.
- Automatic creation of the models, drawings, and images derived from a set of requirements that feed directly into a set of intelligent, parameterized models.
- Concurrently develop weldment design with associative process documentation to reduce the need for expensive physical prototypes.
- Enable engineering calculations to be captured, searched, reused, and protected in a managed, controlled environment alongside related design data
- Manage, share and reuse standard mechanical library parts, symbols, features, etc. in product design
- Facilitate, capture, and share unstructured information, discussions, and opinions within the context of product areas or professional interests. Encourage enterprise-wide capture of knowledge and development of subject matter experts.
- Enable designers to create or update CAD designs faster by finding the right information when working with large and complex products.
- Efficiently introduce and manage electronic component information ensuring accurate component selection in the ECAD design tools.

3/ Change & Configuration management

- Implement a closed-loop standard change process. Adapt routing workflows according to change severity. Automatically capture change history, electronic signatures, and audit trails. Notify affected parties of change effectivity.
- Implement a change process across complete product definition (mechanical, electrical, software, documentation), within the common product information repository. Provide stakeholders with access to all necessary product data and configuration information during evaluation, review, approval, and change implementation.
- Ensure that a common, consistent, change management process is applied to all aspects and artefacts of software development.
- Manage evolving software configurations across the entire life cycle, ensuring all artefacts corresponding to a software deliverable are consistent and reproducible.
- Ensure repeatable software build, packaging, testing, and deployment to system integration and product management environments.
- Implement a flexible online issue/change request process. Allow any affected party to indicate and substantiate the need to rectify a problem or improve a design/process.

4/ BOM management

- Enable a development team to create and maintain the parts and structures needed to define a product.

- Establish a single, synchronized source of product data to capture the correct hardware and software product configuration.
- Enable effective product line engineering through holistic, strategic reuse of system and software assets, including requirements, design, simulations, software source code, and test cases.
- Manage evolving product configurations over entire lifecycle. Accommodate rule-based configurability, substitute parts, serialized parts, effectivity (time or lot-based), and organization-specific BOMs (e.g., as-maintained, as-planned). Provide traceability between upstream design and downstream configurations to ensure change visibility and appropriate change propagation.
- Automate sharing and synchronization of product configuration information across enterprise systems.

5/ Workflows / traceability

- Ensure activity owners and assigned resources provide the appropriate level of work and status reporting so project managers can effectively track and monitor progress against schedule without any unnecessary overhead.
- Capture the necessary data about activity effort and project costs to enable project managers to effectively track project spend to budget.
- Track and monitor the utilization of project resources to identify resource overloads and bottlenecks.
- For any given organization, product family or product development group that draws from a shared pool of resources, identify generic product development capacity and classify the capacity according to role or skill set in order to support capacity-based portfolio optimization.
- Measure the impact of proposed and existing product development projects against weighted business drivers to prioritize projects based on alignment with these objectives.
- Support ongoing, real-time monitoring of progress of software development projects in order to support successful release of software deliverables.
- Improve the predictability of software releases by providing metrics and status summaries on the functional completeness of software artefacts, the quality of those artefacts, and outstanding issues.
- Support iterative and incremental updating of software plans and pull-based scheduling from a prioritized queue of work items.
- Systematically capture issues and risks. Continually assess impact and probability to transparently communicate and make risk-informed program decisions.
- Identify, rank and mitigate potential design and process failure modes, effects and causes associated to either a product structure or a process plan. Perform bottom-up failure analysis before a product is fully designed and built.
- Quantify risk at system or functional level early in the design process. Mitigate risk by connecting to test, control plans, and issue management.
- Identify design elements impacting service and maintainability for improved product operation. Model overall cost based on historical and statistical analysis.

6/ Document management

- Manage and associate documents with relevant product data to improve product definition integrity and increase reuse.
- Automate the transfer of physical prototype surfaces into CAD for reuse in design.

- Automate the generation of 2D production drawings from the 3D master model design data. Eliminate errors and enable concurrent design and drawing development. - Document and deliver 3D designs for downstream consumption and eliminate or reduce the reliance on 2D drawings.
7/ Distributed collaboration - Facilitate, capture, and share unstructured information, discussions, and opinions within the context of product areas or professional interests. Encourage enterprise-wide capture of knowledge and development of subject matter experts. - Use free-form or 2D sketching/3D associative modelling techniques to enable product styling concepts and detailed designs to be developed concurrently. Accommodate iterative changes without time-consuming rework. - Perform design sensitivity studies to establish performance envelopes and trade-off curves. - Enable engineering calculations to be captured, searched, reused, and protected in a managed, controlled environment alongside related design data. - Plan to the appropriate level of schedule detail necessary to ensure key deliverables and milestones are met while reducing unnecessary tracking and reporting overhead. - Systematically execute NPD processes with well-defined decision points, evaluation criteria, performance measures, and project deliverables. Reduce risk for different types of product development initiatives (e.g., new product, technology, platform development). - Systematically capture business decisions, executive acknowledgements and scorecard baselines to make critical program decisions transparent and accessible for future reference. - Relate and reuse 2D engineering concepts in 3D designs in order to shorten design cycles.
8/ Visualisation (Verification & Validation) - Establish cost targets at the product, function and/or component level. Provide program stakeholders with visibility into cost estimate status against the cost targets. - Establish multiple-part cost estimates based on characteristics of part. Estimation of cost may be based on development stage of part, different manufacturing techniques, and whether the part is to be made internally, outsourced, or purchased. - Perform multiple analyses of different configuration of the BOM throughout the product development process to assess if the cost targets are being achieved. Determine the critical cost drivers and take action to validate or reduce cost estimates. - Share compliance, materials, cost, and environmental performance metrics to key stakeholders throughout the enterprise, beginning early in product development. - Standardize the Key Performance Indicators (KPIs) used to manage and measure new product development (NPD) efforts in order to assess project performance at gate meetings and to evaluate projects during portfolio analysis. - Standardize the Key Performance Indicators (KPIs) used to manage and measure new product development (NPD) efforts in order to assess project performance at gate meetings and to evaluate projects during portfolio analysis.

- Automatically generate accurate reports that demonstrate product compliance, support due diligence for regulatory authorities, and meet customer requirements. Provide appropriate levels of disclosure for the intended audiences and systematically build a traceable audit trail.
- Author and capture all test cases and plans. Provide a rich and flexible user environment for handling graphics, tables, text, etc. to fully capture the test's intent.
- Manage and control individual test definitions and specification approval throughout the lifecycle.
- Establish traceability between requirements, associated technical specifications/designs, and test. Ensure comprehensive test allocation.
- Capture test results for variety of test types (manual, automated, system, etc.). Deliver test reports and status to expose problems early.
- Develop associative simulation models based on design models to ensure synchronization and reduce cycle times. Quickly prepare models for analysis regardless of CAD experience level or familiarity with design intent.
- Rapidly visualize and identify design issues in a digital mock-up; track and resolve interferences.
- Manage the simulation activities within an enterprise. Provide traceability between requirements, test cases, design configurations, test configurations, and results.
- Automate integration testing which verifies multiple system's/subsystem's (electrical, hardware, and software) requirements of the product.

The following list accounting for the PLM DEMAND is used to compile the "first order codes" for Case study #2.

1/ Connectivity to sold product

- Establish a highly scalable system for provisioning and deploying large numbers of products and assets, managing complex event processing and Big Data, and operating in an evolving and heterogeneous environment.
- Integrate with enterprise data from business systems, time series data from connected things, and unstructured feedback from people to rapidly respond to changing business requirements and uncover actionable insights.
- Enable personalization capabilities by allowing users to remotely add features or change parameters to enhance their user experience and product performance.

2/ Monitoring sold product

- Interact with connected products to identify and diagnose product issues remotely to eliminate unnecessary service calls and improve first time fix rate.
- Enable customers to quickly diagnose and resolve issues themselves by suggesting actions based on connected product data to maximize product availability.
- Collect and analyze product usage, condition, and consumable data to anticipate customer needs, automatically trigger alerts for cross-sell and up-sell opportunities, forecast future purchases, and create new consumable resupply models.

- Analyze and benchmark product performance and usage data collected through remote connectivity with sensor-equipped products or systems to inform and improve product requirements definition, prioritization of features, options and variants, market segmentation, life cycle costs, and supply chain coordination and planning.
3/ Exploit data about sold product - Aggregate and manage large volumes of unstructured, time-series and transactional data from people, systems and things; establish a highly scalable system for complex event processing and data storage. - Integrate product usage and performance data to enable usage, performance, or outcome based pricing and subscription models that create disruptive business models, and increase value captured and market penetration opportunities. - Aggregate data from products across the installed base and combine it with domain expertise to provide information, advisory, and managed services that enhance the customer's operation of the product or understanding of their business.
4/ Monitor product operations - Monitor connected product operating characteristics and combine with thresholds, trends, and analytics to move from reactive to proactive maintenance. - Establish rules, business logic, and algorithms that analyze and correlate unstructured, time-series, and transactional data to optimize business processes and discover new opportunities and insights that answer key business questions. - Enable customer to monitor and track the usage and performance of their products or benchmark with anonymized peers to optimize the value they extract.
5/ Security coverage - Provide secure real-time bidirectional communication with devices and ensure compliance with policy management for access control, logging, and auditing of interactions with connected products and assets
6/ Manage "agent" lifecycle - Leverage proven agent technology and connectivity services to easily and flexibly connect to any wired or wireless asset via third-party device clouds, direct network connections, open APIs or edge devices. - Remotely identify and manage the as-maintained configuration of fielded products, systems and assets; control the release of software updates and security patches by securely distributing packages of software files and instructions remotely.
7/ Interact in real-time with sold product (EDGE connectivity) - Interact real-time with connected products to perform remote service activities including machine adjustments, software updates, and self-tests to avoid downtime and eliminate need for on-site service calls. - Enable personalization capabilities by allowing users to remotely add features or change parameters to enhance their user experience and product performance.

- Automatically trigger service events based on preemptive connected product alerts, diagnose issues, determine the best service response and dispatch technicians based on SLA entitlements and resource availability.

8/ Analyse and benchmark connected product performance

- Support planning Define holistic service programs that associate and manage all required product support information including service tasks, preventive maintenance schedules, warranty and contract policies, serviceable parts, technical information and training materials to ensure accuracy and completeness.
- Use digital product information to analyse and predict product and component reliability; define recommended maintenance schedules to prevent failures and minimize warranty costs, and iterate the plan based on feedback loop from product performance data.
- Feedback Simulate service activities using 3D design and human factors information for early identification of serviceability issues and evaluation of service skills/time requirements.
- Intelligently link service information to product designs and engineering change processes to streamline change propagation and service/parts information updates.

9/ Capture events driven "objects"

- Continuously analyse field data collected through remote connectivity with sensor-equipped products or systems to improve root cause analysis and corrective actions, product quality, reliability and safety, preventive maintenance, and service.
- Leverage connected product data including configuration, utilization, and location to improve balancing of service level objectives with service parts inventory levels.

10/ Codify "local" maintenance tasks

- Interact with connected products to diagnose product issues and initiate proactive service responses to eliminate unnecessary service calls, avoid product failures and downtime and improve customer satisfaction.
- Capture field diagnostic sessions and feedback and enable social rating and discussion forums to improve diagnostic accuracy and technician efficiency.

11/ Enable remote diagnostics and services tasks

- Provide guided diagnostics based on predicted and actual product issues; track product issues to improve diagnostic efficiency and provide feedback to engineering for product improvements.
- Provide operator / owner with interactive diagnostics to reduce contact centre call volume, improve product uptime and increase customer satisfaction.

12/ Create warranty scoring table

- Automatically identify equipment and customers impacted by warranty issues and recalls. Continually track campaign status to validate compliance and improve customer satisfaction.
- Automatically determine when parts need to be returned, generate Return Material Authorizations (RMA), track part returns through shipping, receiving and inspection to maximize return rates and minimize return costs.

- Continually monitor connected product usage to identify potential warranty compliance issues; automatically notify operator when compliance issues occur to avoid potential product failures and warranty issues.

13/ Establish rules, business logic and algorithms to analyse "unstructured" data

- Analyse performance matrices for field service events across the enterprise to validate compliance with goals and improve field service processes.
- Analyse repetitive and no-fault-found service claims to identify service quality issues; provide feedback to improve training, optimize service schedules and reduce service cycle times.
- Provide product performance feedback to Quality and Engineering for corrective action, continual product improvement and improved product availability.
- Capture sensor-based equipment data and automatically identify trends that could impact performance. Identify all equipment susceptible to trend and pre-emptively address issue before actual performance is impacted.

14 /Analyse product usage, condition, and consumables data

- Optimize scheduling of planned and unplanned service events, including all required parts and resources, to improve SLA compliance, first-time fix rates, technician utilization and customer satisfaction.
- Automatically trigger service events based on pre-emptive connected product alerts, diagnose issues, determine the best service response and dispatch technicians based on SLA entitlements and resource availability to correct issues before actual product failures occur.
- Leverage partner service personnel by assigning tickets to partners for execution to improve SLA compliance, reduce field technician overtime and optimize service event coverage.
- Interact real-time with connected product to perform remote service activities including machine adjustments, software updates and self-tests to avoid downtime and eliminate need for on-site service calls.
- Expand OEM resources by adding partner field service personnel to improve SLA compliance, reduce field technician overtime, and optimize service event coverage.
- Optimize scheduling of partner resources by obtaining visibility into availability of field service partner's service schedules to improve SLA compliance, reduce field technician overtime, and optimize service event coverage.
- Optimize scheduling of planned service events and increase dispatcher productivity to improve SLA compliance, first-time fix rates, technician utilization and customer satisfaction.

15 /Interact with connected product

- Provide connected product monitoring to pre-emptively identify potential product issues and approaching preventive maintenance events. Issue notifications to initiate service responses that minimize downtime and avoid potential product failures.

- Monitor connected product conditions to identify thresholds and trends that indicate potential product failures; automatically initiate service responses to minimize downtime and avoid potential failures.
- Optimize preventive maintenance schedules based on actually product reliability and usage information to maximize product availability and minimize cost of ownership.
- Automatically update product as-maintained configuration, utilization and service history based on connected product data and service events performed across the service network. Analyse asset and fleet history for contract compliance and optimization, deferred and approaching service needs and product upsell and replacement opportunities.

16 /Process and manage healthcare related data

- Analyse and correlate unstructured, time series and transactional data to discover new opportunities and create new data intelligence to answer key business questions.
- Ensure security and compliance with policy management for access control, logging and auditing of interactions with connected products and assets.

17/ Develop apps (model based development environments)

- Use pre-built remote apps to reduce service costs and visits, improve product uptime and enable new managed service offerings and service growth.
- Leverage platform with a model-based application development environment to reduce the time, cost, and risk required to build and maintain innovative connected applications that differentiate products and services and provide a competitive edge.

3/ Abridged example of the coding process

Coding protocol is designed according to the theoretical constructs presented in the review of the literature (chapter 2 above). Our contribution aims at exposing how the blueprinting process compose *"collective hybrids"* (Latour 2005) that convey both, persistency and transiency.

The four sequences that organise the empirical data into meaningful segments, are an attempt to make sense of the movement leading to the inscription of disciplinary entities in a common, cross-disciplinary "frame of reference." We follow how the latter contributes to the generation of a *series of associations* of heterogeneous and discontinuous – but nevertheless, commensurable disciplinary practices, specialised software applications and distributed judgements accounting for the industrial product.

The following example about "baselining" capabilities may help to better understand how the coding logic was deployed. The operationalisation of the coding logic is carried out by looking for associations, correspondences and equivalences between data coding categories.

Compiling First order codes: quotes about how demand and offer express "baselining" capabilities? [69]

Sequence #1/ Identify quotes about functional requirements on "baselining": reed functional requirements and try to understand the Use case about "baselining" capabilities such as: *"The product structure management software must support the concept of "baselines," a snapshot of significant parts within product structures at arbitrary milestones throughout the product and process lifecycle. Because numerous configurations of a product structure will be created over time, these baselines aid in identifying and establishing the product structure configurations of significant interest"* (Request for Quotation).

- Encoder extracts the main functional attributes of the PLM platform about the capabilities to establish "*a snapshot of significant parts within <u>product structures</u> at arbitrary milestones."*

Sequence #2/ Identify quotes about scenarios of use: select quotes about *how* and *what* the scenario of use proposed by the PLM offer, adds/inscribes the targeted disciplinary practice in a cross-disciplinary account about the "product lifecycle".

- Encoder identifies *HOW the scenario of use adds collective capabilities to* move practices from "Domain Integrated" (process formalized at departmental / workgroup level characterized by limited oversight of all changes across product and product lines)

[69] As mentioned above Quote is *"A word or short phrase that symbolically assigns a summative, salient, essence-capturing, and/ or evocative attribute for a portion of language-based or visual data"* (Saldana 2009: 3)

to Enterprise integrated level (the software applications "single product structure" aids locating product information and improves change accuracy)

- Encoder identifies *WHAT is added to collective capabilities* to transform the perimeter of disciplinary tasks and the chain of interactions or associations across discipline boundaries: how the *scenarios of use* proposed by the vendor modify current manual collaboration and data exchange required across domains or departments.

Compiling Second order codes: how PLM mediations perform the commensurable/calculable *condition of being equivalent* across various organisational contexts. The questioning in the case of "baselining," concerns the emergence of multiple interpretations within a consistent set of cross-disciplinary organisational rules (*when & where sharing takes place*)

Encoder asks questions such as:

- How to measure "release reediness" through the introduction of "baselining" and capabilities (consequences of the introduction of "Review/Approval / Release" process and more formal workflows for "Change" process routing and notification events);
- How to agree upon a "lowest configurable item" to enforce "configuration management" management capabilities across disciplines (effectivity, applicability rules);
- How to compare product baselines – and "view" both accounts about a product tracing and identifying "suspect links";
- How traceability matrices show where and how requirements are satisfied;
- How to agree upon the model of account persistence at the "Enterprise" level (Object-Oriented models that span specialized applications modifying canonical representation of request-response messaging).

Sequence #3/ Memos about what holds disciplinary practices and software applications together

Encoder writes memos about the alterations in the way the accountability is (re) assigned across disciplinary boundaries.

- Identify PLM mediations – in this case, a "single product structure" or Bill-of-materials (BOM) – that adds/modifies/moves something – in this case, *associativity* between MCAD / ECAD / Software information.
- Code what modifies the chain of associations between product information: the capability to trace "problem reports, change requests and change notices" across disciplinary boundaries.

Coded quotes at this stage concern the way responsibility is assigned across disciplines.

Encoder asks questions such as:

- How commensurability across heterogeneous validation practices emerge through more abstract, scalable narratives about the "product lifecycle" shared by key disciplines;
- How PLM mediations increase downstream & upstream navigation capabilities supporting traceable accounts about the product;
- How PLM mediations specify and assign accountability about the product accounts across interdependent disciplinary agencies;
- How validation practices are assigned "laterally" across discipline boundaries.

Sequence #4/ Diagramming how the novel "frame of reference" is made durable

To sketch a graphical representation of "trails of connections," the encoder asks questions such as:

- how software applications become interoperable,

- Object-Oriented models enabling “routing and notification events” such as “problem reports”, “change requests” and “change notices”

- how practices become calculable,
  - Metrics that move practices to cross-disciplinary “Enterprise integrated” level - such as “increased process standardization”,[70] “improved change productivity”,[71] “Reduced cost of changes”[72]

- how responsibilities become visible,
  - Dashboard of “Engineering change requests” is visible within and across teams.

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[70] Evidence of calculable indicator is: “Percentage of changes adhering to process (Fast and Full)”.

[71] Evidence of calculable indicators is: “Average change (ECR/ECN) investigation time”, “Cost of people administrating the change process”.

[72] Evidence of calculable indicators is: “Average duration of changes from initiation to completion”, “Reduction in delay due to incorrect change data”, “Percentage reduced rework”, “Percentage reduction in change process turn-around time”.

4/ Summary of coding process

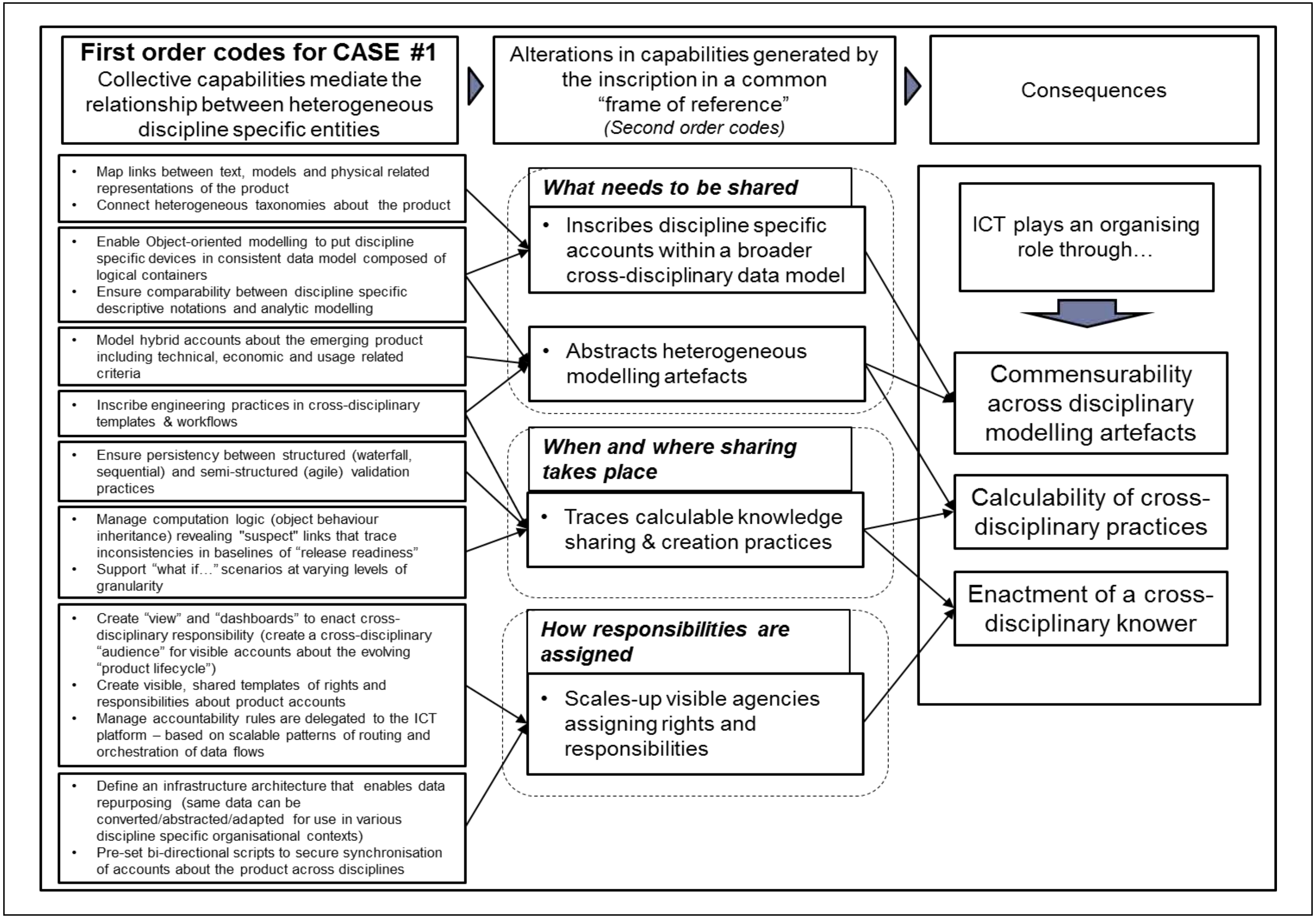
The figures below present the main steps of the coding process.

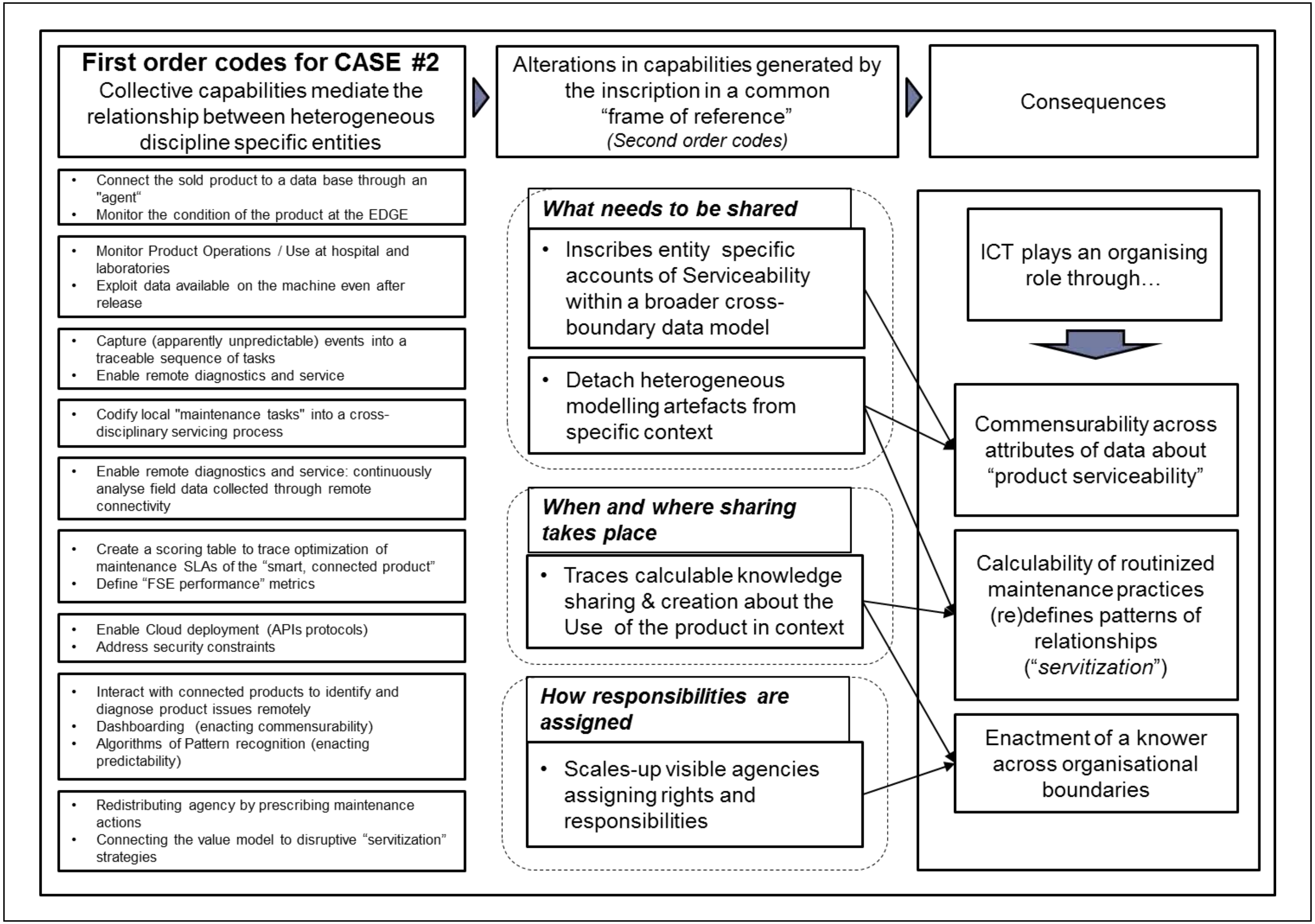
First order codes	Second order codes	Consequences

• List of functional attributes of the PLM platform that mediate the relationships between heterogeneous discipline specific entities
• As expressed by the “demand” and the offer” enacted in a “mock-up” of the PLM platform
	• Composition of “trails of connections” expressing the inscription of disciplinary entities in a common cross-disciplinary “frame of reference”
	• Follow how the PLM blueprinting negotiation establishes ***equivalences*** between disciplinary entities …
		• Distributed and heterogeneous agencies (practices & software applications) become part of a cross-disciplinary account of the “product lifecycle”
		• The account of the product & service lifecycle brings together novel accountability patterns assembling
		  • ***discontinuity*** of agencies
		    • Bookkeeping (map)
		  • ***distributiveness*** of agencies
		    • Narrative (compass)

Encoder formalizes higher level *“categorical aggregation”* about what makes *commensurable* and *calculable* equivalences between software applications and practices:

First order codes	Second order codes	Consequences
How are PLM mediations Composed (**offer meets demand**)?	“Trails of connections” expressing the **inscription of disciplinary entities in a common “frame of reference”**	**Distributed and heterogeneous *mediating agencies* (practices & software applications) become part of a cross-disciplinary *account* of the “product lifecycle”**
Functionality A vs. scenario of use X	Mediation “A” moves disciplinary entities to …	
Functionality B vs. scenario of use Y	Mediation B attaches disciplinary entities to …	
Functionality C + scenario of use Z	Mediation …N	
Etc…		


First order codes for CASE #1
Collective capabilities mediate the relationship between heterogeneous discipline specific entities
Alterations in capabilities generated by the inscription in a common "frame of reference"
(Second order codes)
Consequences
• Map links between text, models and physical related representations of the product
• Connect heterogeneous taxonomies about the product
• Enable Object-oriented modelling to put discipline specific devices in consistent data model composed of logical containers
• Ensure comparability between discipline specific descriptive notations and analytic modelling
• Model hybrid accounts about the emerging product including technical, economic and usage related criteria
• Inscribe engineering practices in cross-disciplinary templates & workflows
• Ensure persistency between structured (waterfall, sequential) and semi-structured (agile) validation practices
• Manage computation logic (object behaviour inheritance) revealing "suspect" links that trace inconsistencies in baselines of "release readiness"
• Support "what if…" scenarios at varying levels of granularity
• Create "view" and "dashboards" to enact cross-disciplinary responsibility (create a cross-disciplinary "audience" for visible accounts about the evolving "product lifecycle")
• Create visible, shared templates of rights and responsibilities about product accounts
• Manage accountability rules are delegated to the ICT platform – based on scalable patterns of routing and orchestration of data flows
• Define an infrastructure architecture that enables data repurposing (same data can be converted/abstracted/adapted for use in various discipline specific organisational contexts)
• Pre-set bi-directional scripts to secure synchronisation of accounts about the product across disciplines
What needs to be shared
• Inscribes discipline specific accounts within a broader cross-disciplinary data model
• Abstracts heterogeneous modelling artefacts
When and where sharing takes place
• Traces calculable knowledge sharing & creation practices
How responsibilities are assigned
• Scales-up visible agencies assigning rights and responsibilities
ICT plays an organising role through…
Commensurability across disciplinary modelling artefacts
Calculability of cross-disciplinary practices
Enactment of a cross-disciplinary knower


First order codes for CASE #2
Collective capabilities mediate the relationship between heterogeneous discipline specific entities
• Connect the sold product to a data base through an "agent"
• Monitor the condition of the product at the EDGE
• Monitor Product Operations / Use at hospital and laboratories
• Exploit data available on the machine even after release
• Capture (apparently unpredictable) events into a traceable sequence of tasks
• Enable remote diagnostics and service
• Codify local "maintenance tasks" into a cross-disciplinary servicing process
• Enable remote diagnostics and service: continuously analyse field data collected through remote connectivity
• Create a scoring table to trace optimization of maintenance SLAs of the "smart, connected product"
• Define "FSE performance" metrics
• Enable Cloud deployment (APIs protocols)
• Address security constraints
• Interact with connected products to identify and diagnose product issues remotely
• Dashboarding (enacting commensurability)
• Algorithms of Pattern recognition (enacting predictability)
• Redistributing agency by prescribing maintenance actions
• Connecting the value model to disruptive "servitization" strategies
Alterations in capabilities generated by the inscription in a common "frame of reference"
(Second order codes)
What needs to be shared
• Inscribes entity specific accounts of Serviceability within a broader cross-boundary data model
• Detach heterogeneous modelling artefacts from specific context
When and where sharing takes place
• Traces calculable knowledge sharing & creation about the Use of the product in context
How responsibilities are assigned
• Scales-up visible agencies assigning rights and responsibilities
Consequences
ICT plays an organising role through…
Commensurability across attributes of data about "product serviceability"
Calculability of routinized maintenance practices (re)defines patterns of relationships ("servitization")
Enactment of a knower across organisational boundaries

Annex 4. Interviews

Functional requirements are often related to one another. In order to get a better understanding of the interdependencies, we have also performed interviews with subject matter experts that authored the RFQ documents.

Interviews are structured around the need to confront "top-down" content (official documents) with "bottom-up" practices of boundary spanning information sharing and creation.

Interviewees sample concern experts from the following departments.

- Design & Engineering disciplines representatives - Mechanical, E&E, SW
- IT department representatives
- Project manager
- Business sponsor
- Procurement
- Meetings with all stakeholders involved in the IT tool qualification.

We used a structured template to deploy the interviews around the following topics:

- Part 1 / Value opportunities
- Part 2/ Scoring Important Business Initiatives
- Part 3/ Ranking Process Importance
- Part 4/ Process AS-IS maturity

Annex 5. Glossary

Agency: (collective capacity to act) encompasses the *act* of providing a practical means for accomplishing something (caring into effect) the *means* whereby some act is accomplished (as in "by means of").[73] In the context of the PhD, *Mediating Agencies* cover: (1) the *act* of using digital models to represent an industrial product (modelling Practices accounting for the

[73] agency. (n.d.) *American Heritage® Dictionary of the English Language, Fifth Edition*. (2011)

product) and (2) the *modelling artefacts* whereby the product is accounted for (software applications *and* Platform "by means of" which engineers account for the emerging product.

Configuration: Software package can be configured to support a customer requirement using standard tools (without programming).

COTS: Software package meets the customer requirement with "Commercial-Of-The-Self" capabilities.

Customization: a change in the software package (requiring programming), must be used to support a customer requirement.

Mediating: (1) acting between parties with a view to reconciling differences, (2) occupying a middle position, (3) forming a connecting link. The PLM platform mediates (reconciles differences) between disciplinary applications and engineering practices.

Modelling artefacts comprise both…

- Specialised, standalone software applications used to model the digital representation of an industrial product (Ex. Computer Aided Design (CAD) software applications
- Cross-disciplinary ICT platforms (Ex. Product Lifecycle Management (PLM) platforms)

"Product Lifecycle Management" (PLM) Platform

- *A "strategic business approach that applies a consistent set of business solutions in support of the collaborative creation, management, dissemination, and use of product definition information across the extended enterprise, spanning from product concept to end of life —integrating people, processes, business systems, and information"* (CIMdata)
- *"PLM is an integrated, information-driven approach comprised of people, processes/practices, and technology to all aspects of a product's life, from its design through manufacture, deployment and maintenance—culminating in the product's removal from service and final disposal."* (Greives 2006:39).

Annex 6. Valorisation

The results of the dissertation contribute to both practitioners and research related activities.

One of the key challenges in complex engineering is the productive alignment of knowledge and expertise across different technical disciplines. This thesis addresses this key concern. In two case studies it is shown how cross-disciplinary accountability can be accomplished *technically* across organisational boundaries. This is one of the main objectives of the PLM blueprinting phase. If this phase is successful, the customer proceeds to the contractual purchase of the software package. However, ICT vendors and their customers have yet to go from the proven technical feasibility to the organisational sustainability of the proposed PLM platform. One of the most fragile links of the emerging *chain of reference* (what is technically needed) concern the definition of the corresponding heterarchic organisational model (who is accountable for what).

Practitioners involved in the actual implementation of PLM platforms can benefit from the main findings to better assign resources and to balance the time allocation between the three main steps of a blueprinting process: (1) requirements elicitation, (2) configuration of the proof of concept and (3) product approval. Most common vendor practices allocate the main part of the blueprinting effort to the clarification of the technical aspects of the Request-for-proposal issued by the customer ('the demand'). In addition, customers acquiring a software package tend to consider that technical interoperability will necessarily secure cross-disciplinary practices. This study shows how this leads to extensive discussions about how *technical* connectivity insures interoperability between the discipline specific representations of artefacts.

Both PLM blueprinting initiatives studied in the dissertation, are contained within a relatively small organisational setting with regard to the overall perimeter of the industrial firms. The ICT vendor tries to avoid engaging in discussions about benefits of potentially disruptive ("messy") heterarchic organisational models – on the contrary, they contain the blueprinting agenda within technical subjects. That is why the decision making processes during pre-sales phases are mainly focused on getting buy-in from IT experts rather than discipline engineers. This myopic strategy does not fully acknowledge the crucial role of discipline engineers.

So, a possible valorisation of these findings is that the the definition of an operational sequence should be included in future blueprinting initiatives in order to help assembling technical interoperability (Object-Oriented links between heterogeneous artefacts) and the design of heterarchic cross-disciplinary collaboration models. As a result, the novel accountability patterns based on peer review control could be consistently scaled-up and sustainably organised.

This study can also be used to advance on research about the role of "object-oriented" (OO) modelling. The latter, convey "*calculative agencies*" that are located in algorithmic "objects" instead of being placed at procedural/project management level. There are still many questions to be addressed about the way calculative agencies are inscribed in "OO artefacts". Particularly, it is unclear what the role is of *visual* evidence (templates, dashboards, etc.) in organising pervasive forms of prescriptive agency. One interesting valorisation path is the study of how the extension of virtual connectedness (Internet of things, etc.) could generate "*preferred courses of action*" within organisations.

Summary of the dissertation

Research domain

The dissertation studies the relationship between the organisation of complex concurrent engineering processes and Information & Communication Technology (ICT). It seeks to contribute to the contemporary academic debates about the role of ICT in organising distributed agencies across disciplinary boundaries.

The investigation is structured around the *blueprinting* process of a Product Lifecycle Management (PLM) platform, which is a collective exercise taking place when an industrial company engages in the acquisition of standard software to *address its business and organisational challenges.*

By investigating the relatively underdetermined and contingent blueprinting process leading to the stabilised, *"black-boxed"* (Latour, 2005) PLM platform, we adopt a heuristic stance that is able to seize the active role played by ICT mediations, *"before the box actually gets closed"* (Lanzara 1999).

Research design

The literature review is organized around three main theoretical debates that have guided the construction of the research question. Firstly, it addresses literature on Knowledge-based Theory studying integrative capabilities that mediate knowledge transfer and exchange. Secondly, the "practice turn" in the Organisation and Management literature that points to the importance of studying *"intersubjective"* cognitive practices within their organisational context. Thirdly, debates about the performative role played by material artefacts in composing "*interobjective*" (Latour 1996) interactions mediating heterogeneous and discontinuous elements as these are shaped and assimilated into a network. *Drawing upon the heuristic framework proposed by Actor Network Theory,* we investigate how ICT mediations reconcile different *"techniques of staging the world"* and *enact* relationships between heterogeneous disciplinary agencies.

The research question is: How does the blueprinting process of a "Product Lifecycle Management" (PLM) platform assemble the disciplinary agencies accounting for a new product across organisational boundaries?

The research question is operationalised through three propositions on how negotiations about the blueprint of the PLM platform alter the ways the emerging industrial product is accounted for across organisational boundaries.

Proposition 1/ The blueprinting process defines *what information needs to be known/shared* across disciplines. We look for empirical evidence of *how the PLM blueprint composes cross-disciplinary mediations* enabling disciplines to access, trace and account for information about the industrial product across disciplinary boundaries.

Proposition 2/ The blueprinting process defines *when & where* information sharing takes place. We look for empirical evidence of *how the PLM blueprint moves disciplinary practices and software applications* to a cross-disciplinary account about both the industrial product and its usage by the final customer.

Proposition 3/ The blueprinting process defines *accountability* across disciplinary boundaries. We look for empirical evidence of *how the PLM blueprint modifies the way roles and responsibilities are assigned* and how disciplinary judgments about the product and its usage *are enacted* across organisational boundaries.

Methodology & case studies outline

The research approach is qualitative, adopting a case study methodology (Yin 2009; Eisenhardt et al. 2013). The case studies are based on two projects aimed at introducing PLM platforms within engineering organisations developing discrete manufacturing products - the first in the defence sector, the second in the biotechnology sector.

The first case study concerns the blueprinting process of a PLM platform supporting information sharing across mechanical, electrical and software engineers developing a combat management system for naval vessels. Our investigation presents how three specialised disciplines address the need to collectively enact a common account about the new combat management system. We study how the blueprinting process of a PLM platform mediates a more consistent – and *"auditable"* - account of the *"product release readiness"* throughout its lifecycle.

The second case study is about the blueprinting process of an extended PLM platform to improve maintenance services of in vitro diagnostics machines used within the medical and industrial sectors. The biotechnology company is engaged in a major strategic shift of its "go to market" strategy. The introduction of a "servitization" approach, requires new cross-disciplinary capabilities to capture the real-time performance of the *in vitro diagnostics* machines that are used by microbiology laboratories and hospitals. We analyse how the PLM platform mediates the introduction of new ways to create and share information about *predictive maintenance. The case study shows how the negotiations between a biotechnology firm and a PLM vendor* redefine maintenance and services operations – particularly, by moving local troubleshooting practices to a cross-disciplinary account of *"predictable product serviceability"* throughout its lifecycle.

The two case studies bring empirical evidence on how the PLM blueprinting process composes and perform a common *frame of reference* assembling the disciplinary agencies accounting for the new product.

Contribution

The contribution builds on Actor Network Theory's *interobjective* heuristic model to highlight how ICT mediations coalesce and perform novel *"techniques of staging the world"* that distribute organising agencies among humans and non-humans. Empirical evidence about these novel techniques depicts how the PLM blueprint *actively organises* agencies to account for the *persistency* of the "auditable" representations of the emerging product while – concurrently - facilitating *transient*, "open" accounts of the product's attributes.

The analysis points particularly to three organising or mediating agencies brought about by the PLM blueprinting process.

Firstly, PLM mediations *abstract* disciplinary notations and categorisations while preserving specificities of disciplinary taxonomies and modelling practices – i.e. *heterogeneity* of software applications becomes commensurable at cross-disciplinary level.

Secondly, PLM mediations enforce *transversal traceability* of engineering practices while preserving forms of adhocratic slack indispensable for distributed engineering cooperation – i.e. *discontinuity* of engineering practices becomes *calculable* at cross-disciplinary level.

Thirdly, PLM mediations create *shared accountability* enacting discipline specific judgements about the product, while ensuring flexible peer-to-peer forms of cross-disciplinary accountability – i.e. *distributiveness* of judgements becomes *visible* and accountable.

Together, these three mediating agencies compose a cross-disciplinary frame of reference *that aligns the conflicting components of concurrent engineering.*

Curriculum Vitae

My interest in the relationship between ICT and distributed organisational environments grew throughout the course of my professional career. I started my career teaching sociology of organisations for 12 years, at the University of Paris Dauphine. I progressively moved from a role of *observer* (as a lecturer and researcher studying the role of ICTs in organisations), to a role of *consultant* (working on Design & Engineering process improvement in various consultancy firms). Since 2006, I have worked as a *prescriber* of product innovation related information management platforms – working as a pre-sales consultant at a PLM software provider.

Throughout my career, I have worked with a number of diverse professional groups (engineering teams, project managers, IT developers, political authorities, R&D managers, consultants, trainers, standardization bodies, etc.), within numerous firms in different verticals (automotive, aerospace &

defence, high tech & electronics, finance, life sciences, government & NGOs) and geographies (Europe, China, USA), involving several types of ICT systems (predominantly on Design & Engineering related PLM platforms).

My background in sociology led me to a reflexive point of view about highly technological driven environments. The resulting participant observer standpoint enabled me to build first-hand insights of how ICT platforms are being used in contemporary organisational forms.

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