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ESTABLISHING 3D-CE APPROACH IN PRODUCT DEVELOPMENT PRACTICES

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INTRODUCTION

Research abstract

In the current competitive environment, integrating supply chain design and production process design with product design has become crucially important to improve supply chain capability and product development performance (van Hoek and Chapman, 2006). Indeed, by aligning supply chain and process features to product features, organizations satisfy efficiently and effectively consumer needs (Pero et al., 2010).

Despite the complex interdependencies among product design, production process design, and supply chain design have been recognized as early as Hoekstra and Romme (1992), until Fine (1998) this insight did not enter the realms of competitive strategy nor capture the attention of top management (Forza et al., 2005).

Fine (1998) advocated the three-dimensional concurrent engineering (3D-CE) approach that suggests the simultaneous and coordinated design of products, manufacturing processes, and supply chains. The 3D-CE extends the concept of the concurrent design of products and processes (Winner et al., 1988) to the simultaneous and coordinated design of product, manufacturing processes, and supply chain.

Integration is the core of concurrent engineering (Paashuis and Boer, 1997). A stream of literature refers to integration as a composite process subsuming communication and collaboration processes (Kahn, 1996). Communication consists in a set of coordinated activities (e.g., meetings, teleconferences, flow of standard documentation) adding structure to how departments interrelate (Kahn, 1996; Ruekert and Orville, 1987). Whereas, collaboration consists in a set of unstructured and intangible activities, e.g. real-time communication, enabling individuals and departments to work together, have mutual understanding and achieve collective goals (Kahn, 1996; Appley and Winder, 1977).

Several researchers address the question of how companies enable and facilitate integration (Paashuis and Boer, 1997; Adler 1995; Cooper and Kleinschmidt, 1995; Clark and Wheelwrigth, 1993; Van de Ven et al., 1976; Thompson, 1967). The results suggest that the selection and the implementation of the most appropriate integration mechanisms in relation to the context in which a firm operates lead to effective communication and collaboration processes and, in turn, enable and facilitate integration.

Recently, in several industrial sectors, ranging from computer software development to automotive development, resources involved in product development projects are no longer centralized. Organizations migrate from centralized to global product development (GPD) practices (Gomes and Joglekar, 2008). These emerging practices in product development exploit distributed and networked development processes in which development teams comprise individuals drawn from multiple countries and company functions (McDonough et al., 2001). The transition to GPD practices requires organizations to enable and facilitate integration among individuals and functions across time zones, languages, cultures and companies. Hence, as global team members are geographically distributed and separated by multiple time zones new ways to integrate teams must be incorporated in GPD practices (Eppinger and Chitkara, 2009).

Much of the reviewed academic discussion on GPD practices has been about what it is, why it should be done and how it should be deployed (Tripathy and Eppinger, 2011; Eppinger and Chitkara, 2009; Eppinger and Chitkara, 2006). Further, discussion on integration in GPD practices has been about how integration mechanisms cope with problems arising from the global dispersion of product development resources (Kleinschmidt et al., 2007; Barczak and McDonough, 2003; McDonough et al., 2001; McDonough and Kahn, 1999). In detail, current views of integration in GPD practices are simply focused on mechanisms building trust, encouraging collective goals and promoting motivation among global team members. Whereas, there has been less focus on frameworks that practitioners can use to decide how to enable and facilitate integration, and, in turn 3D-CE, in GPD practices. Hence, the objective of the present research is to develop a provisional framework explaining how 3D-CE should be facilitated in product development practices. Coherently with the research objective, the research question has been raised as follows: how do high performing organizations facilitate 3D-CE in product development practices?

Although the research question might be termed as intermediate theory research, the gap in the academic literature regarding product development practices places the present research in the theoretical continuum between the nascent theory research and the intermediate theory research (Edmondson and McManus, 2007). Hence, case study methodology has been adopted as it has been considered appropriate to achieve the methodological fit among the research questions, prior work, research design, and theoretical contribution (Yin, 2003; Voss et al., 2002). Further, it has been believed appropriate to design the research including few, focused, in-depth and best-in-class case studies (Handfield and Melnyk, 1998). Further, within-case and cross-case analyses have been conducted to analyse qualitative data collected through in-depth and semi-structured interviews, and documents.

Case study results suggest that high performing companies, exploiting global product development practices in a context where the product architecture is modular and the product development organization is global captive, facilitate 3D-CE (i) designing a modular product development process architecture, (ii) configuring an integration process consisting in communication, and (iii) implementing integration mechanisms comprising: standard specifications defining in advance design activities outputs; enterprise communication technologies formalizing product development process workflows and allowing specialists to access, distribute and store product data; and product champions promoting communication among specialists. On the contrary, high performing companies, exploiting local product development practices in a context where the product architecture is integral and the product development organization is local, facilitate 3D-CE (i) designing an integral PD process architecture, (ii) configuring an integration process consisting in collaboration, and (iii) implementing integration mechanisms comprising: co-location of specialists involved in the product development; face-to-face informal communication; and collaborative techniques.

The present research contributes to the academic literature concerning the global product development (Tripathy and Eppinger, 2011; Eppiger and Chitkara, 2009) and the integration of product development and supply chain management (Pero et al., 2010; Ellram et al., 2008; Hoek and Chapman, 2007; Fine 1998) addressing how high performing organizations facilitate 3D-CE according to distinct product development practices. Further, the research still contributes to theory as observations derived from the cases lead to formulate testable research propositions on how the elements facilitating and affecting 3D-CE are related to each other.

Research background

The thesis presents the results of a three-year research project carried out at Politecnico di Milano within the Supply Chain Management research group. In detail, the study has been developed building on the results of a long-term research project on the alignment between product development and supply chain management (Pero et al., 2010). Indeed, starting from the assumption that by aligning supply chain and process features to product features, organizations satisfy efficiently and effectively consumer needs, the thesis aims to contribute to the academic literature concerning the global product development (Tripathy and Eppinger, 2011; Eppiger and Chitkara, 2009) and the integration of product development and supply chain management (Pero et al., 2010; Ellram et al., 2008; Hoek and Chapman, 2007; Fine 1998) addressing how high performing organizations facilitate 3D-CE according to distinct product development practices.

Research structure

The present thesis has been organized according to the evolution of the research project over time, starting by reviewing the academic literature, followed by designing the research question, model, and methodology, and, finally, conducting empirical research.

Chapters 1, 2, 3, 4 and 5 present the review of the academic literature. In chapter 1, definitions of product design and of product development process are provided. Further, a brief review of the literature on product development processes focused on process architecture and on process models is presented. In chapter 2, the traditional and the concurrent engineering approach to product development are presented focusing on the three-dimensional concurrent engineering concept. In chapter 3, the concept of integration is investigated. In chapter 4, strategic, technological and organizational mechanisms enabling and facilitating collaboration and communication are introduced. Finally, in chapter 5, the phenomenon of globalization in the context of innovation is discussed focusing on the emergence of global product development practices.

Chapters 6, 7 and 8 present the research question, model and methodology. In chapter 6 the research objective and the research question are introduced discussing the dearth in the academic literature concerning the global product development and the integration of product development and supply chain management. In chapter 7, the research model is presented introducing the elements constituting the model and inferring relations among the elements. In chapter 8, the research methodology is described discussing the research design and the operational measures adopted to operationalize the elements of the research model.

Chapters 9, 10, 11 and 12 discuss empirical research. In chapters 9, 10 and 11, case studies are described and within-case analysis is presented. In chapter 12, cross-case analysis is presented.

Finally, chapters 13, 14, 15 and 16 present the conclusions and the limitations of the research. In chapter 13, the research question is answered discussing how high performing companies facilitate 3D-CE in product development practices. In chapter 14 and 15, the managerial implications and the theoretical contributions of the research are advanced and discussed. In chapter 16, research limitations and further research directions are presented.

LITERATURE REVIEW

The review of the academic literature has been conducted according to the techniques provided in the systematic literature review approach developed by Tranfield et al. (2003) allowing to identify, select and analyse secondary data. Hence, a number of key words have been identified in the areas of product design, supply chain, concurrent engineering, integration, integration mechanisms, and global product development practices. Further, the literature search has been executed looking for papers containing any of the pre-defined research key words. The search results have been preliminary reviewed by reading the article title, the abstract and, if coherent with the scope of the literature review, the full paper.

In the next chapters, the evidences emerging from the literature review on product development, concurrent engineering, integration, integration mechanisms and product development practices are discussed.

In chapter 1, as the research deal with product development, definitions of product design and of product development process are provided. Further, the concept of process architecture is defined leading to understand differences between modular product development processes and integral product development process. Finally, as the adoption of formal product development processes has been extensively cited as a differentiating factor between success and failure within product development project, the stage-gate model is presented.

In chapter 2, as pressure on time-to-market forced companies to move from the traditional product development process to the concurrent engineering approach, the literature on concurrent engineering (CE) has been reviewed focusing on the concept of 3D-CE.

In chapter 3, as integration among interdependent product development activities is essential to establish effective 3D-CE practices (Terwiesch et al., 2002; Paashuis and Boer; 1997), the concept of integration in product development has been investigated.

In chapter 4, as organizations enable and facilitate the integration designing and implementing the most appropriate configuration of integration mechanisms (Paashuis and Boer, 1997; Adler 1995; Cooper and Kleinschmidt 1995; Wheelwrigth and Clark, 1992; Mintzberg 1979; Van de Ven et al., 1976; Thompson, 1967), strategic, technological and organizational mechanisms have been reviewed.

In chapter 5, as the globalization in the context of innovation creates requirements to exploit distinct approaches in integrating product development resources (Eppinger and Chitkara, 2009; Barczak and McDonough, 2003), the emerging product development practices have been reviewed.

In conclusion, the reviewed academic literature on GPD practices has been focused on its definition, the reasons why it should be done and the way in which it should be deployed. Further, discussion on integration in GPD practices has been about the way in which integration mechanisms face problems arising from the global dispersion of product development resources. In detail, the focus of current views of integration in GPD practices is simply on mechanisms building trust, encouraging collective goals and promoting motivation among global team members. What literature seems to be nearly missing is a focus on frameworks practitioners can use to decide how to design and implement 3D-CE in GPD practices.

1. *PRODUCT DESIGN AND PRODUCT DEVELOPMENT PROCESS*

Abstract

Within industry practice and academic research there is a lack of agreement on a formal definition of product design. Luchs and Swan (2011) develop a review on product related articles and propose a product-based and a process-based definition of product design. Adopting a product perspective, product design *"is the set of properties of an artefact, consisting of the discrete properties of the form (i.e., the aesthetics of the tangible good and/or service) and the function (i.e., its capabilities) together with the holistic properties of the integrated form and function"*, whereas assuming a process perspective product design process *"is the set of strategic and tactical activities, from idea generation to commercialization, used to create a product design"*. On the other hand, practice and academics definitions of product development process are consistent with the formal definition provided by the product development and management association (PDMA), "*the product development process is a disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts embryonic ideas into salable products or services*".

As a disciplined and defined set of tasks and steps, the product development process is characterized by its architecture. Sanchez (2000) suggests that the process architecture is a decomposition of a process into its component functional activities and a specification of the interface (i.e., interdependencies) between those activities. In line with Sanchez (2000)'s definition, Browning and Eppinger (2002) argue that activities and activities' interdependencies determine the architecture of a process. Further, the process modularity is a property of the architecture of the product development process, so that a modular process architecture is a system of loosely-coupled component functional activities, whereas an integral process architecture is a system of tightly-coupled activities.

In literature the adoption of a formal product development process has been extensively cited as a differentiating factor between success and failure within product development project. In the last years of the 80's Cooper (1990) finds that companies have begun moving widely to a stage-gate model. Stage-gate model consists in a product development process divided into a predetermined set of stages. Each stage is composed of a set of prescribed, related, and often parallels activities. Some activities might be carried out sequentially, others in parallel, and others in overlapping by a team of individuals belonging to different functions. Thus, each stage is cross-functional, there are no product development stage or manufacturing stage, whereas every stage involve product development, engineering, production and supply chain functions. Griffin (1997) confirms the study of Cooper (1990). The author presents findings from the PDMA survey on product development best practices. Results suggest that in the 90's product development process has moved from functional and sequential approaches to stage-gate and cross-functional approaches. Stage-gate model has endured over the years, however the 21st century version has considerably progressed to include principles of lean and rapid product development. Cooper (2008) defines the 21st century stage-gate process as *"a conceptual and operational map for moving new product projects from idea to launch and beyond - a blueprint for managing the new product development process to improve effectiveness and efficiency"*.

1.1. Defining product design and product development process

Within industry practice and academic research there is a lack of agreement on a formal definition of product design. Luchs and Swan (2011) conduct a review on product design including academic articles published from 1995 to 2008. The results point out the absence of a consensually accepted definition of product design. A stream of literature refers to product design as product form (i.e., the visual, aesthetic and appearance of the product), whereas other literature refers to product design as product function (i.e., the selection of the optimal set of attributes). A third stream of literature addresses both product form and function (where form and function are addressed respectively through industrial design and engineering design), however it treats the two dimensions as independent element of product design. Further, in the review of Luchs and Swan (2011) definitions of product design refer both to the object of design (i.e., the product, which could be a tangible good and/or a service) and to the process of designing. Consistently with the previous considerations, the authors propose two discrete and interdependent definition of product design:

"Product design is the set of properties of an artefact, consisting of the discrete properties of the form (i.e., the aesthetics of the tangible good and/or service) and the function (i.e., its capabilities) together with the holistic properties of the integrated form and function".

"Product design process is the set of strategic and tactical activities, from idea generation to commercialization, used to create a product design".

Academics definitions of product development process are consistent with the formal definition provided by the product development and management association (PDMA). The PDMA defines the product development process as *"a disciplined and defined set of tasks and steps that describe the normal means by which a company repetitively converts embryonic ideas into salable products or services"*.

With respect to the product development process, the definition of *product design process* suggested by Luchs and Swan (2011) is consistent with prior definitions that treat it as a set of activities that are pervasive throughout the product development process. In detail, the authors argue that compared to the product development process, the product design process includes only those activities that directly affect the form and the function of the product and their integration (e.g., it is not comprehensive of product launch activities).

1.2. Defining the product development process architecture

Hammer (2002) defines a process as *"an organized group of related activities that work together to create a result of value"*. Browning (2009) builds on the definition of Hammer (2002) arguing that a process *"consists of both activities (work packages) and deliverables (work products). The deliverables flow in the input-output relationships between the activities (a deliverable is a very general object representing any activity relationship, such as a transfer of information, data, knowledge, documents, estimates, prototypes, materials, results of decisions etc.)"*. In particular, Browning (2009) refers to input-output relationships between the activities as *activities' interdependencies*.

Thompson (1967) defines *activities' interdependencies* as the form of dependence between activities. Further, the author identifies three levels of activities' interdependencies: pooled (i.e., independent), sequential, and reciprocal. *Pooled interdependency* exists among independent activities. Whereas, *sequential interdependency* exists among distinct and serially structured activities so that the output of the upstream activity is the input of the downstream activity. Finally, *reciprocal interdependency* means that the upstream activity's input is the downstream activity's output and vice versa. The output from the upstream activity requires adjustment when undertaking the downstream activities, which in turn requires that the upstream activity is adjusted.

Sanchez (2000) suggests that a process architecture is a decomposition of a process into its component functional activities and a specification of the interface (i.e., interdependencies) between those activities. In line with Sanchez (2000)'s definition, Browning and Eppinger (2002) argue that activities and activities' interdependencies determine the architecture of a process. Hence, the authors define the process architecture as *"the structure of activities, their relationships, and the principles and guidelines governing their design and evolution"*. The definition of Browning and Eppinger (2002) is built on the IEEE (2000)'s definition of product architecture stating that *"product architecture is the fundamental organization of a system embodied in its components, their relationships to each other, and to the environment, and the principles guiding its design and evolution*".

As the components of a product architecture, Sanchez (2000) argues that the activities that compose a process architecture are either tightly or loosely coupled (i.e., activities are reciprocal interdependent at one end on the spectrum and pooled interdependent at the opposite end). So, a modular process architecture is a system of loosely-coupled component functional activities, whereas an integral process architecture is a system of tightly-coupled activities.

In a modular process architecture, interfaces among component functional activities are fully specified and standardized creating an information structure (i.e., input and output requirements for development activities) that defines the required outputs of each development task (Sanchez and Mahoney, 1996). As a consequence, since the integration of the overall product development process is embedded in the information structure of required development outputs, development tasks might be concurrently performed by self-contained development teams. That is, development tasks become loosely coupled and self-contained activities integrated by the information structure of a modular process architecture.

1.3. The product development process: stage-gate model

In literature the adoption of a formal high quality product development process has been extensively cited as a differentiating factor between success and failure within product development project. Cooper and Kleinschmidt (1995) find that *"a high-quality product development process is the strongest denominator among high-performance businesses"*.

In the last years of the 80's Cooper (1990) finds a parallelism between different product development processes. Companies have begun moving widely to a stage-gate model. Stage-gate model consists in a product development process divided into a predetermined set of stages. Each stage is composed of a set of prescribed, related, and often parallels activities. Some activities might be carried out sequentially, others in parallel, and others in overlapping by a team of individuals belonging to different functions. Thus, each stage is cross-functional, there are no product development stage or manufacturing stage, whereas every stage involve product development, engineering, production and supply chain functions.

The traditional stage-gate system includes five stages: preliminary assessment, detailed investigation, development, testing and validation, and full production and launch.

Preliminary assessment (i.e., scoping) consists in a quick assessment of the technical issues of the project and its market prospects. The preliminary technical assessment assesses development and manufacturing feasibility, possible costs and times to execute. Whereas, the preliminary market assessment determines market size, market potential, and likely market acceptance through contacts with key users, focus groups, and quick concept test with a handful of potential users.

D*etailed investigation* (i.e., build business case) consists in assessing technical, marketing and business (i.e., financial analysis) feasibility. The detailed investigation stage results in a business case including product and project definition, project justification, and project plan. Concerning product definition, the business case should include: target market definition, specification of a product positioning strategy, delineation of the product benefits to be delivered, definition of the product concept, agreement on essential and desired product features, attributes, and specifications.

Development consists in translating plans into concrete deliverables. The product is designed and developed, manufacturing processes and supply chain are designed, the manufacturing plan is mapped out, marketing launch and operating plans are developed, and test plans for the next stage are defined. Coherently with the study of Ulrich and Krishnan (2001), the development stage includes two macro activities concerning the design and the development of the product: the system architecture design and the detail design. The *system architecture design* includes the definition of the product architecture, the repartition of the product in subsystems and components and the description of functional specifications for each product subsystems. Whereas, the *detail design* includes for each product's part the complete definition of product shape, materials and tolerances.

Testing and Validation consists in providing validation of the entire project: the product, the manufacturing and logistics process, customer acceptance, and the economics of the project.

Full production and Market Launch consists in the beginning of full production and commercial launch.

The entrance to each stage is a gate. Gates serve as quality control points, go/kill and prioritization decisions points, and points where the path forward for the next stage of the project is agreed to. The structure of each gate is similar. Gates consist of deliverables, criteria, and outputs. *Deliverables* consist in the results of a set of completed activities bring to the decision point. Whereas, *criteria* consist in a set of items against which the results of a set of completed activities are evaluated. Finally, *outputs* consist in the decisions (Go/Kill/Hold/Recycle) made in the gate, along with an approved action plan (i.e., an agreed-to timeline and resources committed) and a list of deliverables and date for the next gate. Gates are managed by mangers who act as gatekeepers. The gatekeeper group is multidisciplinary and multifunctional (i.e., the heads of marketing, sales, technical, operations, supply chain and finance), and its members have enough responsibility to approve resources necessary to the project.

Thus, stage-gate is a macro process and not a substitute for project management methods. Rather, stage-gate and project management should be used together. In particular, project management methods should be applied within the stages of the Stage-Gate process. For example, during the development stage project management methods must be applied, such as a team initiation task to define the project (its mission and goals), team-building exercises, timelines or critical path plans, and milestone review points.

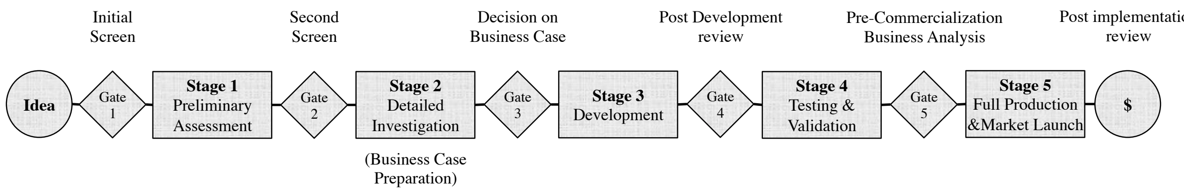

Figure 1. Typical Stage-Gate system (source: Cooper, 1990).

Stage-gate model has endured over the years, however the 21st century version has considerably progressed to include principles of lean and rapid product development. Cooper (2008) defines the 21st century stage-gate process as *"a conceptual and operational map for moving new product projects from idea to launch and beyond - a blueprint for managing the new product development process to improve effectiveness and efficiency"*.

The 21st century stage-gate is a scalable process, scaled to suit different types of product development project, from high risk and complex platform developments (i.e., innovative PD project) through to low risk extensions and modification (i.e., incremental PD project) and to minor changes (i.e., continuous improvement PD project). Cooper (2008) finds that each product development project whether innovative or continuous improvement has risk, consumes resources, and thus must be managed. However, not all projects need to go through the full five-stage process. The author has thus proposed multiple versions of the traditional (i.e., full) stage-gate system: stage-gate Xpress and stage-gate Lite. *Stage-gate Xpress* is proposed for projects of moderate risk, such as improvements, modifications, and extensions, whereas *stage-gate Lite* is designed for continuous improvement projects, such as minor changes. All proposed stage-gate system (i.e., stage-gate Full, stage-gate Xpress and stage-gate Lite) enter *gate 1* for an initial screen. The idea screening decision is defined as the routing decision leading to identify the type of project and the version of stage-gate it should be adopted.

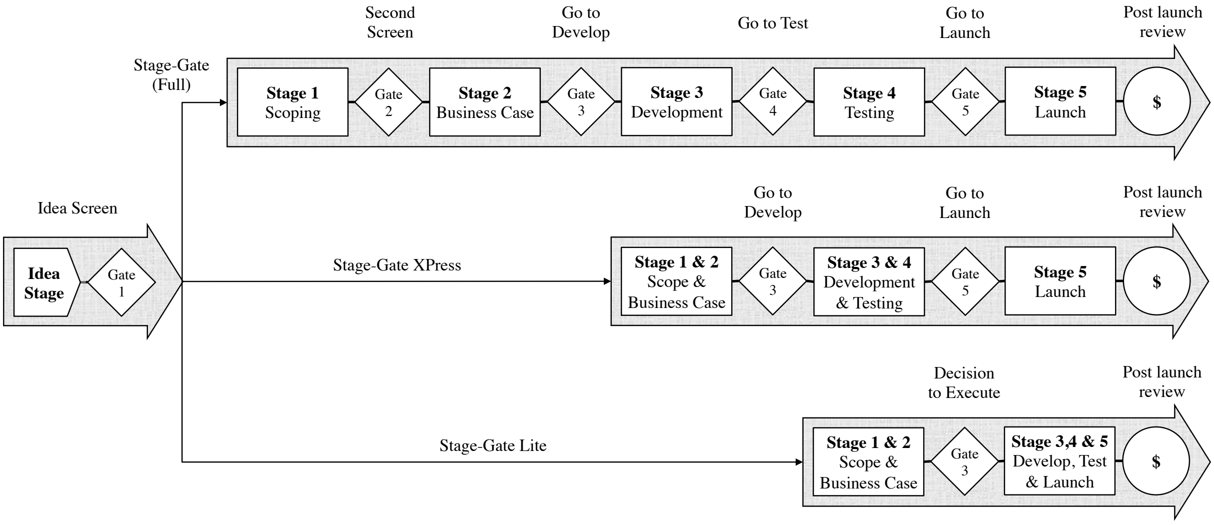

Figure 2. Next generation Stage-Gates is scalable to suit different projects (source: Cooper, 2008).

Further, the 21st century stage-gate is defined as a *flexible*, *adaptable*, and *lean* process. *Flexibility* means simultaneous execution. Activities and even entire stages overlap, not waiting for perfect information before moving forward. *Adaptability* refers to the concept of *spiral* or *agile development* allowing project teams to move rapidly to a finalize product design through a series of *build-test-feedback-and-revise* iterations (Cooper and Edgett, 2005). Agile development bridges the gap between the need for sharp product definition before development begins versus the need to be flexible and to adjust the product's design to new information and market conditions as development proceeds. *Lean* since waste and inefficiency are removed applying the concept of value stream analysis from lean manufacturing. A value stream is simply the connection of the process steps with the goal of maximizing customer value (Fiore, 2005). Within the product development, a value stream represents the linkage of value-added and non-value-added activities associated with the development of a product. The value stream map tool is used to identify and document value streams in product development process improving idea-to-launch process (Cooper, 2008).

Finally, in the next-generation stage-gate the governance process consists in gates and criteria allowing efficient and timely decision-making. The project is executed by a dedicated team of players and led by an entrepreneurial team leader.

2. *PRODUCT DEVELOPMENT: TOWARD A CONCURRENT ENGINEERING APPROACH*

Abstract

As firms come under greater pressure to shorten time-to-market, product development processes began to move from the traditional approach (i.e. sequential and functional process) to the concurrent engineering approach (i.e., concurrent and cross-functional process). In the next sections the traditional and the concurrent engineering approach to product development are presented.

2.1. The traditional product development process: sequential and functional

The traditional product development process is characterized by a sequential and functional approach. Development activities of product design, production and marketing are carried out sequentially and different functions are involved in the project independently from one other.

Sprague et al. (1991) find that in the 80's traditional development methodologies were based on sequential process without any interaction among disciplines. Projects were carried out sequentially moving from the definition of requirements, to product development, process development, and production. Further, functions involved in the product development project (e.g., R&D, product design, engineering, production, marketing) were divided in watertight compartments. In the extreme, the traditional approach to product development has each function performing its activities and then passing results to the next function in a serial chain leading to multiple design iterations as manufacturability problems emerge in the late phases of the development process.

Coherently with the previous study, Adler (1995) finds that in the traditional product development process, designs are *"thrown over the wall"* to manufacturing discovering that the design is not producible or that product design modification would facilitate the production ramp-up, lower costs and improve quality. Consistently with the concept of the *"thrown over the wall"*, Liker et al. (1996) refers to the traditional product development process as a *"point-based approach"*. Designers develop a particular design solution - a point in the design space - that fits design criteria (e.g., product functionality). Then manufacturing engineers examine the design and suggest incremental changes to make the design easier to manufacture (e.g., changing curvatures and reducing numbers of parts). The design progresses through several iterations, as changes are made to satisfy various criteria (e.g., manufacturing criteria, supply criteria). Those changes force reconsideration of previous decisions dilating feedback cycles and iterative loops. In turn, the dilation of feedback cycles and iterative loops increase development lead time (i.e., increase time-to-market).

Cooper (2008) argues that traditional product development processes led to almost double the length of developments compared to concurrent engineering processes. Reasons of high development time are: sequential activities, hand-offs, and commitment. *Activities* are designed in sequence rather than in parallel. H*and-offs* (i.e., thrown over the wall) are throughout the process, as one function passed the project on to the downstream department. And, *commitment* to the project is invisible and, in turn, accountability is missing.

2.2. The CE product development process: parallel execution and cross-functional

Pressure on time-to-market forced companies to move from the traditional product development process to the concurrent engineering approach.

Concurrent engineering (CE) is widely considered a systematic approach that is essential to successful product development project. The essence of CE is the simultaneous execution of design and development activities (e.g., concurrent design of product and manufacturing process, concurrent development of product subsystems) with the support of information technology and organizational arrangements (e.g., cross-functional teams). In literature the essence of CE is embodied in different terms: simultaneous engineering, concurrent design, integrated design and engineering, integrated product development, cooperative product development, and design for manufacturing, assembly, logistics, automation, or excellence.

Winner et al. (1988) define CE as *"a systematic approach to the integrated concurrent design of products and their related processes, including manufacturing and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life cycle from conception through disposal, including quality, cost, schedule, and user requirements"*.

Parallel execution in CE product development process

Winner et al. (1988) asserts that the concurrent design of product and processes is the core of concurrent engineering. In a concurrent approach to product development, information flows are bidirectional and decisions are based on consideration of downstream as well as upstream inputs.

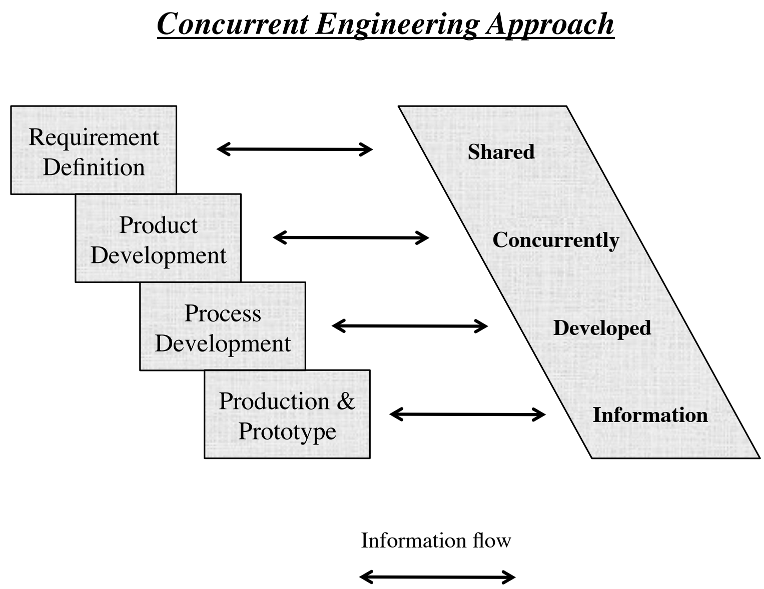

Figure 3. Concurrent Engineering (source: Winner et al., 1988).

In line with Winner et al. (1988), Krishnan et al. (1997) argue that parallel and overlapping product development activities are the essence of the CE product development process. In addition the authors suggest that an approach to concurrent engineering involves removing the coupling between development activities enabling the upstream and the downstream activity to be executed in parallel (i.e., to design a modular product development process architecture). However, since decoupling development activities is not always possible, an alternative approach to parallel execution is to overlap development activities. In contrast to sequential execution, in which the downstream activity (e.g., process development) receives and utilizes design information only after the upstream activity (e.g., product development) finalizes it, overlapping execution enables the concurrent execution of coupled activities through frequent exchange of design information and knowledge.

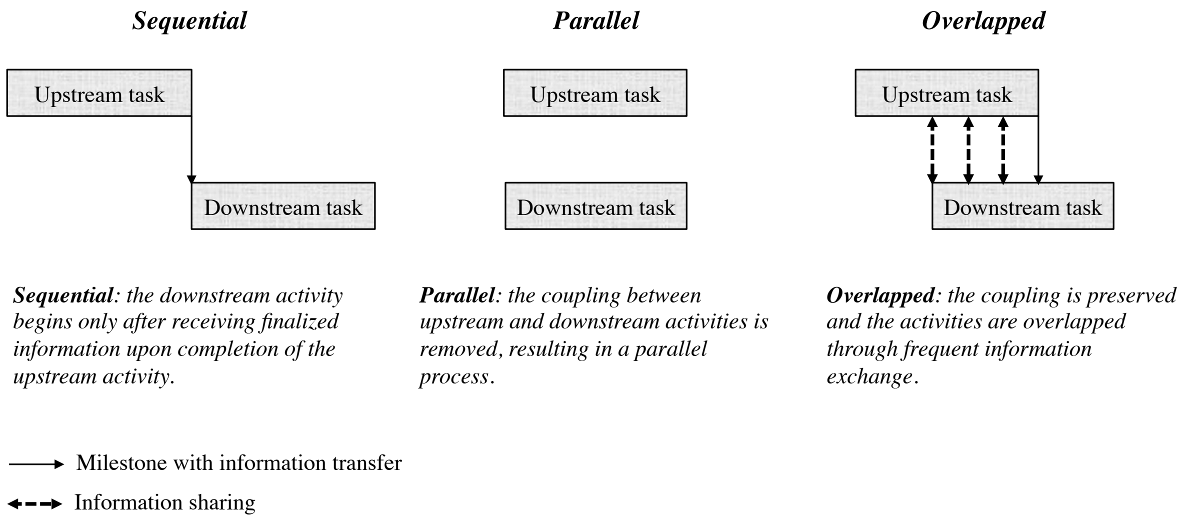

Figure 4. Sequential, Parallel and Overlapped development activities (adapted from Krishnan et al., 1997).

Further, Liker et al. (1996) suggest that moving from a sequential to a concurrent approach (i.e., overlapped execution) involves a corresponding revolution in the underlying paradigm of design. Companies move from the traditional point-based paradigm to a set-based concurrent engineering approach. In a set-based approach, in which development activities are overlapped, designers explicitly communicate set of design options, both at conceptual and parametric levels. The set of options includes a number of discrete designs or a range of parameter values. The designers gradually reduce design options eliminating infeasible alternatives based on available information. Then, more design options are eliminated gathering additional information on the remaining alternatives. Distinctive information is gathered through further development, different disciplines, and research. The process continues until the designers converge, rather than evolve, on the final design solution. According to Liker et al. (1996), the set-based concurrent engineering approach allows activities' overlapping leading the upstream and the downstream functions to find intersections of feasibility sharing distinctive information in the early stage of the upstream activity. In turn, sharing information in the early stage allows to short feedback cycles, iterative loops and, thus, development time.

Wu and O'Grady (1999) confirm on the study of Liker et al. (1996) arguing that parallel and overlapping execution result in shorter feedback cycles and iterative loops. Making product and process decisions in overlapping as much as possible and including production considerations into the early stage of the product design lead to a fundamental trade-off. On one hand CE reduces the re-designing and re-working activities (i.e., it reduces the development time) and increases the chance for a better fit between design and manufacturing (i.e., it decreases cost and improves quality). On the other hand, CE increases the complexity of the development process requiring tightly integration among interdependent activities through organizational (e.g., cross-functional team) and technological support.

Cross-functional teams in CE product development process

Winner et al. (1988) suggest that achieving a concurrent approach requires both organizational and technology support. In line with the study of Winner et al. (1988), Pennell and Winner (1989) identify three complementary classes of activities that support concurrent engineering: engineering process initiatives, computer-based initiatives, and formal methods. *Engineering process initiatives* are defined as management actions improving the organization and the procedures used to develop a product (e.g., the involvement of representatives of manufacturing early in the design process). For instance, an engineering process initiative consists in establishing cross-functional teams including specialists (e.g., marketing, production, engineering, support, purchasing, and other specialist) able to contribute to the design effort by early identification of potential problems and by timely initiation of actions to avoid bottlenecks. *Computer-based support initiatives* are defined as a set of computer-aided tools, database system, special purpose computer systems that improve design verification, and computer-based support of product design, production planning, and production (e.g., CAD, CAP, CAM, CAQ Assurance, PPC). The authors argue that the use of a shared and common data object by individuals belonging to different disciplines provides a mechanism supporting the concurrent design of the product and the manufacturing process. Finally, *formal methods* are defined as a set of techniques supporting the understanding of the behaviour of processes, products, and mechanisms (e.g., QFD, DfM, DfA, Simulation Techniques, Rapid Prototyping).

Coherently with the study of Pennell and Winner (1989), Adler (1995) suggests that to coordinate design and manufacturing departments (i.e., to execute concurrent engineering), organisational and technological arrangements are necessary to ensure an acceptable fit between product design and manufacturing process parameters. The author finds that moving to the CE approach, companies begun to adopt several organisational and technological arrangements (e.g., cross-functional teams, design rules, transition teams, CAD/CAM integration, job rotations) to manage the cross-functional design-manufacturing relationship. In particular, results suggest that through cross-functional teams manufacturing engineers are involved into the design process earlier enabling both to developing production processes as early as possible and to offer product designers informal advice on how to enhance the producibility of emerging designs.

Consistently with Adler (1995)'s findings, Brown and Eisenhardt (1995) observed that in establishing CE approach companies adopt cross-functional teams. The authors refer to the project team as *"the heart of the product development process ... cross-functional team are critical to process performance"*. The term *team* refers to those groups that display high levels of interdependency and integration among members (Katzenbach and Smith, 1993). Specifically, Cohen and Bailey (1997) defined the team as "*a collection of individuals who are interdependent in their tasks, who share responsibility for outcomes, who see themselves and who are seen by others as an intact social entity embedded in one or more larger social systems, and who manage their relationship across organizational boundaries*". Thus, cross-functional teams are defined as project teams in which members drawn from a variety of functional disciplines (e.g., engineering, manufacturing, marketing) transform vague ideas, concepts, and product specifications into saleable products (Brown and Eisenhardt, 1995). Building on the previous definitions, Holland et al. (2000) define the cross-functional team as *"a group of people who apply different skills, with a high degree of interdependence, to ensure the effective delivery of a common organizational objective"*. The key elements are variety of skills, interdependence of work and delivery of a common objective. In addition, since not all teams are *under one manager*, Holland et al. (2000)'s definition applies to both teams working within a matrix (i.e., organizations maintain functional specialization while improving integration, but may create goal conflicts for individuals) and within project team (i.e., organizations establish a team focuses on a specific goal, thus allowing the team to create a shared environment) organization.

Gupta and Wilemon (1998) find that cross-functional teams lead to improve product development processes on several dimensions: speed, complexity, customer focus, creativity, organizational learning, and single point of contact. The *speed* (i.e., the time-to-market) of the product development process is enhanced involving relevant functions and key participants from the beginning of the project, and in turn, anticipating producibility issues. Cross-functional teams make informed and agreed decisions relating to product and process issues resulting in trade-off among design features, part manufacturability, assembly requirements, and material needs. In turn, informed and agreed decisions allow minimizing iterative loops (Bowonder et al., 2004). The *complexity* of product development projects (i.e., interdependent multifunctional tasks) is reduced establishing cross-functional teams free from restrictions, opened to new ideas and opinions, and allowed to fail. Cross-functional teams enhance *customer focus* during development activities facilitating the understanding of the market as well as involving customers in the development process. The *creativity* in finding solutions to complex development problems is enhanced encouraging informal problem solving among various disciplines involved in the development project. The *organizational learning* is accelerated sharing technical information among specialists. Finally, cross-functional teams offer an organization the advantage of having one group (i.e., *single point of contact*) in charge of the development project investing the team with accountability, authority, and the necessary resources needed to accomplish development goals.

Although cross-functional teams are associated with decreased product development times and increased product success in the marketplace (Griffin, 1997), several researchers suggest that those teams are difficult to manage (McDonough and Kahn, 1999; Denison et al., 1996). Denison et al. (1996) find that cross-functional team members have competing social identities and loyalties, leading individuals to identify more strongly with their function, both socially and psychologically, than with the team as a whole. Further, cross-functional teams are temporary task teams undergoing significant pressure and facing high performance expectations (i.e., aspirational goals of compressing development times, creating knowledge and enhancing organizational learning). Identities, loyalties, pressures and high performance expectations create specific issues for cross-functional teams, which firms have to recognize and address to minimizing conflicts among team members.

Coherently with the findings of Denison et al. (1996), McDonough and Kahn (1999) suggest that cross-functional teams face the challenge of getting individuals belonging to different functions to work together. Specialists are diverse in nature (Lawrence and Lorsch, 1967). Individuals belonging to different disciplines bring into the product development team different orientations toward time (e.g., *"R&D has a longer time horizon than does manufacturing"*), bases for performance evaluation (e.g., *"sales is rewarded for product sales while manufacturing is rewarded for efficient manufacture of the product"*), terminology, managerial styles, and departmental cultures (e.g., *"R&D typically operates in a more open manner while manufacturing is more likely to operate in a more structured and hierarchical manner"*). As a consequence, communication among team members is subjected to misunderstandings due to the different terminology of each discipline. Reward structures, departmental climates, and leadership styles contribute to differences exacerbating conflicts among team members. Further, integrating communication and decision-making practices between the cross-functional teams and the functional departments is another challenge.

In line with the study of McDonough and Kahn (1999), Holland et al. (2000) cite a 1994 survey of 43 Fortune 500 companies in the US revealing six challenges of cross-functional teams related to the existing tension among team goals and functional priorities: conflicting organizational goals, competition for resources, overlapping responsibilities, conflicting personal goals, no clear direction or priorities, lack of integration.

2.3. The two-dimensional CE

Most of the former studies on CE are focused on a two-dimensional approach combining production considerations with product design issues (i.e., 2D-CE). 2D-CE presumes that products and production processes should be designed simultaneously, involving cross-functional teams, which include suppliers and customers (Koufteros et al., 2002; Swink, 1998; Blackburn et al., 1996; Birou and Fawcett, 1994).

Fine (1998) suggests that the concurrent design of product and process deals with the simultaneous and coordinated development of product specifications and process technologies, equipment and manufacturing systems (i.e., decisions concerning plant and operations systems design and layout, such as job shop focus vs. cellular focus).

In the literature, it is well established that integrating product and process design (Hayes and Wheelwrigth, 1979) ensures the fit between product and process parameters (Adler, 1995). In turn, aligning product and process parameters results in better overall operating performance on several measures (Safizadeh et al., 1996; Ettlie, 1995). For instance, Coughlan (2002) finds that integrating product and process design contributes to improve product quality, lower costs, and acceleration of the product development process. Further, Jacobs et al. (2010) claim that aligning product modularity and process modularity improves customer responsiveness, minimizes manufacturing lead times and increases delivery speed. However, 2D-CE no longer provides a source of competitive advantage, or rather, in 2D-CE supply chain development tends to be haphazard.

2.4. From two-dimensional CE to three-dimensional CE

In 1997, as firms begun to compete on customization and delivery speed, researchers begun to stress the need to incorporate supply chain issues with product and process design considerations. For instance, Fisher (1997) indicates that the supply chain structure must match the processes and abilities of the manufacturer to meet customer requirements, and the product structure. The author defines products structure as either functional (e.g., have stable, predictable demand and long life cycles) or innovative (e.g., unpredictable demand and short life cycles) and proposes corresponding structure for the supply chain. Fisher (1997)'s study finds that functional products require efficient process and functional supply chain, whereas innovative products necessitate responsive process and innovative supply chain.

A comprehensive discussion of a three-dimensional approach to concurrent engineering has been given by Fine (1998). The author introduces the concept of the three-dimensional concurrent engineering (3D-CE) recognizing the strategic nature of supply chain design. The 3D-CE extends the concept of the designing for manufacturing (i.e., the simultaneous design of product and manufacturing process) to the designing for supply chain management (i.e., the simultaneous design of product, manufacturing process and supply chain). So, the concepts constituting the foundation of 3D-CE are product design, process design and supply chain design. Table 1 provides definitions from the literature of 3D-CE concepts.

3D-CE basic concept	*Definition*	*Contributing authors*
Product design	Product design determines product's function and specifications including strategic and tactical activities from idea generation to commercialization.	Luchs and Swan (2011), Koufteros et al. (2002), Brown and Eisenhardt (1995), Fine (1998).
Process design	Process design determines the production system including manufacturing methods and technologies, production processes, equipment, equipment layout and capacity.	Safizadeh et al. (1996), Fine (1998), Hayes and Wheelwright (1979).
Supply chain design	Supply chain design determines network's strategy and procurement, logistic and distribution system including the definition of the supply chain structure, processes and operations.	Ivanov (2010), Sharifi et al. (2006), Simchi-Levi et al. (2004), Muriel and Simchi-Levi (2003), Harrison (2001), Beamon (1998).

Table 1. 3D-CE basic concept (adapted from Ellram et al., 2007).

Fine (1998) suggest that coordinating interdependencies among product, process, and supply chain design decisions maximise the operational and supply chain performance aligning product, process and supply chain parameters. For instance, considering supply chain and process parameters (e.g., facilities location, capacity and manufacturing methods) over product design (which determines materials, components and products specifications flowing through the supply chain) conduces product engineers to define the optimum product design and architecture. Further, considering product design alternatives over supply chain and process design conduces process engineers and supply chain professionals to define the optimum manufacturing methods, logistics systems, and facilities' locations and capacities. Figure 5 provides a listing of the activities of concern in the areas of product, process and supply chain design underlining those activities that are at the intersection of two areas. A 3D-CE approach in product development should embrace the simultaneous design and integration of several activities in each area of product, process and supply chain.

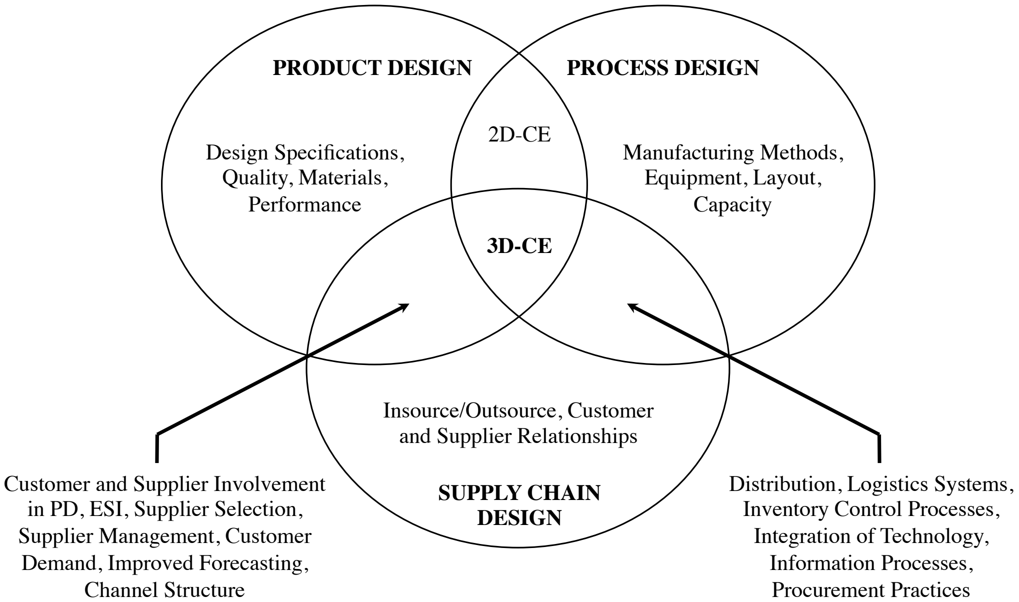

Figure 5. 3D Concurrent Engineering (source: Ellram et al., 2008).

Building on Fine (1998), a stream of literature develops quantitative approaches to coordinate interdependencies among product, process, and supply chain design decisions.

Singhal and Singhal (2002) propose a component compatibility matrix leading to identify feasible product design solutions at various stages of the product development process through a simultaneous consideration of product, process and supply chain decisions.

Fixson (2005), recognizing the product architecture as an element linking decisions across the domains of product, process and supply chain, introduces a multi-dimensional framework allowing comprehensive product architecture assessments. The author claims that the product architecture assessment map leads to identify optimal product design solutions acting as a driver toward trade off decisions.

Fine et al. (2005) develop a goal-programming approach to facilitate the assessment of trade offs among potentially conflicting objectives in product, process and supply chain design (e.g., the choice of a low cost supplier might be associate with low quality and long lead times creating a conflict both with the product engineer, who might prefer expensive suppliers associated with high quality and excellent development capabilities, and the process engineer, who might prefer short and reliable lead times). In detail, the developed approach solves trade offs considering simultaneously constraints related to distinct design decisions.

Blackhurst et al. (2005) develop a network-based approach, called Product Chain Decision Model (i.e., PCDM), allowing the comprehension of the effect of product, process and supply chain design decisions on supply chain performance. In detail, the PCDM describes the operation of the modelled supply chain considering decisions related to product design and manufacturing process design.

Huang et al. (2005) applied an optimization mode to study the impact of platform products on decisions related to supply chain configuration including supplier selection, selection of transportation delivery modes, determination of inventory quantities and stocking points, manufacturing processes selection, and production time. Further, the impact of platform products on supply chain design decisions is evaluated quantifying the total supply chain cost, consisting of inventory, production, procurement and transportation cost.

The reviewed studies in the fields of operations, supply chain, and management indicate the interest in the 3D-CE as an approach to improve traditional product development performance and supply chain capabilities including production process capabilities.

2.5. Benefits of the 3D-CE approach in product development

Sprague et al. (1991) suggest that CE allows to achieve goals related to time-to-market, total quality, affordability, and flexibility creating an environment in which process iterations are reduced considering constraints and requirements from different disciplines as the design progresses. Consistently with the previous study, Paashuis and Boer (1997) claim that CE results in reduced costs, improved manufacturability, and reduced design and manufacturing lead time enabling an as early as possible start of product design related activities and, in turn, reducing the need for redesign.

Building on the previous studies investigating the benefits of CE, the literature supporting 3D-CE concepts focuses on product development performance and on process and supply chain capabilities improvements such as time-to-market reduction, development cost reduction, product quality improvement, delivery lead time reduction, production and logistic cost reduction, and inventory reduction.

Bowonder et al. (2004) emphasizes the pivotal role of 3D-CE in reducing time-to-market. The authors attribute the improvement in time-to-market to the possibility of overlapping the product development stages, eliminating the fuzziness and freezing the designs early in the product life cycle, by validating product, process and supply chain parameters.

Petersen et al. (2005) present findings from a survey research on the effect of 3D-CE on product development performance and on financial performance. Results suggest that linking supply chain to product and process improves overall design and financial performance providing evidence on the relevance of integrating product, process and supply chain design decisions to achieve competitive advantage.

Ro et al. (2007) find that in the automotive industry the simultaneous design of product, process, and supply chain allows producers to increase the modularity of the offer and, in turn, to exploit the benefits of the build-to-order minimizing finished goods inventories as customized products are not produced until customer orders arrive.

Ellram et al. (2008), citing the study of Judson (1998), assert that whether the supply chain design is not explicitly integrated as a part of the product development, it is likely that higher costs and reduced performance will ensue.

In conclusion, the reviewed studies claim the 3D-CE as the forthcoming level of breakthrough in improving product development performance and supply chain capabilities.

2.6. Aligning product, process and supply chain features

Fine (1998) argues that the 3D-CE approach improves product development performance and supply chain capabilities as it leads to align product, process, and supply chain features coordinating interdependencies among design decisions. In detail, the author claims that the 3D-CE aims to align product, process, and supply chain along the architectures dimension. That is, integral products need integral production processes and supply chains, whereas modular products need modular production processes and supply chains. Thus, the degree of modularity in the product has a one-to-one correspondence with the degree of modularity in the production processes and supply chains. The author refers to *product modularity* as a property of the architecture of any product. Product architectures refer to the degree of interdependency among components. So, modular products comprise autonomous, interchangeable and individually upgradeable components. In contrast, integral products comprise highly interdependent components. Similar to product modularity, *production process modularity* is a property of the architecture of any production process. Process architectures can be integrated in both time and space, integrated in either time or space, or dispersed in both space and time. So, process modularity increases when the coupling between the production process components (i.e., production activities) decreases in time (i.e., production is spread over multiple time intervals) or place (i.e., production takes place on dispersed locations). As product and process modularity, *supply chain modularity* is a property of the architecture of any supply chain referring to the degree of proximity of elements measured along three dimensions: geographic proximity, organizational proximity (e.g., ownership, interpersonal interdependencies), and cultural proximity (e.g., commonality of language, ethical standards). So, in an integral supply chain, the manufacturer and first-tier suppliers are concentrated in one geographic region, have common ownership, and share a common business and social culture. In contrast, in a modular supply chain, the manufacturer and its first-tier suppliers are geographically dispersed actors, each one characterized by autonomous managerial and ownership structures, and diverse cultures.

Pero et al. (2010) confirm and build on the study of Fine (1998). The authors provide recommendations on which is the optimal match between product features (i.e., modularity, variety, and innovativeness) and supply chain features (i.e., configuration complexity, collaboration complexity and coordination complexity) to improve supply chain capabilities.

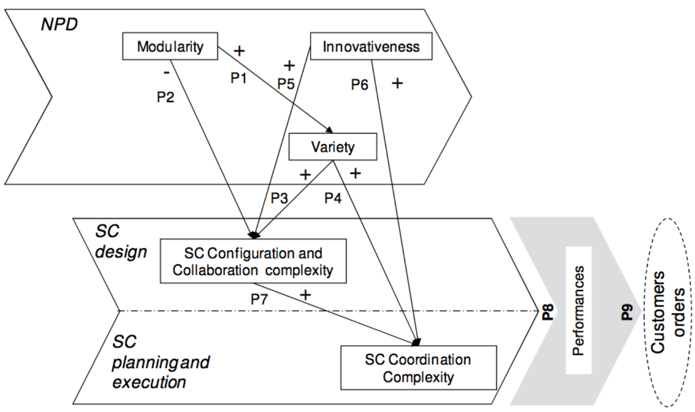

Figure 6. NPD-SCM alignment framework (source: Pero et al., 2010).

3. CONCURRENT ENGINEERING: A MATTER OF INTEGRATION

Abstract

Paashuis and Boer (1997) state, *"CE is an internally consistent configuration of processes, technologies and organizational arrangements that is externally consistent with the company's corporate and market strategies, through a match between market demands (qualifiers and order winners) and the performance (capabilities and capacities) of the new product development function. However, CE does not affect each and every aspect of developing new products: the new thing about CE is integration".*

Integration among interdependent product development activities is essential to establish effective concurrent engineering practices (Terwiesch et al., 2002). Recognizing the existence of uncertainty and interdependence within development activities let to view the product development process as an information transferring process (Gomes and Joglekar, 2008). Thus, assuming an information processing perspective of the product development process, development activities can be considered as information processing tasks whose uncertainty and interdependency create requirements for integration among individuals and functions.

Based on the previous assumption, Kahn (1996) presents a model of integration, where integration is a multidimensional process comprising both communication and collaboration. The author argues that communication and collaboration are to be considered distinct because each process represents unique attributes of integration. Moenaert and Souder (1990) define communication as the process in which information originating in one function (e.g., design) is transferred to another function (i.e., manufacturing). Whereas, Kahn (1996) define collaboration as the process in which several individuals with different and complementary skills work together to perform development activities.

In the academic literature, researchers prove the benefits of effective communication and collaboration in product launch performance, either in terms of market relevance or in terms of manufacturing and supply chain ability to successfully deliver what is promised (Tessarolo, 2007; Swink, 2003; May and Carter, 2001; Dyer et al., 1999; Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1994; Clark and Fujimoto, 1991). For instance, Brown and Eisenhardt (1995) find that communication affects process performance. Findings indicate that an effective communication process increases information and, in turn, is essential for high-performing development processes. Further, Song et al. (1997) finds that collaboration ensures that marketing, technical, manufacturing and supply chain capabilities are combined to develop a product that satisfies customer needs.

In line with the previous studies, Tessarolo (2007) suggests that effective communication and collaboration allows overlapping activities, managing overlapped activities through mutual understanding of design requirements, anticipating problems, and stimulating team creativity. In turn, *overlapping development activities* speed up the product development process (Clark and Fujimoto, 1991). *Managing overlapped activities* avoids delays (Swink, 2003). *Anticipating* downstream development problems allows quickly solutions (Eisenhardt and Tabrizi, 1995). And, *stimulating team creativity* allows finding solutions to problems arising during the development process (Griffin, 1997).

3.1. An information processing perspective of the product development process

Gomes and Joglekar (2008) propose an information processing view of the product development process based on the central idea of the information processing (IP) theory developed by Newell and Simon (1963). The authors argue that the recognition of *uncertainty* and *interdependence* within development activities underlies the IP perspective of the product development process viewing it as an information transferring process.

Galbraith (1973) defines the *uncertainty* as the difference between the amount of information required to execute a particular task and the amount of information already possessed by the organization. Within the product development process Souder and Moenaert (1992) find four sources of uncertainty: user needs (i.e., unrealised market requirements), technological environments (i.e., lack of knowledge about technological solutions), competitive environments (i.e., absence of information about competition), and organizational resources (i.e., absence of information about the human, finance and technical resources needed to develop products). Consistently with the IP theory, transforming input information into output information reduces task uncertainty, whereas the available knowledge and skills determine the requirements to the transformation of information into outputs. For instance, product design engineers reduce uncertainty transforming market requirements, methodologies, standards and practice (i.e., input information) into drawings, specifications and technical reports. In addition, transforming input information into output information, product design engineers need to acquire and exploit technical and managerial knowledge (e.g., unavailable knowledge belonging to different specialties).

Thompson (1967) defines *reciprocal interdependency* as the most complex form of dependence between activities. *"Reciprocal interdependencies (i.e., reciprocal dependence) between activities means that one activity's input is another activity's output and vice versa. The output from each activity requires adjustment when undertaking the other activities, which in turn requires that the first activities are adjusted and so on"*. As outlined in the section *"Defining the product development process architecture"*, the author defines three levels of task interdependencies: pooled (i.e., independent), sequential, and reciprocal. Within the product development process, *pooled* interdependency is common in activities that are coordinated by standards and rules-based mechanisms. In a pooled development process each function is relatively independent since development activities do not require exchange of information among specialties. *Sequential* interdependency is common where the development activities of each module are distinct and serially structured so that the output of the upstream module is the input of the downstream module. *Reciprocal* interdependency occurs when there is mutual exchange of information and activities require on-going adjustments and adaptation among functions (i.e., the output of a product design activity is the input of a manufacturing activity, and the output of the manufacturing activity is the input back again into a product design activity). Within the product development process, activities outputs are inputs to other activities and iterations occur due to recursive dependence (i.e., reciprocal interdependence) on activities outputs. For example, product design's interpretation of market requirements leads to specifications of product features that dictate required manufacturing capabilities. Because of these interdependencies, achieving higher levels of information sharing among product design and manufacturing has been considered an important goal (Adler, 1995).

Thus, assuming an IP perspective of the product development process, development activities can be considered as information processing tasks whose uncertainty and interdependency create requirements for information and knowledge transfer and sharing among individuals and functions. Hence, the development activities in a product development process interact by exchanging of information and knowledge.

Coherently with the IP perspective, Kahn (1996) finds that traditional product development processes, in which activities are carried out sequentially, requires information and knowledge transfer from one individual or function to another. Whereas, concurrent product development processes, in which activities are overlapped, requires also information sharing among individuals and functions. Specifically, in a concurrent approach, reciprocal interdependency activities requires information and knowledge sharing among specialists, whereas sequential interdependency development activities are decoupled so as loose coupling might be defined in standard specifications (e.g., in the form of design rules or standard documentations) at the beginning.

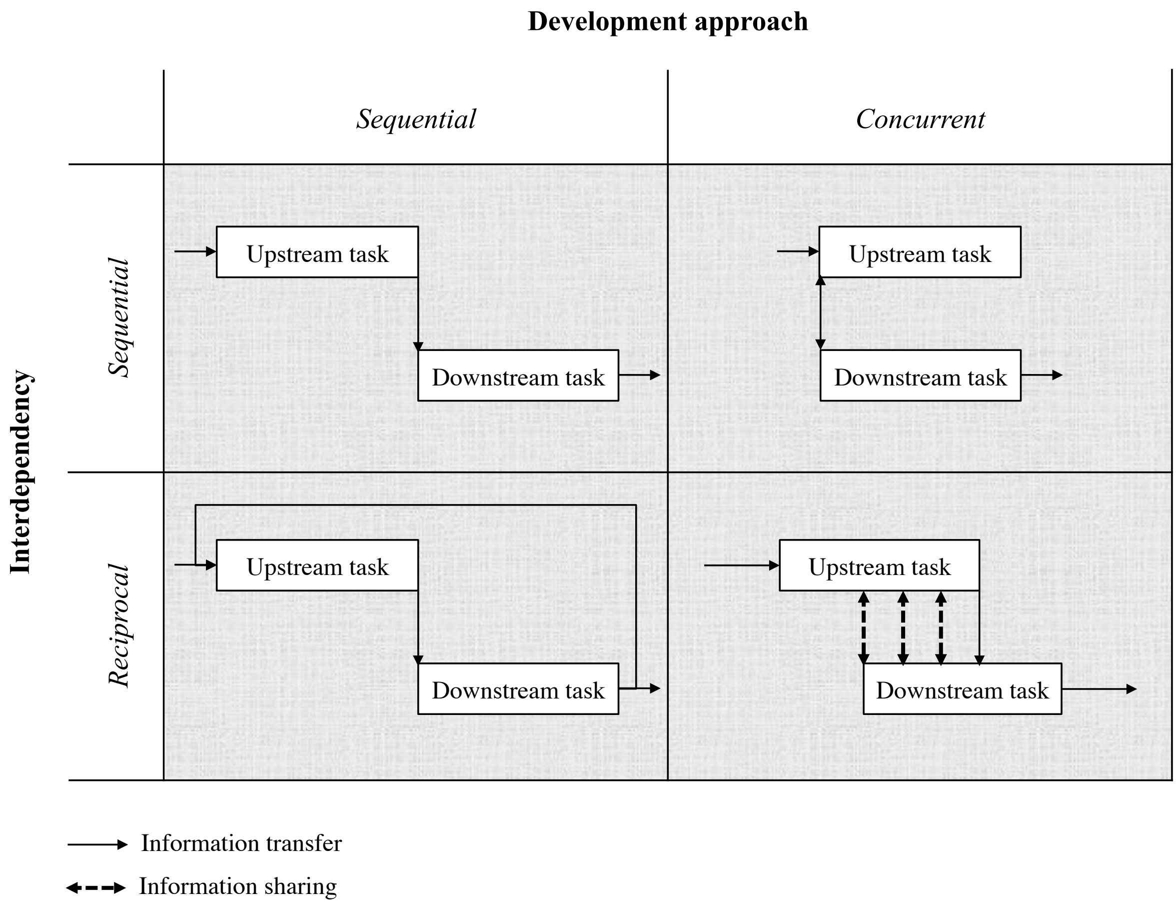

Figure 7. In a concurrent approach, reciprocal interdependency tasks require information sharing.

Paashuis (1997) suggests that within the product development process several flows of information, knowledge and skills occur among individuals and functions. Consistently with the nature of development tasks, information and knowledge might be transferred and shared among individuals belonging to the same functions (i.e., *within function* communication and collaboration processes) as well as among specialists belonging to different functions (i.e., *cross-functional* communication and collaboration processes). For instance, *within function*, product design engineers transfer and share each other's relevant input and output information, knowledge and skills. Whereas, at the *cross-functional* level, product design engineers share technical knowledge with process engineers and production engineers facilitating the right decision as to the assembly sequences and the production technologies. Similarly, process engineers and production engineers share relevant information and knowledge with product design engineers as to the specifications facilitating the assembly and the production.

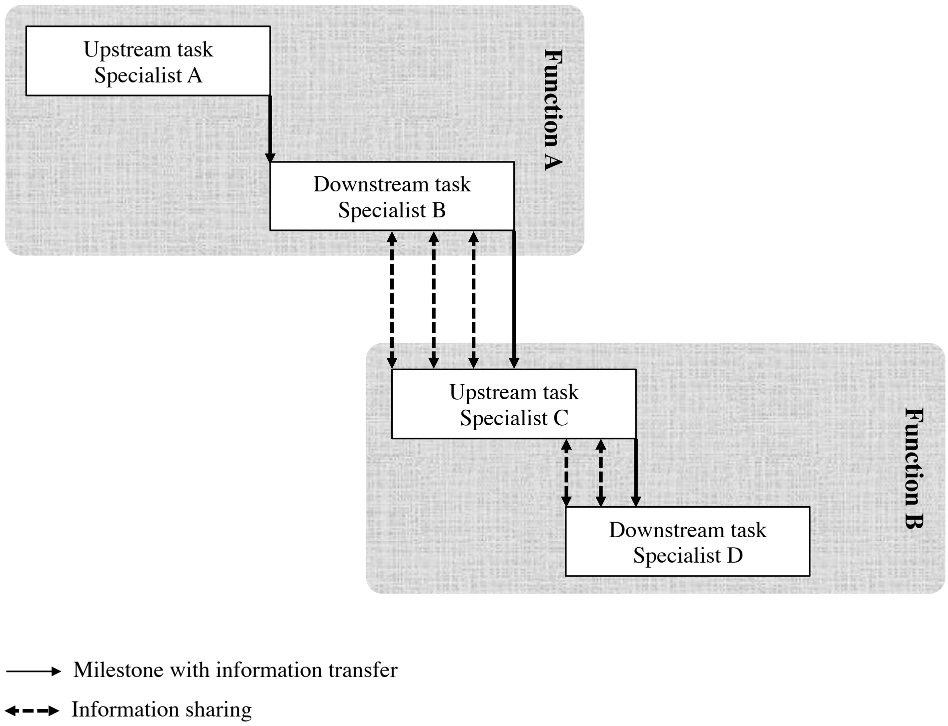

Figure 8. Within-functional and cross-functional communication and collaboration.

In line with the previous studies, Loch and Terwiesch (1998) suggest that the dependence structure of the product development process (i.e., the product development process architecture) determines the requirements of upstream and downstream activities integration in terms of information transferring and sharing.

Several studies on product development in automobiles (Clark and Fujimoto, 1991) and electronics (Iansiti, 1995) find that differences in product development performance are due to the degree of integration in the development process. Hoopes and Postrel (1999) suggest that in the task of designing and developing products, integration facilitates communication and knowledge sharing among the different specialties and disciplines involved in the development process (e.g., from market research to component technology, from manufacturing to maintenance). Further, Hoopes (2001) finds that integration enhances collaboration in terms of cooperation among specialists with different interests, coordination among development activities, and mutual understanding of disciplines constraints.

3.2. Integration is coordination

Several studies in different research areas have investigated the topic of coordination. Malone and Crowston (1994) review the discussion of coordination in the fields of organization theory, computer science and economics. The authors cite the definition of coordination proposed in the study of Van de Ven et al. (1976), *"coordination means integrating together different parts of an organization to accomplish a collective set of tasks"*. Consistently with the definition of Van de Ven et al. (1976), several researchers suggest that the two terms coordination and integration refers to the same concept. In the present research study, it has been used the term integration.

3.3. Defining integration

Consistently with the information processing theory, in the literature different dimensions of integration have been proposed. A stream of literature refers to integration as communication or interaction (Griffin and Hauser, 1992; Ruekert and Orville, 1987), whereas other literature associates integration with collaboration (Lawrence and Lorsch, 1967; Lawrence and Lorsch, 1965). In both cases, integration is seen as a single dimension, communication-based or collaboration-based. Instead, a third stream of literature refers to integration as a multiple dimension comprising both communication and collaboration (Kahn, 1996; Gupta et al., 1985). Ruekert and Orville (1987) define interaction as a set of coordinated activities, which include meetings, teleconferences, conference calls, and flow of standard documentation. Consistently with the previous study, Kahn (1996) argues *"interaction activities are structural in nature because they regulate communication through frequency of occurrence, adherence to a routine schedule/plan, and/or upper management mandates. In sum, the interaction process is structural because it adds structure to how departments interrelate"*. Whereas, Lawrence and Lorsch (1967) define integration as *"the quality or state of collaboration that exists among departments that are required to achieve unity of effort by the demands of the environment"*. Appley and Winder (1977) build on the definition of Lawrence and Lorsch (1967) and define collaboration as an effective, volitional, mutual process where individuals and departments work together, have mutual understanding, have a common vision, share resources, and achieve collective goals. Coherently with Appley and Winder (1977), Kahn (1996) argues, *"collaboration activities are unstructured and intangible, not easily regulated, difficult to sustain without joint efforts, and represent a higher level of interrelationship"*.

Based on these definitions, Kahn (1996) presents a model of integration, where integration is a multidimensional process comprising both communication (i.e., interaction) and collaboration. The author argues that interaction and collaboration are to be considered distinct because each process represents unique attributes of integration. Consistently with this model, the study explores how collaboration and interaction affect product development performance and product management performance (i.e., post-launch performance). Empirical findings suggest that collaboration constitutes a main factor for success in product development, supporting the role of collaboration in integration as well as contrasting previous literature stressing interaction alone.

3.4. Integration: collaboration and communication processes

As observed, research defines the integration as a multidimensional process comprising communication and collaboration processes. Within product development, integration is the process by which information and knowledge are transferred and shared among individuals and functions. In detail, communication is the process by which information and knowledge are transferred from one individual or a function to another, whereas collaboration is the process by which information and knowledge are shared among individuals and functions.

Communication process

Considering that designing products is an information processing activity, communication (i.e., communication both among individuals and across functional boundaries) is required to perform product development tasks. Moenaert and Souder (1990) define communication as the process in which information originating in one function (e.g., design) is transferred to another function (i.e., manufacturing). Coherently with the previous study, Kahn and McDonough (1997) suggest that the communication process is characterized as the information exchange element of integration, comprising activities such as committee meetings, teleconferencing, conference calls, and exchange of standard documentation.

Collaboration process

A stream of literature has identified integration with collaboration, where individuals and functions work collectively with common goals. Kahn (1996) defines collaboration as the process in which several individuals with different and complementary skills work together to perform development activities. Coherently with the previous study, Kahn and McDonough (1997) suggest that the collaboration process is characterized as the affective and mutual element of integration, corresponding to a willingness to work together. Hence, collaboration focuses on working together, having mutual understanding, sharing a common vision, sharing resources, and achieving collective goals.

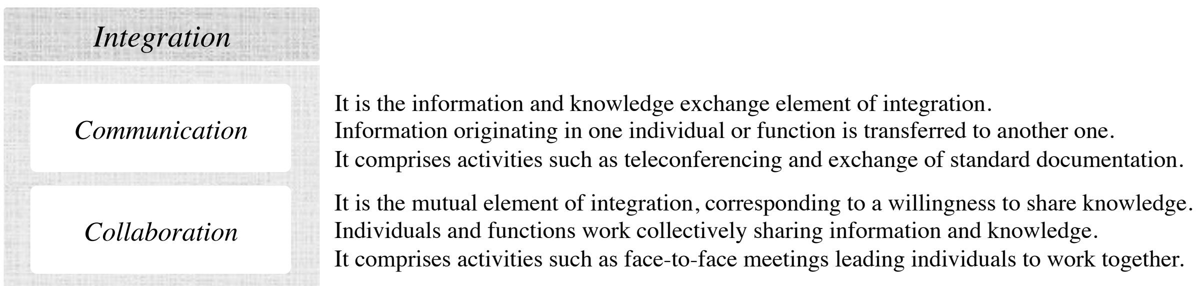

Figure 9. Integration: Communication and Collaboration.

For instance, coherently with the IP perspective, sequential interdependent activities carried out sequentially require integration through communication (i.e., information and knowledge need to be transferred from one individual or function to another). Whereas, reciprocal interdependent activities carried out in overlapping require integration both through collaboration and communication (i.e., information and knowledge need to be also shared among individuals and functions working collectively).

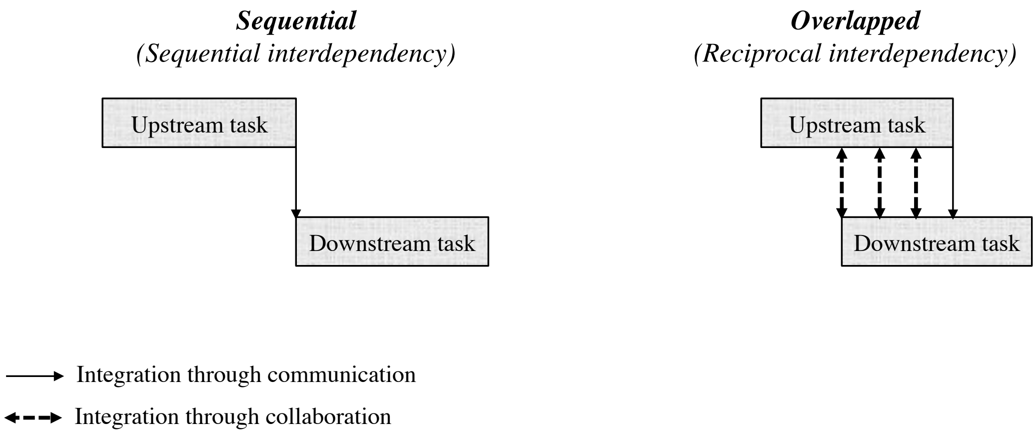

Figure 10. Integration through communication and collaboration.

Hence, coherently with Kahn (1996)'s findings, in a CE product development approach, in which activities are overlapped, communication represents a necessary but insufficient condition to product development success. Empirical evidence suggests a strong positive influence of collaboration among different functions on product development performance (McDonough, 2000; Pinto and Pinto, 1990). Consistently with the study of Kahn (1996), Berends et al. (2007) claim that, in a CE approach, integration should focus on knowledge sharing instead of knowledge transfer, since the effectiveness of integration requires a mutual understating of individuals' and functions' contributions. Berends et al. (2007)'s considerations are in line with research on integration within product development, which finds that the effectiveness of a project is dependent on the process of crating a shared understanding (Song et al., 2005; McDonough, 2000; Kahn, 1996; Pinto and Pinto, 1990).

3.5. Benefits of integration processes

In the academic literature, researchers prove the benefits of effective communication and collaboration in product launch performance, either in terms of market relevance or in terms of manufacturing and supply chain ability to successfully deliver what is promised (Tessarolo, 2007; Swink, 2003; May and Carter, 2001; Dyer et al., 1999; Brown and Eisenhardt, 1995; Cooper and Kleinschmidt, 1994; Clark and Fujimoto, 1991).

Through a literature review on product development, Brown and Eisenhardt (1995) find that communication affects process performance. Findings indicate that an effective communication process increases information and, in turn, is essential for high-performing development processes. An effectively structures communication process reduces misunderstanding and barriers to information exchange so that the amount of information conveyed is increased. In turn, it improves the speed and productivity of the entire product development process.

Further, several researchers suggest that collaboration is essential to establish high-performing development processes. Song et al. (1997) finds that collaboration ensures that marketing, technical, manufacturing and supply chain capabilities are combined to develop a product that satisfies customer needs. Kahn (1996) proves that an effective collaboration process increases information richness enabling overlap among interdependent development activities. In turn, overlap reduces development lead-time (Swink, 2003; Krishnan et al., 1997).

In line with the previous studies, Tessarolo (2007) suggests that effective communication and collaboration allows overlapping activities, managing overlapped activities through mutual understanding of design requirements, anticipating problems, and stimulating team creativity. In turn, *overlapping development activities* speed up the product development process (Clark and Fujimoto, 1991). *Managing overlapped activities* avoids delays (Swink, 2003). *Anticipating* downstream development problems allows quickly solutions (Eisenhardt and Tabrizi, 1995). And, *stimulating team creativity* allows finding solutions to problems arising during the development process (Griffin, 1997).

4. *INTEGRATION MECHANISMS*

Abstract

In the literature several researchers address the question of how companies enable and facilitate the integration process (Paashuis and Boer, 1997; Adler 1995; Cooper and Kleinschmidt 1995; Wheelwrigth and Clark, 1992; Mintzberg 1979; Van de Ven et al., 1976; Thompson, 1967). The results suggest that the selection and the implementation of the most appropriate integration mechanisms in relation to the context in which an organization acts lead to effective communication and collaboration processes that, in turn, enable and facilitate integration.

Consistently with the previous stream of literature, Paashuis and Boer (1997) suggest that integration encompasses a wide range of mechanisms, aimed at closer collaboration, earlier and more frequent communication between the functions involved in the product development process.

In addition, Van de Ven et al. (1976) distinguish between formal (i.e., impersonal) and informal (i.e., personal) mechanisms. *Formal* integration mechanisms are non-interactive and impersonal in nature such as plans, schedules, formalized rules, policies and procedures, and standardize and communication systems. The common element of formal mechanisms is a codified blueprint of action that is impersonally specified. The authors cite March and Simon (1958) underlining that the blueprint lead to start activities immediately since actions are obvious and human discretion does not enter into the determinant of what, where, when and how roles are to be articulated to accomplish a given set of tasks. Whereas, *informal* integration mechanisms are personal, peer-oriented, and interactive in nature such as informal meetings, liaison roles, integrator roles, and supervisors.

In line with the academic literature, mechanisms enabling and facilitating collaboration and communication have been classified into three categories: strategic, technological, and organizational. In the next sections integration mechanisms are presented.

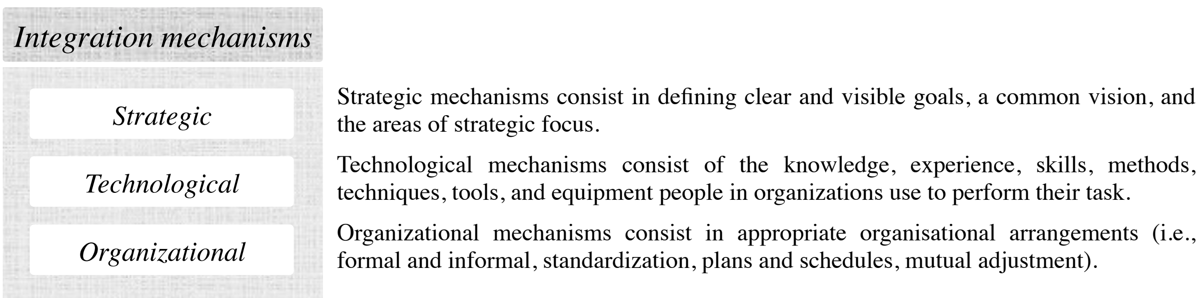

Figure 11. Integration Mechanisms: Strategic, Process, Technological and Organizational.

4.1. Strategic mechanisms

In literature numerous studies suggest that having an explicit product development strategy, which defines the goals of product development, specifies the areas of strategic focus (i.e., product and market arenas), and formalizes the organizational structures, results in effective product development.

Clark and Wheelwrigth (1993) suggest that a product development strategy aims to create, define and select a set of projects that will provide superior products and processes, to integrate and co-ordinate development activities and individuals involved in the development process, to manage development efforts to achieve business goals as effectively and efficiently as possible, and to create and improve the capabilities needed to make the development a competitive advantage over time.

Cooper and Kleinschmidt (1995) report the results of a benchmarking study investigating product development performance and how top-performing companies achieve positive results. The authors find that top-performers possess a product development strategy, driven by the top management and its strategic vision for the business. The product development strategy consists in defining clear and visible goals, a common vision, the areas of strategic focus, and in establishing a long-term thrust and focus on development projects. *Clear and visible goals* such as percentage of sales to be generated from product developed in the next years, percentage of profits, and number of product launches per year, allows making the perspective of different specialists (e.g., marketing, product design, manufacturing, logistics) involved in the product development process complementary rather than conflictual. Different functional areas in an organization have different specialized knowledge, deal with different parts of a firm's environment and have different roles and responsibilities. Functional goals therefore are often conflictual (Griffin and Albert, 1996). *Common visions* allow individuals involved in the product development process to be aware of product objectives and of the role that the product plays in the product development strategy. A common vision is created setting goals and making them clear and shared to everyone involved in the process. Clearly defined *areas of strategic focus* give direction to the product development efforts defining products, markets and technologies companies would focus on. The authors argue that with unambiguously communicated areas of strategic focus, the research of product ideas and opportunities is focused leading to a consistent portfolio of product development projects. *Long-term thrust and focus* on development projects imply strategy and project that are long-term in nature giving direction to product development efforts.

Consistently with the study of Cooper and Kleinschmidt (1995), Paashuis and Boer (1997) suggest that unambiguously communicated strategies and common goals enhance cross-functional collaboration (i.e., clear and visible strategies facilitate the integration) giving a sense of direction to individuals involved in the product development, motivating them, acting as guidelines for decision making, and providing a standard for assessment.

Strategic	***Integration mechanisms***	***Contributing authors***
Strategic	Create a common vision. Define clear and visible goals. Identify the area of strategic focus. Establish long-term thrust and focus on project.	Paashuis and Boer (1997), Griffin and Albert (1996), Cooper and Kleinschmidt (1995), Clark and Wheelwrigth (1993).

Table 2. Strategic Integration Mechanisms

4.2. Technological mechanisms

Paashuis and Boer (1997) suggest that *"integration technology consists of the knowledge, experience, skills, methods, techniques, tools, machines and equipment people in organizations use to perform their task"*. The integration technologies used in organizations can be classified in three categories: humanware, software and hardware.

Humanware mechanisms

Paashuis and Boer (1997) define humanware mechanisms as the knowledge, experience, technical, social and managerial skills (e.g., skills communication, leadership, decision making, project management) that people use to execute their job. Knowledge and skills can be classified as technical, social and managerial. Wheelwrigth and Clark (1992) define *technical* knowledge and skills as the understating of upstream and downstream activities. On one hand, technical knowledge is the upstream department ability to understand downstream operations developing solutions that fit downstream constraints. On the other hand, technical knowledge is the downstream ability to understand requirements from upstream operations, manage the risk associated with activities uncertainty and unexpected changes from upstream department. Zahra et al. (2000) build on the definition of Wheelwrigth and Clark (1992). The authors refer to technical knowledge as mechanism enduring the capture, analysis, interpretation, and integration of different types of knowledge among different functional units within the firm. Kahn and McDonough (1996) define *social* knowledge and skills as the ability to develop a shared team identity and to establish supportive and collaborative personal relationships inducing individual to act as effective team member with and through other specialists involved in the product development process (i.e., *social* knowledge and skills regard attitude toward cross-functional collaboration and communication). Lawson et al. (2009) find that social knowledge and skills facilitate collaboration among individuals and functions providing incentive to build interpersonal trust and knowledge exchange. Daft et al. (2001) defines *managerial* knowledge and skills as the ability to select and achieve goals, to take and share responsibility for development activities, and to monitor and correct own and others activities when it is required.

In addition to technical, social and managerial knowledge and skills, Paashuis and Boer (1997) suggest that formal training, training on-the-job, and job rotation constitutes important integration mechanisms ensuring individuals to perform activities effectively. In particular, multifunctional training, in which managers in a functional area are provided with opportunities to learn about other functional areas, helps individuals with understand the goals, perspectives, and priorities of other functions reducing the misunderstanding due to differences in thoughts (Griffin and Hauser, 1996). Consistently with the study of Paashuis and Boer (1997), Maltz and Kohli (2000) suggest that multifunctional training include directly learning of function's subject matter, participating in training sessions with people from other functions, and working in more than one function (job rotations). Further, the study of Barczak and McDonough (2003) confirm and build on the study of Paashuis and Boer (1997) introducing the perspective of multicultural teams. The authors suggest that training on the cultural values and behaviours of the different nationalities represented on the team ensure individuals from different countries to understand each other. The results of

Anderson et al. (2008) systematic study confirm that explicit preparation and training enable collaboratively work.

Paashuis and Boer (1997) assert that humanware mechanisms result in the understanding of different disciplines requirements and, in turn, in an effective communication and collaboration process among different specialists involved in the product development process stemming the lack of understanding. Consistently with the previous study, Gupta and Wilemon (1998) find that having the capabilities for teamwork (e.g., the ability to communicate clearly, work within the context of a team, and use interpersonal skills) is a prerequisite for effective product development process.

Software mechanisms

Paashuis and Boer (1997) define software mechanisms as the methods, techniques, work practices, procedures, either automated (i.e., in the form of computer software) or not, that people use to execute their job. Design technologies such as computer-aided design (CAD), computer aided process planning (CAPP), computer-aided design and manufacturing (CAD/CAM), product data management systems (PDM), product lifecycle management systems (PLM), engineering data management system (EDM), engineering databases (EDB) and electronic data interchange (EDI) enable and facilitate integration in the product development process. Applications such as fax, e-mail, teleconferencing, and videoconferencing facilitate communication among individuals working in different locations. Whereas, techniques and methods, not necessarily automated in form of computer software such as quality function deployment (QFD), failure mode and effects analysis (FMEA), and the whole range of Design for (e.g., DfM, DfA) force different disciplines involved in the product development process (e.g., design, manufacturing, logistic, marketing) to collaborate.

Consistently with the study of Paashuis and Boer (1997), Bowonder et al. (2004) find that EDM and PDM/PLM systems enable and facilitate integration in product development process allowing individuals to access, distribute, store and retrieve information concerning products, parts, and processes. In addition, EDM and PDM/PLM systems provide support to a formalize process workflow giving project leaders release control over project and drawings. However, the authors suggest that an effective implementation of EDM or PDM/PLM system requires a complementary product development process to smooth the workflow.

Bardhan et al. (2005) propose a classification of software technologies consistent with the levels of interdependency supported by the technology itself. *Core Communication Technologies* (CCT) include basic technologies (e.g., fax, e-mail and web portals) supporting loosely coupled development activities. *Enterprise Computing Technologies* (ECT) formalize sequential interactions among functions and support structured sequential interactions among individuals enabling them to access and exchange data in a structured format. ECTs encompass software technologies (e.g., CAD, CAM, PDM, PLM, EDB) that facilitate information exchange among activities serially sequenced. *Group Collaboration Technologies* (GCT) support reciprocal interdependencies in which collaboration involves information that is exchanged, processed, and adapted by different functions involved in the project. GCTs encompass collaboration technologies that enable team members to communicate in real time (e.g., online team spaces, discussion databases, QFD, FMEA, DfX).

Hardware mechanisms

Consistently with the study of Paashuis and Boer (1997), hardware technologies include tools, machines, computers, handling devices and other communication equipment enabling the use of the software applications mentioned in the previous section.

Technological	***Integration mechanisms***	***Contributing authors***
Humanware	Technical knowledge and skills *(e.g., abilities to understand upstream and downstream operations).* Social knowledge and skills *(e.g., attitudes towards cross-functional communication and collaboration).* Managerial knowledge and skills *(e.g., abilities to select and achieve goals, to take and share responsibilities, to monitor and correct development activities).* Training *(e.g., formal training, training on-the-job, multifunctional training, multicultural training, job rotation).*	Lawson et al. (2009), Daft (2001), Zahra et al. (2000), Maltz and Kohli (2000), Barczak and McDonough (2003), Paashuis and Boer (1997), Kahn and McDonough (1996), Wheelwrigth and Clark (1992).
Software	Core communication technologies *Basic technologies (e.g., fax, e-mail, teleconferencing, videoconferencing, web portals).* Enterprise computing technologies *Computer aided software (e.g., CAD, CAM, PDM, PLM, EDB, EDI).* Group collaboration technologies *Collaboration technologies (e.g., online team spaces, discussion databases, QFD, FMEA, DfX).*	Bardhan et al. (2005), Bowonder et al. (2004), Paashuis and Boer (1997), Adler (1995).
Hardware	Tools, computers, handling devices and other communication equipment enabling the use of software mechanisms.	Bardhan et al. (2005), Paashuis and Boer (1997).

Table 3. Technological Integration Mechanisms

4.3. Organisational mechanisms

Paashuis and Boer (1997) suggest that integration by organisation refers to enabling and facilitating communication and collaboration in product development adopting suitable organisational arrangements (i.e., the more or less durable, formal and informal, structural and cultural arrangements organizations use to divide and co-ordinate labour).

In the literature several classifications of organisational arrangements have been proposed. Thompson (1967) identifies three generic organisational approaches to integration: standardization, plans and schedules, and mutual adjustment. Van de Ven et al. (1976) classifies organisational mechanisms into impersonal, personal, and group modes. Mintzberg (1979) relates the organisational arrangements to three basic mechanisms: standardization, mutual adjustment, and direct supervision. In addition, the author finds that individuals working side by side in small groups communicate and collaborate each other informally, adopting mutual adjustment mechanisms. As the group complexity increases (i.e., different shifts of labour, different locations, complex technical system), direct supervision mechanisms become a necessity to control the workflow of the group. Further, as the work become more involved, the favoured integration organisational mechanism seem to shift from direct supervision to standardization. However, whereas tasks are impossible to standardize, mutual adjustment (i.e., *"the simplest, yet most adaptable coordinating mechanism"*) is back the favoured integration organisational mechanism again. Sabherwal (2003) builds on the previous studies identifying four organisational arrangements: standards, plans, formal mutual adjustment, and informal mutual adjustment.

Considering these classifications, organisational mechanisms have been classified into six categories: standardization (i.e., standards), formalization (i.e., schedules and plans), direct supervision, formal (i.e., impersonal) mutual adjustments, informal (i.e., personal) mutual adjustment, and dedicated teams.

Standardization

Integration by standardization means that communication and collaboration processes among different functions involved in the product development are defined in standard work processes, outputs, and knowledge and skills (i.e., communication and collaboration processes are defined in advance).

Work processes are standardised when the content of the work is specified. Pahl and Beitz (1996) refer to the stage-gate model as an approach to standardise product development procedures. Gates are used to divide the development process in stages and specific documentation is required at each gate, before entering the next stage. The activities are therefore standardised in the process without focusing on the overall outcome. Griffin and Hauser (1996) finds that standardization in work processes (i.e., the use of standard forms and technical terms such as compatibility standards and data dictionaries) enables integration.

Output are standardise when the result of the work is specified. Adler (1995) suggests that producibility design rules (i.e., explicit characterization of manufacturing capabilities) defined in the pre-project activities allow product engineers in the design phase to assure the producibility of the product (i.e., standard outputs) knowing the limits within which the design must fit. Product engineers are not told how to achieve the outputs of the design, producibility design rules told product engineers what the results should be.

Knowledge and skills are standardised when the experience and the training required to perform the work are specified. Paashuis (1997) cites the study of Weegeman (1997) arguing that knowledge and skills are specified when work programmes are built into individuals. Individuals know exactly what to expect each other relying on respective training and experience. Standardisation of knowledge and skills achieves indirectly what standardisation of work processes and outputs achieves directly (i.e., standard knowledge and skills control and co-ordinate the work).

Thompson (1967) finds that standardisation is an effective integration mechanisms when product development activities are relative stable, repetitive (i.e., can be anticipated in advance), and few enough to permit matching with similar activities (i.e., the appropriate outputs can be identified). Consistently with the study of Thompson (1967), Paashuis (1997) suggests that integration by standardisation is limited to activities in which uncertainty can be handled. Whereas, unique and non-routine activities (i.e., relative unpredictable and iterative activities) require informal mutual adjustment.

Formalization

Integration by formalization means that communication and collaboration processes among individuals and functions involved in the product development are defined in formal work processes (i.e., communication and collaboration processes are structured in advance).

Work processes are formalised when the content of the work is structured. Aiken and Hage (1966) define formalization as the degree to which organizational rules, procedures, and instructions are written or codified and enforced.

Kleinschmidt et al. (2007) suggest that stage-gate system provides project formalization through a detailed schedule of activities, milestones and gates to be implemented throughout the product development process. Griffin and Hauser (1996) finds that formalization in work processes assists the removal of several barriers to integration in product development. Clearly articulating what the roles and tasks that each responsibility has to fulfil, and formalizing the levels and degrees that the functions have to integrate, enable and facilitate communication and collaboration processes. Coherently with the study of Griffin and Hauser (1996), Rice et al. (2007) find that the adoption of formal procedures and structured processes significantly increased the effectiveness of integration.

Direct supervision

Integration by direct supervision means that communication and collaboration processes among different functions are under responsibility of a single individual, called *supervisor* (i.e., project leader, project manager). The role of the supervisor is to plan and control integration among development activities carried out by different functions, issuing instructions and monitoring activities. Clark and Fujimoto (1991) suggest that direct supervision allows individuals involved in the product development process to focus on specialised activities since the supervisor makes sure that requirements and constraints of other functions are taken into consideration. As a consequence, supervisors should have the knowledge and skills to understand and translate the requirements and the constraints of different specialists (e.g., product design, production, logistics and marketing) bringing different functions in contact with each other. Hence, to enable and facilitate integration supervisors must receive relevant project information and be aware of progresses over a project.

Consistently with the study of Clark and Fujimoto (1991), Brown and Esinehardt (1995) state *"even though the cross-functional team is the heart of efficient product development, the project leader is the pivotal figure in the development process"*. Coherent with the communication and collaboration perspective, the project leader is defined as the *"linking pin"* among specialists involved in the product development process as well as between the project team and the senior management. The authors define power and vision as the central characteristics of the project leader. Powerful project leaders have a significant decision-making responsibility, organization wide authority, and high hierarchical level. Such leaders are effective in obtaining resources (i.e., personnel and budgets) for the execution of the project. Whereas, vision involves *"the cognitive ability to mesh a variety of factors together to create an effective, holistic view and to communicate it to others"* (i.e., project leaders, through vision, mesh together firm specific competencies (e.g., technical, marketing, and strategies) with market requirements).

Concerning the role of senior management in the product development project, Brown and Eisenhardt (1995) cite Imai et al. (1985) noting that rather than playing just a supportive role senior management should engage a subtle control. Subtle control refers to a supervision through which senior management exercises control (i.e., such control that enable the product fit with project strategy and goals) allowing, however, creative problem solving at the project team level (i.e., giving team members the freedom to work autonomously). Consistently with the previous study, Cooper and Kleinschmidt (1995) find that senior management commitment to, and involvement in, product development processes lead to effective projects. The authors suggest that in profitable development projects senior management commits the necessary resources to achieve project's goals (i.e., senior management encourages collaborative efforts on project goals) and is closely involved in the project Go/Kill decisions playing a central in the process reviews.

Formal mutual adjustment

Integration by formal mutual adjustment is defined as establishing communication and collaboration processes by means of formal integration mechanisms aimed at getting individuals together, such as liaison personnel (e.g., liaison role and product champion role) and review meetings (e.g., design, producibility, and status review meetings).

Liaison personnel is an organizational mechanism used to integrate different development activities by means of mutual adjustment. Paashuis (1997) suggests that liaison personnel are organisationally positioned in liaison roles or product champion roles. Individuals playing *liaison roles* belong to a functional area and have the responsibility to ensure that the requirements of the home function are made visible to others disciplines. Further, liaison individuals have to assure that the relevant information for home function is received from others disciplines. Whereas, individuals playing *product champion roles* have the responsibility to integrate the entire projects, including product design, production, logistic and marketing. Hence, product champions take responsibility for the management of the interface among design, manufacturing, supply chain and marketing ensuring fit among product, production process and supply chain. Consistently with the study of Paashuis (1997), Anderson et al. (2008) assert that product champions are *"ultra-lightweight project managers, who – instead of direct or dotted-line supervisory control over their reports – employ a mix of soft skills to coordinate, translate, negotiate, and mediate across organizational interfaces to ensure successful product integration"*. Citing Galbraith (1973), Paashuis (1997) argues that playing as liaison personnel is challenging since liaisons and product champions do not have the formal authority over the people they intend to involve in communication and collaboration. However, liaisons and product champions have the formal authority in aspects of the decision process that cut among different functions involved in the product development project (e.g., product planning, approving completed decisions, drawing up budgets).

Review meetings are formal meetings established to coordinate design engineers (i.e., design review meetings), to ensure an acceptable fit between product design and manufacturing process parameters (i.e., producibility review meetings), or to assess the progress of the project identifying and solving critical interface issues (i.e., status review meetings). In detail, Adler (1995) defines design review meetings as common procedures established to ensure the coordination of different subunits within the product design department. In the design reviews others specialists (e.g., manufacturing engineers) involved in the project do not participate. Whereas, producibility review meetings involved both design engineers and manufacturing engineers to ensure that producibility requirements and constraints are considered in the design activities. Finally, every function involved in the product development project participates in status review meetings identifying and solving (i.e., making decisions) critical interface issues (i.e., issues involving product, production process, logistic and marketing parameters). Further, Gupta and Wilemon (1998) suggest that effective status review meetings are invaluable in gauging product development performance and in maintaining enthusiasm in the project.

Informal mutual adjustment

Informal mutual adjustment differs from formal mutual adjustment in that the communication and collaboration processes are established by means of unstructured and informal integration mechanisms such as face-to-face meetings and co-location.

Face-to-face meetings represent an informal form of team communication leading to build relationships among individuals involved in the project. In face-to-face communication team members receive information in the same order, and the flow of information is smooth and synchronized allowing people involved to react directly to information received from others. Barczak and McDonough (2003) find that face-to-face meetings improve communication and collaboration processes providing the team with the opportunity to form interpersonal bonds, set project goals, develop project plans, define roles and responsibility, coordinate activates, solve interface problems, and maintain team motivation and focus on the project.

Co-location consists in bringing together individuals from different functions into a single location. In some instances, every individual involved in the product development project is brought in a single location, whereas in other instances, only key members are co-located. Regardless of the format, Kahn and McDonough (1997) find that co-location enable easier and more frequent interaction among members of different departments removing organizational barriers and promoting close collaboration in development activities. Hence, the frequency and the nature of interactions induced from co-location enhance integration among different specialists involved in product development projects (i.e., facilitate close collaboration among engineering, marketing, manufacturing and supply chain functions). Consistently with the previous study, Eppinger and Chitkara (2009) argue that co-located teams could concurrently execute development activities (i.e., from understanding market and customer needs, through conceptual and detailed design, testing, analysis, prototyping, manufacturing engineering and post sales services) achieving better product designs, faster time to market and lower cost production.

Dedicated teams

Integration by dedicated teams can be defined as facilitating communication and collaboration processes by means of organizational arrangements such as cross-functional teams, self-contained groups, and transition teams.

Cross-functional teams enhance integration increasing the amount and the variety of information and knowledge available to design products. Brown and Eisenhardt (1995) find that increasing the technical information available from different disciplines (i.e., functions) enables project team members to understand the design process from a variety of perspectives. For instance, the increased technical information allows the team to consider in advance downstream constraints such as manufacturing difficulties or market mismatches solving design criticalities in the early phase of the product development process (i.e., when problems are generally smaller and easier to fix).

Self-contained groups facilitate integration in product development project partitioning specialists involved in the project into relatively self-contained groups with a minimal number of critical cross-groups interactions and then aligning those groups with several interactions. Coherently with the study of Anderson et al. (2008) the aim of partitioning (i.e., self-contained groups) is to design the bundle of tasks assigned to each specialists to be self-contained (i.e., modular) as possible.

Transition teams facilitate integration in project developing design engineers' understanding of manufacturing. Adler (1995) finds that firms established transition team, in which several design engineers moved with the design into manufacturing on temporary assignment, to manage design revisions after the product is released to manufacturing.

Organizational	***Integration mechanisms***	***Contributing authors***
Standardization	Standard work processes *(e.g., standard workflow, standard forms, data dictionary).* Standard outputs *(e.g., design rules such as producibility design rules).* Standard knowledge and skills.	Paashuis (1997), Griffin and Hauser (1996), Pahl and Beitz (1996).
Formalization	Formal procedures. Detailed schedule of activities. Project milestones.	Kleinschmdt et al. (2007), Rice et al. (2007), Griffin and Hauser (1996).
Direct supervision	Supervisor *(e.g., a project leader).* Senior management commitment.	Brown and Esinehardt (1995), Clark and Fujimoto (1991).
Formal mutual adjustment	Liaison personnel. Product champions. Review meetings.	Anderson et al. (2008), Paashuis (1997), Adler (1995), Gupta and Wilemon (1998).
Informal mutual adjustment	Face-to-face meetings. Co-location.	Barczak and McDonough (2003), Kahn and McDonough (1997).
Dedicated teams	Cross-functional teams. Self-contained groups. Transition teams.	Anderson et al. (2008), Holland et al. (2000), Adler (1995), Brown and Esinehardt (1995).

Table 4. Organizational Integration Mechanisms

4.4. Factors influencing the configuration of integration mechanisms

Consistently with the study of Adler (1995), the objective of integrating design, manufacturing, and logistic functions is to ensure an acceptable fit among product design, manufacturing process and supply chain parameters. Thompson (1967) suggests that depending on the degree of fit uncertainty, different integration mechanisms are needed. Adler (1995) builds on the study of Thompson (1967) and identifies two dimensions of fit uncertainty: fit novelty and fit analysability. A higher degree of *fit novelty* (i.e., the product, process or supply chain parameters had been changed significantly relative to previous projects) creates uncertainty by making the choice of product design parameters more sensitive to the choice of process and supply chain parameters and vice versa. Coherently with Adler (1995)'s findings, the studies of Sethi (2000) and Avlonitis et al. (2001) indicate that uncertainty associated with radical innovative product is much greater than in the case of incremental product, because as the degree of newness increases, the amount of relevant experience and knowledge decreases, which then enhances the degree of uncertainty surrounding the project. Hence, higher fit novelty leads firms to adopt intensive integration mechanisms to enable and facilitate greater requirements for communication and collaboration among different functions (i.e., to enable and facilitate intensive use of the available fit information). Whereas, a lower degree of *fit analysability* (i.e., the difficulty of the search for an acceptable solution to the given fit problem) creates uncertainty by impeding the resolution of fit issues at the current phase of the development process. Hence, lower fit analysability leads firms to adopt integration mechanisms to create fit information, in particular moving from the product, process and supply chain requirements that guide the pre-project capabilities development activity, to the drawings and specifications that emerge from the design phase, to the concrete product, process and supply chain that are created in the manufacturing phase.

Coherently with the considerations emerging from fit analysability, Adler (1995) suggests that the integration mechanisms to be established vary in relation to the degree of interdependence (i.e., fit analysability) required in a specific phase of the product development process. The author classifies the integration mechanisms according to three, notionally distinct, temporal and overlapping phases of the product development process: pre-project, design-phase and manufacturing-phase. The *pre-project* phase (i.e., conceptual design) consists in the activities preceding the initiation of a project and the output is a set of design and manufacturing skills, procedures, and technologies. The *design-phase* (i.e., detail design) includes activities related to the definition of product and processes releasing a set of specifications (i.e., product and process specifications). The *manufacturing-phase* consists in activities performed successively the release to manufacturing of product and processes specifications and the output is a saleable product. Consistently with the proposed taxonomy, Adler (1995) finds that pre-project mechanisms include formulating functional strategies for the design and manufacturing departments, cross-functional skill development, setting producibility standards and creating approved parts databases. Design-phase mechanisms consist in standards and producibility design review. Whereas, manufacturing-phase mechanisms include transition team in which several design engineers move to manufacturing on temporary assignment to ensure producibility of design revisions.

Coherently with the dimensions of fit uncertainty, Adler (1995) suggests that the design of coordination mechanisms depends on both the degree of fit novelty and the degree of fit analysability. In detail, the degree of fit novelty determines the extent to which each integration mechanism (e.g., standardization, formalization, direct supervision, mutual adjustment and dedicated teams) is established (i.e., integration dimension). Whereas, the degree of fit analysability determines the phase of the product development process (i.e., pre-project, design, manufacturing) in which each integration mechanism is established (i.e., temporal dimension). Hence, the optimal integration approach involved a portfolio of mechanisms. Finally, Adler (1995) underlines that the adoption of a set of integration mechanisms (e.g., standardization) does not preclude simultaneous use of another set (e.g., mutual adjustment). Just as, the use in the earlier phases of the product development process of a set of integration mechanisms does not preclude the use of that set of mechanism in the later phases.

5. GLOBALIZATION IN THE CONTEXT OF INNOVATION

Abstract

The current market environment is internationalized and globalized. In the last decades, internationalization and globalization have been an observable trend that has posed difficulties and opportunities for businesses in both manufacturing and service sectors. In the context of operations, organizations have established global supply chains. Raw materials and components are sourced from around the world. Manufacturing processes are internationally dispersed. Also support services are transferred to overseas sites. In the context of innovation and, more specifically, in product development, organizations have begun to disseminate product development effort globally, leveraging company and third party resources, assets and capabilities at a global level in order to exploit internationally dispersed capabilities and to maximise the returns on commercialising innovations on an international scale (Eppinger and Chitkara, 2006; Perks and Wong, 2003).

In 1990's companies in technologically intensive industries such as electronics and automotive began to move from a centralized approach to a global product development (GPD) practice, in which PD resources and activities are geographically dispersed.

According to Kahn and McDonough (1996), companies have begun to explore GPD practice to reflect the demands of customers from multinational countries. In addition, Kummerle (1997) argues that a centralized approach to product development is not suitable as resources of relevant knowledge emerge across the globe. Thus, companies began to establish GPD to commercialize products in multinational markets and to access globally distributed knowledge.

Kahn and McDonough (1996) find that the need to adopt a GPD practice results in establishing global product development teams comprised of individuals drawn from multiple countries and company functions. Consistently with Kahn and McDonough (1996), in the Daimler-Benz High Tech Report '97, Klaus-Dieter Vöhringer, Chief Technology Officer at DaimlerChrysler, recognized the necessity *"to create a culture in which employees realize that cooperation across regional and departmental boundaries is essential to the continued success of the company. ... We are well aware of the growing need to combine our internal expertise and know-how with that of top performing research facilities worldwide"*

Gupta and Wilemon (1998) confirm and build on the study of Kahn and McDonough (1996). They study the emergence of global development teams, and find that global teams rely on disciplinary specialists in various geographical locations. As such, they argue that global teams usually encounter operational and cultural challenges beyond that of a site-specific development team. Consistently with Gupta and Wilemon (1998), McDonough et al. (2001) find that the process of development products and bringing them to the market is more complex as global teams experience more behavioural challenges and project management challenges than site-specific development team.

Barczak and McDonough (2003) state, *"the unique characteristics of a global team require a unique approach to meeting these challenges"*. According to McDonough et al. (2001), the authors find that companies to establish effective GPD practice have to build trust among team members, ensure effective communication, encourage collective goals, promote motivation and keep project on schedule and within time.

In 2003 a Deloitte Research study of North American and Western European manufacturers notes that 48% of the companies surveyed had located engineering operations and functions outside of their home region. According to Deloitte Research findings, Eppinger and Chitkara (2006) find that in the first five years of the 21^{st} century, globalization pressure has begun to have a significant impact on the practice of product development across several industries. They state "*best practice in product development is rapidly migrating from local, cross-functional collaboration to a mode of global collaboration*". These emerging practices in product development exploit highly distributed, networked development process, in which centralized functions are combined to resources located to other sites or regions of the world through fully digital PD system. Since GPD practice involves multiple organizations in different countries, Eppinger and Chitkara (2006) note that several GPD modes were emerging.

Similarly, Gomes and Joglekar (2008) find that in several industrial sectors, ranging from computer hardware and software development to automotive development, product development resources are not longer centralized in the focal development company. Consistently with the previous study, Anderson et al. (2008) find that in the recent years, the use of GPD approach involving multiple companies that are geographically dispersed and separated by organizational boundaries (e.g., outsourcing, offshoring, alliance) to develop products has spread dramatically.

Based on the previous studies, Eppinger and Chitkara (2009) define GPD as *"a single, coordinated product development operation that includes distributed teams in more than one country utilizing a fully digital and connected, collaborative product development process. This may include third parties that provide engineering or design capacity, or it may be an entirely captive, company-owned operation"*.

5.1. Factors to move to global product development practices

Companies began to move from a centralized approach to a global product development (GPD) process for several reasons.

Kahn and McDonough (1996) argue that companies have begun to explore GPD approach to reflect in products the demands of customers from multinational countries.

Kummerle (1997) states *"companies must build global product development that excel at tapping new centers of knowledge and at commercializing products in foreign market with the speed required to remain competitive"*. That is, companies dispersed geographically PD resources and activities to access knowledge from local scientific community and to move product from development to market at a more rapid pace.

McDonough and Kahn (1999) argue that companies adopt GPD approach to access technical assets that are not available in the focal development company geographic area.

McDonough et al. (2001) suggest that GPD approach has the potential to offer high product development performance since global teams have higher levels of creativity and develop better alternatives to a problem than non-multicultural teams.

Barzack and McDonough (2003) find two competing needs that induce companies to GPD approach. On one hand the need to develop a global product that addresses multinational customers by a common product platform. On the other hand the need to develop a tailored product that incorporates unique needs and requirements of a local market. The authors argue that the nature of GPD allows identifying and incorporating market requirements emerging from different countries into the product as well as to develop common product platforms.

Eppinger and Chitkara (2009) confirm and build on the previous studies. They argue that companies build GPD capabilities for any of the following four reasons: lower cost, improved process, global growth, and technology access.

Companies that establish GPD for *lower cost* reason strive to reduce PD operating costs by redistributing activities and resources to take advantage of engineering talent in low cost and medium cost countries (the authors consider low cost and medium cost to be, respectively, 10% to 20% and 20% to 50% of the equivalent engineer's salary in the United States). Even if offshore knowledge is similar to that available onshore, the cost of utilizing the offshore knowledge might be cheaper. Consider, for example, the way that companies leverage software programmers in Bangalore, India; aerospace technologists in Russia; or chip-set designers in China to cut the costs of product development processes.

Companies that set up GPD for *improved process* reason look for greater product/process/supply chain fit and for shorter time-to-market.

Companies that establish GPD for *global growth* aim to access information about demands of customers from multinational countries using local engineers to create direct connections with potential markets. Take, for example, the cellular phone industry. Nokia Corp. extended the innovation process into China and India, where the company saw that mobile phones could potentially substitute for a fixed line network, winning the battle against Motorola Inc.

Finally, companies that move to a GPD approach for *technology access* aim to develop integrated PD processes including resources located in regions where critical new technology has been developed and where technical experts reside. Consider, for example, the pharmaceutical industry. Companies such as Novartis AG and GlaxoSmithKline Plc. realize that the knowledge required in drug discovery extends beyond traditional chemistry and therapeutics to include biotechnology, genetics, advanced computers and robots. This knowledge has emerged from diverse sources away from the companies' traditional R&D labs in Basel, Bristol or New Jersey. Instead, it is often located far away in California, Tel Aviv, Cuba or Singapore. As a result, pharmaceutical companies have learned that globalization of product development processes is no longer optional, whereas it has become imperative (Santos et al. 2004).

5.2. From co-located cross-functional teams to global cross-functional teams

In 2000's an increasing number of companies face the need to access critical resources that are dispersed around the world. The result is the establishment of global product development teams comprised of individuals drawn from multiple countries and company functions.

Researchers distinguish three different types of teams: co-located, virtual, and global. According to O'Hara-Devereaux and Johnson (1994) *co-located* team are comprised of members who work together in the same physical location and are culturally similar. Whereas, in a *Virtual* team members work in different physical location, but are culturally similar (i.e. members are located in different areas of the same country). Finally, in a *global* team, members work and live in different countries and, consequently, are culturally diverse.

McDonough and Kahn (1996) find that in several respects global and virtual product development teams are similar to co-located teams. In fact, as co-located teams, global and virtual teams are comprised of members from several functions and disciplines (e.g., marketing, engineering, manufacturing), led by a project leader, and charged with the development of a product. In other respects global teams differ from virtual and co-located teams. In fact, members of global teams represent different nationalities, are geographically dispersed, operate in different time zones, have different cultural background, and speak a variety of languages.

Consistently with the nature of global and virtual teams, McDonough et al. (2001) find challenges in GPD practice that are also present in the traditional approach to product development. In fact, as co-located teams, global and virtual product development teams experience the challenge of getting diverse group of individuals belonging to different functions to work together effectively. According to McDonough and Kahn (1999), individuals belonging to different disciplines bring into the product development team different orientations toward time, bases for performance evaluation, terminology, managerial styles, departmental cultures, and decision-making practices.

In addition to the traditional challenges experienced by a cross-functional team, McDonough et al. (2001) suggest that global teams face additional challenges such as physical distance, cultural diversity, language barriers, and technological infrastructure differences.

Gupta and Wilemon (1998) argue that since global team members are geographically distributed and separated by multiple time zones (*physical distance*), real-time interaction and everyday discussions that occur during a project are not quite as simple (i.e., informal mutual adjustment).

Consistently with the previous study, McDonough and Kahn (1999) suggest that an implication of these problems is the need to maintain team member motivation. Neff (1995) suggests that awareness of cultural differences is a necessary condition for effective global team; in fact, treating each member equally, as if there are no differences will lead to ineffectiveness (*culture diversity*).

Gupta and Wilemon (1998) confirm on the study of Neff (1995), they find differences on time perception *"to most western team members time is a valuable commodity and should not be wasted. In some parts of Asia time has a very different meaning. These varying perspectives on time can lead to conflicts and a lack of understanding of what's important ad what's relevant"* and on leadership style *"In some societies strong leaders are valued whereas in other places leadership is more diffused and indirect"*.

In addition, global team's members are likely to have different work, communication and decision-making norms since they are culturally diverse. These differences increase communication complexity, slower decision-making and create conflicting responsibilities.

So, to establish effective product development teams (whether local, virtual or global), McDonough et al. (2001) argue that companies must take actions to build trust, ensure effective communication, encourage collective goals, and promote motivation.

In the same study, McDonough et al. (2001) find that global teams face more behavioural challenges than virtual and co-located teams due to the complications of culture and languages. Differences in global team members increase the complexity of interpersonal relationships and, thus, a global team requires greater management skills (i.e., requires integration through humanware mechanisms). In addition, McDonough et al. (2001) find that global and virtual teams face the same extent of project management challenges (e.g. identifying key customers needs, ensuring project goals remain stable, staying on budget, keeping on schedule, and having sufficient resources). According to Allen (1977) this evidence suggests that project management challenges are related to distance between team members, rather than cultural and language differences.

Consistently with the study of McDonough et al. (2001), von Zedtwitz and Gassmann (2001) find that physical distance imposes the main challenges in global teams. In fact, distance impacts communication effectiveness (i.e., data and information exchange cannot be achieved at the same quality, speed and frequency as in co-located teams), raises transaction costs, and introduces principal agent related difficulties. In addition, the authors argue that the exchange of tacit knowledge, the creation of trust, and a common working culture require direct face-to-face communication that cannot be replaced by modern communication technologies.

Consistently with previous considerations, to establish effective GPD practice, McDonough et al. (2001) suggest that companies must train project leaders and establish organizational infrastructure to face challenges associated with virtual and global teams.

5.3. Global cross-functional teams: challenges arising from the nature of global teams

The characteristics of global and virtual teams require a tailored approach to meet challenges arising from physical distance, cultural diversity, language barriers, and technological infrastructure differences.

According to the nature of global product development team, McDonough and Kahn (1999) suggest that different approaches and mechanisms are required to ensure effective communication.

Based on this statement, the study of McDonough and Kahn (1999) explores how companies cope with communication problems arising from GPD and the impact of communication mechanisms (i.e. videoconferencing, fax, and e-mail, face-to-face meetings, phone calls, teleconferencing, company databases and videophones) on global product development teams performance.

McDonough and Kahn (1999) argue that cultural diversity and physical distance impact the need for communicating information quickly, communicating different volumes of information, and communicating rich information - Daft and Lengel (1986) define information richness as *"the bandwidth at which information can be communicated without error"* -.

The authors find that these differences affect communication indirectly as a consequence of six factors: problem-solving approach, communication mode to leaders and across functional boundaries, decision-making practices, different languages, technological capability, and physical distance between team members. Different *problem-solving styles* (e.g., analyse the entire problem and potential approaches for solving the problem prior to taking any action rather than adopting trial and error approach) led to different volumes of data to transmit among team members and dictated the frequency with which data is transmitted. Different *communication mode to leaders and across functional boundaries* (e.g., informal rather than formal dialogue, engineers in different departments communicate directly rather than inter-departments communication requires passing information up through a manager, across to the manager in the other department and then down to the individual who needed the information) influence the volumes and the richness of information to be transmitted. Different *decision-making practices* (e.g., consensus-driven decision making rather than independent-driven decision making) led to different volumes, richness and frequency of data. Different *languages* required additional communication since actions to be taken are not always understood by everyone. Across different countries, different level of *technology capability* (e.g., the standard use of technologies, technical system) influence communication. Finally, the *physical distance* impacts on communication as a consequence of a reduction in the amount of real time interaction and of spontaneous intra-team communication.

To deliver large amounts of rich information immediately, McDonough and Kahn (1999) find that companies need to use different communication mechanisms. In fact, some mechanisms meet the need for immediate information transfer better than others (e-mail, phone calls, and fax), while other mechanisms are better at providing rich data to team members (face-to-face meetings, mail, and company databases). Consistently with McDonough and Kahn (1999) findings, Anderson et al. (2008) find that face-to-face meetings have greater information richness than telephone calls, which have, in turn, higher information richness than e-mail.

Barczak and McDonough (2003) confirm and build on the study of McDonough and Kahn (1999). They explore how companies undertaking GPD practice build trust and keep product development project on schedule and within budget.

The authors state, *"because global team members are not co-located, building relationships and trust and fostering collaboration through frequent face-to-face interaction is simply not possible. Yet, without trust and strong relationships, collaboration suffers and communication wanes"*. Trust implies an expectation that team members will do what they have said and that they are capable of doing it. Trust needs to be built in global teams to allow members working together effectively over time and completing the project successfully. Since trust is undermined by a lack of clarity regarding purpose and responsibilities, face-to face meetings at the beginning of the project allow members to discuss and agree on project's goals and individual roles and responsibilities. In addition, the authors suggest that trust can also be built by: having competent people as members of the team, open communication in which team members share their views and thoughts but also listen to the views and thoughts of others, being reliable and doing what you say you will, and treating all team members equally. Whereas, keeping the product development project on schedule and within budget, finding adequate resources for the project, and keeping project goals stable are program issues. However, generating a sense of ownership of the project and a team orientation is not quite as simple due to the pressures that global teams face from on-site manager and due to the barriers of physical distance and cultural diversity.

To deal with these challenges, Barczak and McDonough (2003) identify four steps to lead global teams more effectively: meet face-to-face at the beginning, meet for a minimum of three days, increase the quantity and quality of communication, and hold project progress meetings.

Meet face-to-face at the beginning of the project ensure that the goals are clearly understood and shared among team members. McDonough and Kahn (1999) find that one of the most important elements to ensure project effectiveness is clarity of goals. In addition, initial face-to-face meeting allows teams to develop schedules and milestones as well as to define individual roles and responsibilities. Finally, meeting face-to-face at the beginning allows individuals to establish policies for communicating (e.g., certain information should be shared via e-mail while information related to an important project decision should be communicated via face-to-face meetings, teleconferences or video conferences) and making decisions within the team.

Meet for a minimum of three days allows team members to build relationships with other members and learn how to communicate with them, thereby developing trust and communicating effectively. These are necessary conditions to enable quickly decision-making procedures and continuously information and ideas sharing.

Increase the quantity and quality of communication allows enhancing the strength of the relationships among team members that, in turn, impacts team motivation and project performance. Frequent communication and extensive information sharing is critical to ensure that team members have the necessary data and information about critical aspects of project design and implementation so that decisions can be made quickly.

Finally, *hold project progress meetings* are necessary to keep the team focused on project goals, maintain commitment to the project and its goals, enhance motivation, and maintain relationships among team members. In fact, frequent progress updates via teleconferencing, e-mail or videoconferencing allows team members to discuss project goals, solve ambiguities and enhance commitment to the project.

Eppinger and Chitkara (2006) confirm and build on the previous studies. They state, *"the transition to GPD must incorporate new ways to collaborate among teams and individuals across time zones, languages, cultures and companies"*. The authors suggest that an effective capability to integrate and monitor the entire global product development process in terms of milestones, technical work quality and cost is critical to manage the complexity of distributed operations. Detailed project planning determines roles and responsibilities of individuals (i.e., which decisions are made at what levels and locations) and how to integrate across the operation to ensure alignment and proper execution. In addition, the authors argue that a consistent set of processes and standard is critical to enable collaboration among global team members. Eppinger and Chitkara (2006) find that many companies have had success in creating a consistent set of processes and standard by transferring a manager from central location to an offshore design centre to educate the offshore team on PD processes and to act as a liaison with the central location.

Finally, Kleinschmidt et al. (2007) find that the experience embodied in senior management and their involvement as leaders and facilitators play a critical role in reducing cultural distance among global team members, in translating company objectives and values to individuals, and in pulling together the elements of a GPD program and team.

5.4. From centralized to global product development process

Eppinger and Chitkara (2009) find that *"it is actually very hard to keep processes efficient as you distribute them"*. A centralized process is as lean and efficient as possible, disrupting such a process and distributing it globally make it less lean and less efficient.

The authors suggest that to establish an effective distributed process companies have to understand the structure of the product development process in terms of activities connections (i.e., which activities needs to connect with which other activities) and connections responsibilities (i.e., who makes those connections). Then, since activities have few connections that are strong and many connections that are weaker, Eppinger and Chitkara (2009) argue that it is possible to design a GPD process that doesn't require too much high-bandwidth communication between different locations. Therefore, according to the authors, creating a modular product development process allows companies to get efficiency within each site and to manage coordination as necessary among different sites.

5.5. Emerging organizational forms of product development

GPD practice involves multiple organizations that are geographically dispersed and separated by organizational boundaries (e.g., outsourcing, offshoring). Based on the concepts of outsourcing and offshoring, Eppinger and Chitkara (2006) suggest four fundamental organizational forms of PD.

The authors use the *outsourcing* concept and the *offshoring* concept to identify respectively the ownership and the location of the resources involved in PD process. The *ownership of resources* is defined *outsourced* when *"PD resources are owned by a third party"*, while *insource* or *captive* when *"PD resources belong to the focal manufacturer"*. Whereas, the *location of resources* is defined *onshore* when *"resources are located on-site at the company, down the road at the third party's offices or halfway around the world"*, while *offshore* when *"resources are located in lower-cost regions"*.

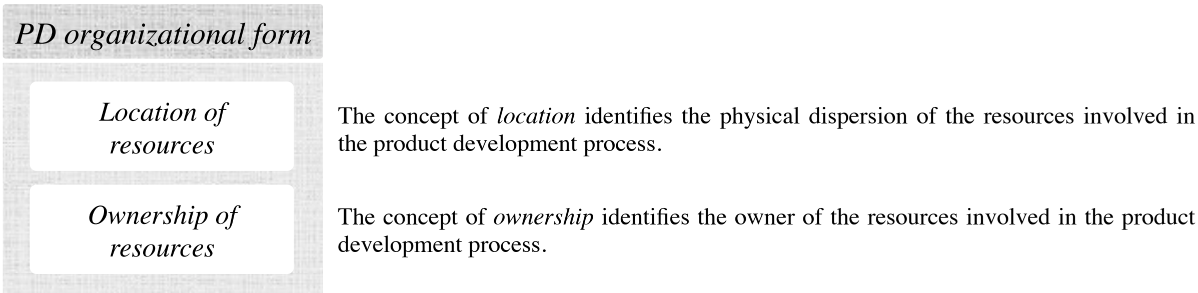

Figure 12. PD organizational form: Location and Ownerships of PD resources.

Viewing the concepts of ownership and location together allows the authors to envision four organizational forms of product development operations: centralized, local outsourcing, captive offshoring, and global outsourcing.

In the *centralized* form product PD resources belong to the company and are located on-site. The authors suggest that centralized operation can include different project teams in multiple countries.

A *local outsourcing* form of GPD is established when manufacturers use on-site resources owned by a third party to support product development activities. Companies set up local outsourcing GPD to access distinctive competencies or to face temporary capacity constraints.

In a *captive offshore* form PD resources belong to the company but are located offshore. Companies establish captive offshore GPD to gain access to a market in which it has never done business.

Finally, a *global outsourcing* form of GPD is established when PD resources are located offshore and owned by a third party. The authors note that initially companies contract with a service provider located offshore to accomplish basic engineering tasks (e.g., update drawings, implement engineering change orders, writing technical publications). On one hand, this approach allows focal manufacturers to understand the technical capability, the costs and the timeliness associated to the service provider. On the other hand, the service provider understands PD processes, methods and protocols adopted by the focal manufacturer. The mutual understanding of capabilities and processes potentially leads to shift the ownership of the whole process from the focal manufacturer to the outsourced provider. In this case, the focal manufacturer may define the technical requirements, while the outsourced provider does the high-level design, detailed design, prototyping, testing and redesign, ultimately delivering a completed design along with the necessary models, documentation and test results.

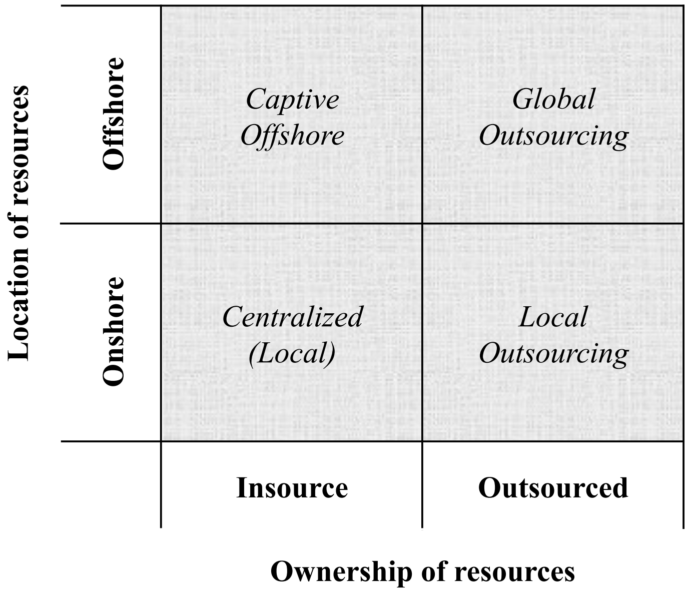

Fig. 13. Fundamental modes of GPD (source: Eppinger and Chitkara, 2006).

5.6. Deploying a global product development strategy

Until the study developed by Eppinger and Chitkara (2006), the academic discussion on global product development has been focused on understanding what it is and why companies establish GPD practice. There has been less focus on how companies deployed effective GPD practice.

Eppinger and Chitkara (2006) observed that best-practice leaders deploy a GPD strategy adopting a three-staged approach, starting with process outsourcing, followed by component outsourcing, and finally, establishing captive design center. The first stage, *process outsourcing*, consists in outsourcing PD process steps to an engineering services provider that is responsible for executing tasks that are easy to document and to separate from other activities. The second stage, *component outsourcing*, requires decomposing the product into components and modules, whose development is assigned to suppliers. Initially, companies assign to suppliers the development of simple components, then the design of integrated components, and finally the development of complete product modules. The third stage, *captive design center*, consists in the development of a captive global design center. Initially, the captive design center is responsible for the design of derivate products, than for the development of global products, product platforms and next-generation innovation.

In addition, the authors argue that a mature GPD structure combines all three stages and exploits a balance of captive and outsourced resources, geographically distributed.

Tripathy and Eppinger (2011) confirm and build on the previous study. The authors explore GPD structures adopting a process flow and system architecture perspectives and propose a process to establish effective GPD practice. Through observations derived from five case studies, a three-steps process that company takes to set up its GPD practice has been proposed, starting with identifying GPD structure, followed by designing the development process, and finally deploying GPD stages. The first step, *identifying GPD structure*, is undertaken by companies during the system architecture development phase and consists in defining the location and the ownership of PD activities. The selection of the activities to be outsourced and/or offshored is influenced by the GPD intent. On one hand, companies pursuing GPD to meet market needs or seeking complementary knowledge (i.e. competencies essential for the development of the product) establish offshore development facilities that are captive or outsourced based on core competence, business criticality and economic consideration. In this case, companies exactly know the basic content for offshoring. Thus, the decomposition of the system architecture (i.e. the product architecture and the development process architecture) in modules and components to define the content for offshoring is carried out after the identification of the GPD structure. On the other hand, companies pursuing GPD to seek efficiencies (except for complementary knowledge) need to first identify the content for offshoring, decomposing the system in modules, components and tasks and then differentiating between those that are to be offshored and/or outsourced from those that are not. In this case, the final offshoring content is *"the output of an iterative process involving the decomposition method, corresponding economic analysis, and the captive /outsource decisions"*.

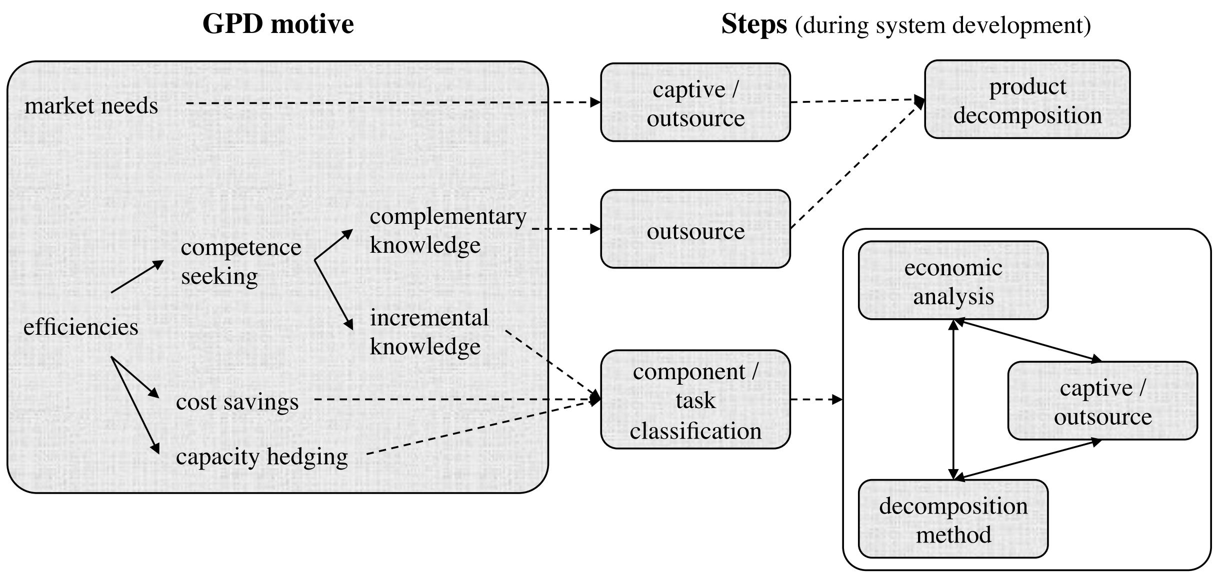

Figure 14. Steps toward identifying the GPD structure (source: Tripathy and Eppinger, 2011).

The second step, *designing the development process*, consists in identifying the process model for the development of the product. The authors identify the system architecture development as the first phase of the process model. During this phase GPD structure is defined. The central R&D function (competence centre) has complete responsibility for this phase, while offshore centres (whether captive or outsourced) provide inputs during concept development and system design. Finally, the system architecture approval is retained at the competence centre. The authors state *“this responsibility ensures that the home location/competence centre retains control on the design content, interface decisions, onshore/offshore responsibilities, sourcing decisions, etc., ensuring final product integrity”*. The second phase of the process model is the component/task development (both onshore and offshore). In this phase an appropriate exchange of information between the onshore and the offshore facilities is necessary as required by the system architecture. The final phase of the process model is the system integration. As for the architecture development, the competence centre has complete responsibility for the final phase, while offshore provide inputs. However, the final system integration approval is retained at the competence centre and is a core competence.

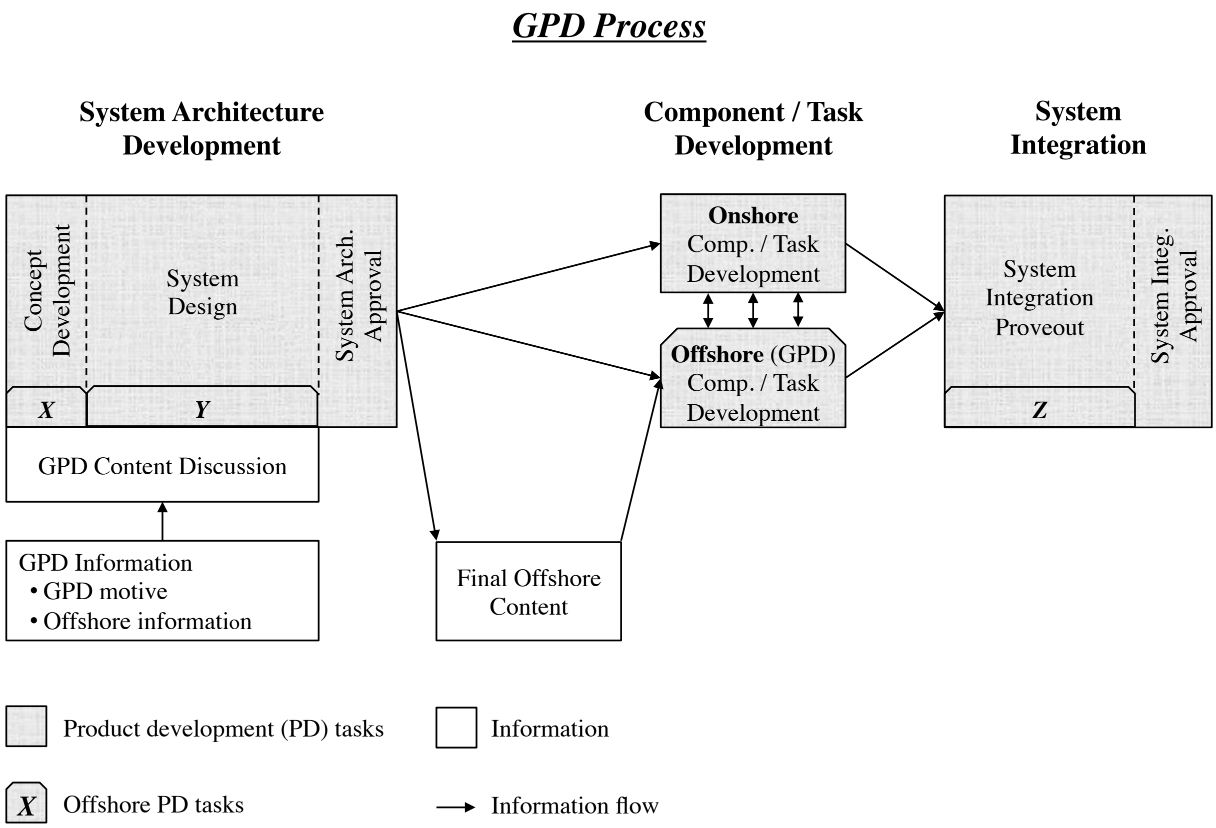

Figure 15. Process model for GPD (source: Tripathy and Eppinger, 2011).

The final step, *deploying GPD stage*, is aligned with the three-staged approach developed by Eppinger and Chitkara (2009). In addition, Tripathy and Eppinger (2011) suggest an initial *“exploring, experiencing, and learning”* step before the three-staged approach. This initial stage consists in understanding the offshore location in terms of work norms (e.g., product knowledge, standards followed, existing processes and practices), communication norms and decision-making norms.

RESEARCH QUESTION, MODEL AND METHODOLOGY

Abstract

In the next chapters the research objective and the research question are introduced discussing the dearth in the academic literature concerning the global product development and the integration of product development and supply chain management. Further, the conceptual model developed to address the research question is presented outlining the constituent elements and inferring the relations among the conceptual elements. Finally, the research methodological approach designed to answer the research question is discussed.

6. RESEARCH QUESTION

As emerged in the literature review, GPD is rapidly becoming the next-generation practice of product development spurred by international competition and worldwide market opportunities. Firms are rapidly adopting GPD practices exploring various modes and moving to global operations. The transition to GPD practices implies the adoption of organizational forms in which product development resources are globally distributed. Thus, as specialists involved in product development processes are dispersed over countries, time zones and cultures, organizations exploit different approaches in integrating product development resources to establish effective 3D concurrent engineering practices.

However, much of the reviewed academic discussion on GPD practices has been about what it is, why it should be done and how it should be deployed. Further, discussion on integration in GPD practices has been about how integration mechanisms cope with problems arising from the global dispersion of product development resources. In detail, current views of integration in GPD practices are simply focused on mechanisms building trust, encouraging collective goals and promoting motivation among global team members. Whereas, there has been less focus on frameworks that practitioners can use to decide how to design and implement 3D concurrent engineering in GPD practices. Hence, the objective of the present research is to develop a provisional framework explaining how 3D concurrent engineering should be facilitate in product development practices. Coherently with the research objective, the research question has been raised as follows:

How do high performing organizations facilitate 3D Concurrent Engineering in Product Development practices?

A prerequisite to address the research question is to investigate the elements facilitating 3D concurrent engineering. As concurrent engineering consists in a configuration of processes and mechanisms consistent with the organization's context, the elements facilitating 3D concurrent engineering reside in processes and mechanisms. In the reviewed literature three elements emerged: the product development process, the integration process and the integration mechanisms. In detail, the configuration of the product development process determines the information processing structure (i.e., the product development process architecture) constituting the basis of 3D concurrent engineering. Further, the configuration of the integration process determines the information processing requirements of the product development process (i.e., whether the information processing requires communication or collaboration) constituting the conditions enabling 3D concurrent engineering. Finally, the configuration of strategic, technological and organizational arrangements determines the information processing capabilities of integration mechanisms (i.e., whether integration mechanisms are capable of enabling communication or collaboration) providing support to 3D concurrent engineering.

Further, as the configuration of processes and mechanisms should be consistent with the organization's context, another prerequisite to address the research question is to investigate the contextual elements affecting 3D concurrent engineering. In the reviewed literature three contextual elements emerged: the product development organizational form, the product architecture and the product innovativeness. For instance, as in GPD practices real-time and spontaneous interactions among specialists are simply not possible, it might be inferred that the product development organizational form affects the configuration of the elements enabling 3D concurrent engineering. Similarly, as interdependence patterns and uncertainty of development activities varies depending on the nature of component interfaces and technology discontinuities, it might be inferred that the product architecture and the product innovativeness affect the design of 3D concurrent engineering in product development.

In addition to the aforesaid contextual elements, organization size and industry might affect the configuration of the elements enabling 3D concurrent engineering. However, as the aim of the present research is to investigate how 3D concurrent engineering is designed and implemented to fit product development organizational form, product architecture and product innovativeness, it has been chosen to observe firms employing similar product development teams in terms of size and operating in similar industries. Further, since it has not been feasible to address every contextual element emerged from the reviewed literature, the product innovativeness has been modelled as a control variable. Hence, it has been opted to investigate development processes in which designed products have similar degree of innovativeness avoiding the effect of product innovativeness on the configuration of the elements enabling 3D concurrent engineering.

These arguments lead to detail the research question as follows:

How do high performing companies configure product development process architecture, integration process and integration mechanisms to facilitate 3D Concurrent Engineering in product development practices depending on product development organizational form and on product architecture?

To address the research question, product development processes of high performing manufacturing companies have been investigated. In detail, coherently with the concept of the 3D concurrent engineering, the focus has been on the development stage of the product development process during which the product, the manufacturing process and the supply chain are designed and developed (*see the section "The product development process: stage-gate model"*). As a consequence, in terms of specialists involved in the product development process, the focus has been on product engineers, process engineers and supply chain professionals.

7. *RESEARCH MODEL*

In the next chapters the conceptual model developed to address the research question is presented outlining the constituent elements and inferring the relations among the conceptual elements.

7.1. Conceptual model

The model used to address the research question has been developed coherently with the contingency approach in operations management leading to understand how practices (e.g., Concurrent Engineering in product development) should be designed and implemented to fit contextual elements, so as to be effective in terms of performance (Sousa and Voss, 2002).

As discussed in the section *"Research question"*, the elements enabling 3D concurrent engineering in product development are the product development process architecture, the integration process and the integration mechanisms. Whereas, contextual elements affecting product development process architecture, integration process and integration mechanisms are the product development organizational form, the product architecture and the product innovativeness. Further, the fit of the elements enabling concurrent engineering with the contextual elements affects organization's performance.

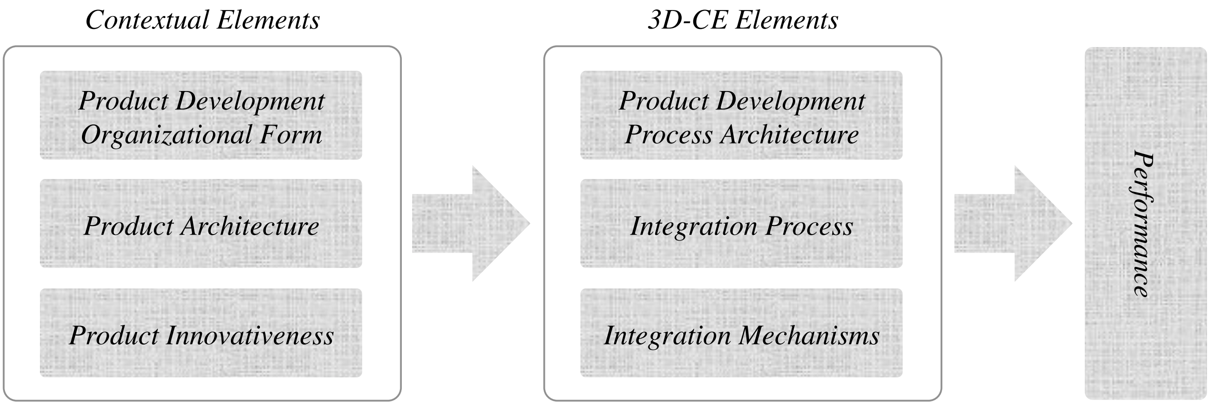

Figure 16. Conceptual model.

In summary, the model suggests that the configuration of the elements enabling 3D concurrent engineering (i.e., the configuration of the product development process, the integration process and the integration mechanisms) will vary in its effectiveness depending on the product development organizational form, the product architecture and the product innovativeness. However, to delve into the conceptual model, in the next sections, based on the reviewed academic literature, the elements constituting the model along with the relations among the elements are introduced and discussed.

7.2. Elements constituting the conceptual model

In the next sections the elements constituting the conceptual model are introduced and discussed. It is here worth to notice that several elements (e.g., the product development process architecture, the integration process and the integration mechanisms) have been exhaustively introduced in the *Literature Review* chapter. Therefore in the next sections, concerning these elements, simply an outline of the considerations drawn in the literature review process is reported.

Product Development process architecture

In line with the study of Sanchez (2000), the Product Development process architecture is defined as the system of functional development activities and the interfaces (i.e., interdependencies) among development activities (*see the section "Defining the product development process architecture"*). Similarly to the components of a product architecture, development activities that compose a process architecture are either tightly or loosely coupled. In detail, a modular process architecture is a system of loosely-coupled component functional activities, whereas an integral process architecture is a system of tightly-coupled activities.

Integration

Kahn (1996) defines the integration as a multidimensional process comprising communication and collaboration processes (*see the section "Integration: collaboration and communication processes*). Within product development, integration is the process by which information and knowledge are transferred and shared among individuals and functions. In detail, communication is the process by which information is transferred from one individual or a function to another. Whereas, collaboration is the process by which information and knowledge are shared among specialists, who develop mutual understanding and achieve common goals working collectively.

Integration mechanisms

In the reviewed literature several researchers define integration mechanisms as the strategic, technological and organizational arrangements aimed at enabling and facilitating collaboration and communication (i.e., integration) among individuals and functions involved in the product development process (*see the section "Integration mechanisms"*). In the present research, consistently with the reviewed academic literature, the integration mechanisms have been classified into three categories: strategic, technological, and organizational.

Product Development organizational form

In GPD practices, individuals involved in the development process are drawn from multiple functions, countries and even organizations (Eppinger and Chitkara, 2006). So, viewing together the location and the ownership of specialists performing development activities (i.e., design engineers, process engineers and supply chain professionals) allows recognizing different forms of Product Development organization (*see section "Emerging organizational forms of product development"*).

Figure 17 shows the method adopted to outline Product Development organizational forms providing a couple of examples.

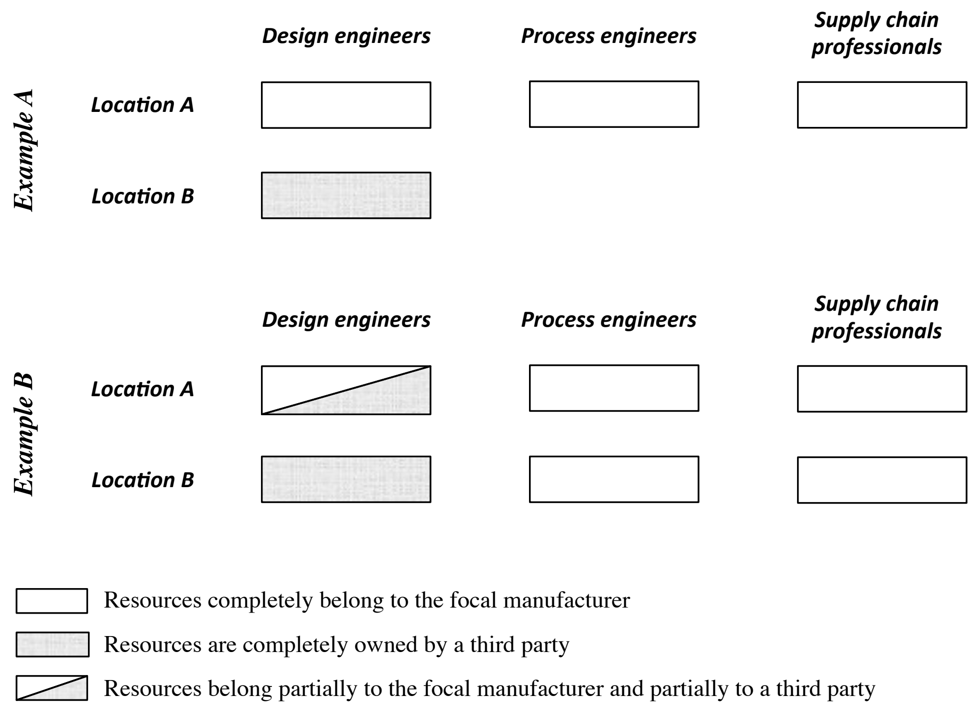

Figure 17. Method adopted to outline the Product Development organizational form.

In summary, the location and the ownership of individuals involved in the development process determine the form of the Product Development organization. So, for each discipline (i.e., design engineers, process engineers and supply chain professionals) the locations in which individuals are physically sited and the ownership of individuals are analysed and outlined. For instance, in the *Example A*, design engineers are located both in *Location A* and *Location B*, whereas process engineers and supply chain professionals are located in *Location A*. Further, design engineers located in *Location A* belong to the focal manufacturer, whereas design engineers located in *Location B* are owned by a third party. Whereas, in the *Example B*, design engineers, process engineers and supply chain professionals are located both in *Location A* and *Location B.* However, design engineers located in *Location A* belong partially to the focal manufacture and partially are owned by a third party, whereas design engineers located in *Location B* are owned by a third party.

Product architecture

Ulrich (1995) defines the Product architecture as *"the scheme by which the function of the product is allocated to physical components ... more precisely ... the arrangement of functional elements; the mapping from functional elements to physical components; the specification of the interfaces among interacting physical components"*. In particular, the *function* of a product is *"what it does"*.

In line with Ulrich (1995)'s definition, Sanchez (2000) asserts that the product architecture is the system of functional elements and the interface among individual components. In detail, the component interface specifications in product architecture define essential component interactions, such as attachment interface (i.e., how one component is physically connected to another), transfer interface (i.e., how power or material is transferred between components), control and communication interfaces (i.e., how the state of one component will be communicated to and/or controlled by other components), and spatial interfaces (i.e., the spatial location and volume a component may occupy).

Further, as a system of interrelated functional elements, the product architecture is characterized by the extent to which components are tightly coupled or loosely coupled (Voordijk et al., 2006; Fixson, 2005; Fine, 1998; Ulrich, 1995). A modular architecture is a system of loosely-coupled components (i.e., modules) including one-to-one mapping from functional elements to physical components. In a modular architecture, components are interchangeable, autonomous, loosely coupled, individually upgradeable and interfaces are standardized (Fine, 1998). On the contrary, an integral architecture is a system of tightly coupled components including complex mapping from functional elements to physical components. In an integral architecture, a change in a component requires a change in other components for a correct functioning of the product (Voordijk et al., 2006). Hence, the modularity is a property of the product architecture, so that every product has *modular* or *integral* architecture (Ulrich, 1995, Fixson, 2005).

Product innovativeness

Through a review of the literature from the marketing, engineering and product development disciplines, Garcia and Calantone (2002) define Product innovativeness as *"a measure of the degree of 'newness' of an innovation ... 'Highly innovative' products are seen as having a high degree of newness and 'low innovative' products sit at the opposite extreme of the continuum"*.

Literature review findings suggest that product innovativeness refers to the degree of discontinuity in marketing and/or technology (Goldenberg et al., 1999; Kessler and Chakrabarti, 1999). Coherently with previous studies on product innovation, Garcia and Calantone (2002) discuss innovativeness as the potential discontinuity a product might generate in the marketing and/or technological process.

Further, the authors distinguish between a macro and a micro perspective. From a macro perspective, product innovativeness is defined as *"the capacity of an innovation to create a paradigm shift in the science and technology and/or market structure in an industry"*. Whereas, from a micro perspective, product innovativeness is defined as *"the capacity of an innovation to influence the firm's existing marketing, technological resources, skills,* *knowledge, capabilities, or strategy".* For instance, product innovation might require marketplaces to evolve or new marketing capabilities for the firm (i.e., macro or micro marketing discontinuity). Similarly, product innovation might require a paradigm shift in the state of science or technology embedded in a product or a shift in the production processes for a firm (i.e., macro or micro technological discontinuity). Whereas, others product innovation might require discontinuities in both marketplace and technological dimensions.

Viewing together the two levels of product innovations (i.e., the macro versus micro and marketing versus technology perspective), Garcia and Calantone (2002) provide a typology for classifying innovation envisioning three types of product innovativeness: radical, really new, and incremental. *Radical* innovation causes marketing and technological discontinuities on both macro and micro level. Radical products do not address an existing market but instead create a demand previously unrecognized. *Incremental* innovation occurs at the micro level causing either a marketing and/or technological discontinuity. Incremental products provide improvements to existing technology and in the existing market involving the refinement of existing products and/or production and supply chain systems. Whereas, *really new* innovation occurs both at the macro level causing either a marketing or technological discontinuity and at the micro level causing either a marketing and/or technological discontinuity. Further, really new innovations might evolve into new product lines, product line extensions with new technology, or new market with existing technology.

Performance

3D-CE in product development is credited with high performance including reduced time-to-market, reduced development costs, improved quality, reduced delivery leas times, reduced production and logistic costs, and reduced inventory costs (*see the section "Benefits of the 3D-CE approach in product development"*). Therefore the Performance element included in the research model consists in time, cost and quality criteria aimed at measuring product development performance and production process and supply chain capabilities in terms of efficiency and effectiveness.

7.3. Relations among the elements of the conceptual model

In the next sections the relations among the elements constituting the conceptual model are introduced and discussed.

Integration and Integration mechanisms

Prior to discuss relations between Integration and Integration mechanisms, it is here worth to provide evidence distinguishing the two elements. De Luca and Atuahene-Gima (2007), citing the studies of Sobek et al. (1998) and "*The World's Most Innovative Companies"* (BusinessWeek 2006), provide anecdotal evidence that supports the distinction between integration and integration mechanisms.

The former study finds that, despite the high degree of collaboration among its functional units (i.e., individuals from different functions work collectively), Toyota established integration mechanisms, including standardized reporting and documentation, formalized work processes (e.g., project reviews), problem-solving meetings, and integrative leaders, to ensure knowledge and information transfer among its different units.

The latter, a study of the most innovative firms in the world indicates that Southwest and BMW have adopted mechanisms, such as co-location and face-to-face meetings to share the knowledge among cross-functional teams members, despite the high degree of collaboration proclivity (BusinessWeek 2006).

The distinction of the two constructs is crucial because integrating knowledge of individuals from different functions is challenging for firms, even when collaboration is established among them (Grant 1996).

Provided evidence distinguishing Integration and Integration mechanisms, it is here discuss the relation between these elements of the research model. As discussed in the chapter *"Concurrent Engineering: a matter of Integration"*, in product development processes, communication and collaboration are to be considered distinct because each process represents unique attributes of integration (Kahn, 1996). Further, the extent to which integration consists in communication and/or collaboration processes (i.e., the information processing requirements of the product development process) reflects specific capabilities of integration mechanisms. For instance, collaboration implies the capability of the implemented integration mechanisms to enable and facilitate collectively working among individuals having different and complementary skills (De Luca and Atuahene-Gima, 2007).

Further, as discussed in the chapter *"Integration mechanisms"*, in product development processes, integration mechanisms are designed and implemented to enable frequent communication and closer collaboration among individuals and functions (Paashuis and Boer, 1997). Further, the extent to which integration mechanisms should be capable (i.e., the information processing capabilities of the integration mechanisms) of enabling communication and/or collaboration reflects specific information processing requirements. For instance, whereas the capability of enabling communication and/or collaboration varies among mechanisms, as the requirements for working collectively and sharing technical knowledge increase, integration mechanisms such as face-to-face meetings, co-location and collaboration technologies are essential to enable integration in the form of collaboration (McDonough et al., 2001; Kahn, 1996). In contrast, as the requirements for working collectively decreases, integration mechanisms such as standard work processes and outputs, detailed schedule of activities, liaison personnel and software technologies are essential to enable integration in the form of communication (McDonough and Kahn, 1999; Kahn, 1996).

These arguments suggest the existence of a correspondence between the extent of each integration attribute (i.e., the information processing requirements of the product development process) and the integration mechanisms designed and implemented to enable integration (i.e., the information processing capabilities of integration mechanisms).

PD process architecture and Integration / Integration mechanisms

As discussed in the section *"Defining the product development process architecture",* modular PD process architectures consist in systems of loosely coupled development activities whose loosely interdependencies are defined in standard specifications (Sanchez, 2000). In detail, standard specifications define activities' output so that loosely coupled development activities might be performed independently. For instance, within a modular PD process architecture design engineers might perform independently development activities aimed at designing different modules of a product as interfaces among modules (i.e., loosely interdependencies among development activities) are defined in standard specifications in the form of design rules or design protocols. As a consequence, integration among individuals and functions performing loosely coupled development activities consists in exchanging standard documentations (e.g., design rules or design protocols) through which information and knowledge are transferred from one individual or a function to another (i.e., integration consists basically in communication process). In turn, mechanisms facilitating integration within modular PD process architecture should be capable of enabling the definition of standard specifications and the exchange of standard documentations.

On the contrary, integral PD process architectures consist in systems of tightly coupled development activities whose tightly interdependencies are not completely definable in standard specifications and interfaces. Indeed, tightly interdependency (i.e., reciprocal interdependencies) requires on-going adjustments and adaptation so that individuals having different and complementary technical skills work together to perform tightly coupled development activities. For instance, within an integral PD process architecture design engineers might perform collectively development activities aimed at designing tightly coupled components of a product as the design of one of the component requires adjustment when designing the other components and vice versa. As a consequence, integration among individuals and functions performing tightly coupled development activities consists in letting specialists work collectively (i.e., integration consists basically in collaboration process). In turn, mechanisms facilitating integration within integral PD process architecture should be capable of enabling collectively working through which specialists mutually share information and knowledge.

Therefore, assuming an Information Processing perspective (*see the section "An information processing perspective of the product development process"*), the Product Development process architecture might influence the correspondence between the information processing requirements of integration (i.e., the extent to which integration consists in communication and/or in collaboration processes) and the information processing capabilities of integration mechanisms (i.e., the configuration of integration mechanisms capable of enabling integration in term of communication and/or collaboration processes).

PD organizational form and 3D-CE

As discussed in the sections of the chapter *"Globalization in product development practices"*, GPD practices require tailored approaches to 3D-CE according to the nature of the organizational forms adopted in the product development process.

As in global PD organizational forms team members face physical and time distance, cultural diversity, language barriers and technological infrastructure differences, the traditional approach to 3D-CE established in centralized PD organizational forms is simply not possible (Kleinschmidt et al., 2007; Eppinger and Chitkara, 2006; Barczak and McDonough, 2003; McDonough and Kahn, 1999). For instance, in global PD organizational forms, real-time and spontaneous interactions among specialists (i.e., informal mutual adjustment mechanisms) enabling collectively working, through which specialists mutually share tacit knowledge and create trust, are not quite as simple (Gupta and Wilemon, 1998). Further, fostering collaboration among specialists through frequent face-to-face communication is not possible because modern communication technologies cannot replace face-to-face meetings (Zedtwitz and Gassmann, 2001).

As a consequence, within global PD organizational forms, a different approach to 3D-CE is needed. For instance, Eppinger and Chitkara (2006) suggest that in GPD practices integration mechanisms such as standard work processes, standard outputs, detailed schedules of activities, and project milestones are essential to enable an effective communication process capable of managing the exchange of information and knowledge among physically dispersed specialists. In addition, Kleinschmidt et al. (2007) find that in GPD practices the involvement of senior managements in global product development processes as integrators reduces the cultural distance among specialists creating a common vision and defining shared objectives.

These arguments suggest that the PD organizational form might affect the configurations of the elements enabling the 3D-CE (i.e., PD process architecture, Integration and Integration mechanisms) in product development practices.

Product architecture and PD process architecture

Consistently with the study of Sanchez (2000), modular product architectures whose components are loosely coupled (i.e., component interfaces are defined in standard specifications) determine an information processing structure (i.e., a product development process architecture) in which outputs of development activities are defined in standard specifications. As long as design outputs are defined, component development activities become loosely coupled and self-contained activities. Therefore, the loose coupling of component designs in a modular product architecture induces a loose coupling (i.e., the modularization) of development activities determining a modular product development process architecture.

On the contrary, integral product architectures whose components are tightly coupled determine an information processing structure in which the input of a development activity is the output of another development activity and vice versa. As long as reciprocal interdependency occurs, component development activities become tightly coupled activities requiring on-going adjustments and adaptation. Hence, the tight coupling of component designs in an integral product architecture induces a tight coupling of development activities determining an integral PD process architecture.

These arguments suggest that the Product architecture might affect the Product Development process architecture determining the interdependence patterns (i.e., tight or loose coupling) of the development activities.

Product innovativeness and 3D-CE

As discussed in the section *"Factors influencing the configuration of integration mechanisms"*, Adler (1995) suggests that higher degree of product innovativeness creates uncertainty by making the choice of product design parameters more sensitive to the choice of process and supply chain parameters and vice versa. As a consequence, product design activities heavily depend on manufacturing and supply chain specialists (i.e., product development activities are tightly coupled to process and supply chain development activities) for the expertise, information and knowledge needed to design a successful solution (i.e., a solution able to maximise product, process and supply chain performance). Coherently with the study of Adler (1995), Song and Swink (2002) find that higher degree of uncertainty requires access to deep and concentrated sources of functional expertise and technological knowledge. These arguments suggest that within higher degree of product innovativeness, integration consists in letting specialists work collectively sharing functional expertise and technological knowledge. In turn, mechanisms facilitating integration should be capable of enabling collectively working among individuals having different and complementary technical skills.

In contrast, uncertainty associated with incremental products (i.e., lower degree of innovativeness) is lower, because as the degree of newness decreases, the available experience and knowledge needed to design a successful solution increase, which then reduces the degree of uncertainty surrounding the project (Avlonitis et al., 2001). Hence, product design activities are less dependent on manufacturing and supply chain specialists and, in turn, interdependencies might be defined in standard specifications, for instance, in the form of design rules. As a consequence, within lower degree of product innovativeness, integration consists in exchanging information and knowledge from one specialist or a function to another. In turn, mechanisms facilitating integration should be capable of enabling the exchange of information and knowledge, for example, in the form of standard documentations.

Therefore, the relations among the elements enabling 3D-CE in product development (i.e., PD process architecture, Integration and Integration mechanisms) might be moderated by the degree of product innovativeness (i.e., radical or incremental) since uncertainty and interdependency related to development activities varies depending on the nature of the innovation (Garcìa et al., 2008).

PD organizational form, Product Innovativeness, 3D-CE and Performance

As discussed in the section *"Benefits of the 3D-CE approach in product development"*, improvements in product development performance and in production process and supply chain capabilities depend on the effective implementation of 3D-CE and, in turn, on the effective integration of people, information and activities (Noori and Lee, 2007). Therefore, coherently with the contingency approach in operations management (Sousa and Voss, 2002), as the product development process is essentially an information processing process, an efficient correspondence between the information processing structure (i.e., the PD architecture), requirements (i.e., the integration process), and capabilities of its integration mechanisms (i.e., integration mechanisms) and the contingencies affecting the product development process (i.e., PD organizational form and product innovativeness) might be effective in terms of performance.

7.4. A preliminary framework inferring relations among research elements

The observations derived from the academic literature suggest the existence of specific relations among the elements constituting the conceptual model. Hence, building on previous research studies, a preliminary framework inferring those relations is proposed.

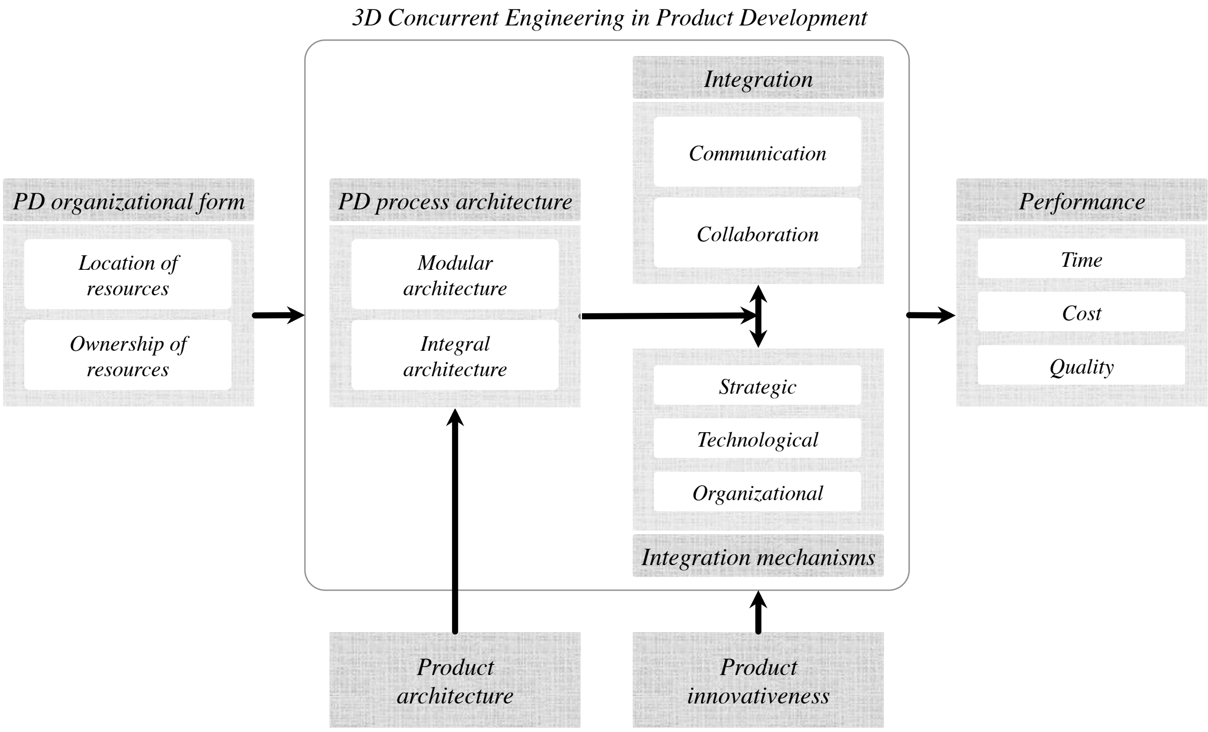

Figure 18. A preliminary framework inferring relations among research elements.

In detail, within 3D-CE elements, the configuration of the PD process architecture moderates the correspondence between integration and integration mechanisms (i.e., the information processing requirements of integration and the information processing capabilities of integration mechanisms). Whereas, with regards to the contextual elements, the PD organizational form and product innovativeness affect every element enabling concurrent engineering, whereas the product architecture affects only the PD process architecture. Further, the fit of the elements enabling concurrent engineering with the contextual elements affects performance in terms of time, cost and quality.

Consistently with the research question, the present study will exclusively investigate relations among the elements enabling 3D-CE, the product development organizational form, and the product architecture. In fact, since it has not been feasible to address every contextual element emerged from the reviewed literature, the product innovativeness has been modelled as a control variable. Further, as in theory and practice it is well established that effective 3D-CE approaches improve product development performance and leverage production process and supply chain capabilities, it has been assumed that the fit of the elements enabling concurrent engineering with the contextual elements leads to higher performance in terms of time, cost and quality.

8. *RESEARCH METHODOLOGY*

Edmondson and McManus (2007) argue that methodological fit promotes the development of rigorous and compelling field research. In detail, fit refers to internal consistency among research questions, prior work, research design, and theoretical contribution. Several archetypes of methodological fit have been delineated, in which three levels of prior work (i.e., nascent, mature, and intermediate) correspond to three methodological approaches (i.e., qualitative, quantitative, and hybrid). Although the archetypes represent a mean tendency in effective field research, *"by no means does it comprise a rigid rule"*. For instance, *"intermediate theory may draw primarily from qualitative data, with minimal quantitative data in the background, or it may rely extensively on quantitative data, with supplementary qualitative data to shed light on mechanisms ... off-diagonal opportunities exist when - with awareness of the literature on a particular topic - a study's focus is reframed from the broad to the narrow"*.

The present research aims to present provisional explanations of phenomena introducing novel constructs and proposing relationships between novel and established constructs drawn from prior work. The research question conducts to develop theory exploring how firms facilitate 3D Concurrent Engineering practices and generating testable research propositions about how different elements are related to 3D Concurrent Engineering practices. As discussed in the section *"Research Question"*, the research addresses a gap in the academic literature regarding product development practices, in particular the absence of any connection among a firm's PD organizational form, how 3D-CE is facilitated in product development, and product's characteristics.

Although the research question might be termed as *intermediate theory research*, the gap in the academic literature regarding product development practice places the present research in the theoretical continuum between the *nascent theory research* and the *intermediate theory research*. As a consequence, case study methodology represents an appropriate fit among the research questions, prior work, research design, and theoretical contribution (Edmondson and McManus, 2007; Yin, 2003; Voss et al., 2002).

8.1. Case study design

Citing the study of Nachmias and Nachmias (1992), Yin (2003) defines the case study design as *"a plan that guides the investigator in the process of collecting, analysing, and interpreting observations. It is a logical model of proof that allows the researcher to draw inferences concerning causal relations among the variables under investigation"*. Further, Yin (2003) refers to the research design as a logical plan for connecting the empirical data to the research question and the conclusions.

So, as the present research question conducts to produce provisional explanations of phenomena introducing novel constructs and proposing relationships between novel and established constructs (i.e., mapping constructs and building relationships), it has been considered appropriate to design the research including few, focused, in-depth and best-in-class case studies (Handfield and Melnyk, 1998). Further, within-case and cross-case analyses have been conducted to analyse qualitative data collected through in-depth and semi-structured interviews, and documents.

Sample design

As the present research aims to develop a provisional model to explain how firms facilitate 3D-CE practices in product development, it has been believed essential to select high performing organizations in the design of the research sample (i.e., best-in-class case studies). Further, as the design and the implementation of 3D-CE practices might be affected by company size and industry, it has been chosen to include in the sample firms employing similar product development teams in terms of size and operating in similar industries. The previous choice is coherent with the aim of investigating how 3D-CE is designed and implemented to fit the product development organizational form and the product characteristics avoiding the moderating effect of company size and industry. Finally, firms whose organizational structure gives the choice to adopt either a local or a global product development organization have been considered. These arguments lead to the selection of the criteria adopted to design the research sample:

- excellent financial performance over years,
- leader in the market segment in terms of market share and product performance,
- outstanding manufacturing and supply chain capabilities,
- experienced in executing product development activities,
- large or medium size,
- operating in the metal and electronic manufacturing industry (ISIC 25-28[1]).

Under the previous criteria, three high performing manufacturing companies have been selected to constitute the research sample. Such a sample is believed to be representative of how high performing companies with similar characteristics to the ones of the cases behave.

Within the research sample, the unit of analysis of each case is the development of a product come in market on time and within target. In addition, since the Product Innovativeness has been modelled as a control variable (*see the section "Research Question"*), it has been opted to investigate development processes in which designed products have similar degree of innovativeness.

Data collection

Data has been collected through interviews conducted in the three companies constituting the research sample. In detail, six in-depth and semi-structured interviews have been conducted. The respondents were the technical program manager (once) and the industrialization product manager (twice) in company *Alpha*, the project leader (twice), the mechanical designer (twice), and the project manager (once) in company *Beta*, and the project director (twice) and the operations director (twice) in company *Gamma*.

The in-depth and semi-structured interviews have been conducted on-site, recorded, and then transcribed in full-length to enhance data analysis effectiveness gaining from the information richness provided by an interview context. The duration of the interviews range from 3 hours to 4 hours.

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1 According to the Rev.4 of the International Standard Industrial Classification (ISIC), economic activities in the 25-28 range include: manufacture of fabricated metal products (except machinery and equipment), manufacture of computer, electronic and optical products, manufacture of electrical equipment, and manufacture of machinery and equipment.

Further, interviews have been conducted following a semi-structured blueprint. Although the blueprint has been generally observed during the interviews, the interview setting was enough flexible to allow debates on interesting topics arisen during the discussions.

In detail, the topics addressed during the interviews are as follows (*see the appendix "Interview Blueprint" for a whole overview of the semi-structured blueprint*):

- General information
  - Company overview
  - Respondent position and background overview
  - Product related information
  - Production processes related information
  - Supply chain related information
- Product development process (3D-CE perspective)
  - Product development process model
  - Product development process content
  - Product development process architecture
  - Product development process related performance (concerning the observed process)
  - Product related performance (concerning the observed product)
  - Manufacturing and supply chain related performance (concerning the observed product)
- Organization of product development resources
  - Organizational structure designed and implemented to execute the product development process
  - Organization of product design engineers, process engineers and supply chain professionals
- Strategic integration mechanisms (3D-CE perspective)
  - Product development strategy defining goals and area of strategic focus
- Technological integration mechanisms (3D-CE perspective)
  - Knowledge and skills
  - Software
- Organizational integration mechanisms (3D-CE perspective)
  - Standardization
  - Formalization
  - Direct supervision
  - Formal mutual adjustment
  - Informal mutual adjustment
  - Dedicated teams
- Challenges in integrating product development resources (3D-CE perspective)
  - Challenges in integrating product engineers, process engineers and supply chain professionals
  - Challenges in integrating co-located resources
  - Challenges in integrating global resources

In addition to the interviews, several documents including annual reports, internal reports, and workflows diagrams (e.g., Gantt diagram) have been analysed to collect detailed data and to triangulate information obtained during the interviews.

Data analysis

Eisenhardt (1989) states *"analysing data is the heart of building theory from case studies, but it is both the most difficult and the least codified part of the process"*. Data analysis consists of data reduction, data display and conclusions drawing and verification (Miles and Huberman, 1994). Further, a distinction is made between within-case data analysis and cross-case data analysis. In detail, within-case analysis allows to *"become intimately familiar with each case as a stand alone entity"*, whereas cross-case analysis *"force investigators to go beyond initial impressions, especially through the use of structured and diverse lenses on the data ... see evidence thru multiple lenses ... look for within-group similarities coupled with intergroup differences."* (Eisenhardt, 1989).

In the present research both within-case and cross-case analyses have been performed. First within-case analysis has been executed to draw insights out each case allowing in-depth understanding of cases patterns and context. Then, cross-case analysis has been executed looking for similarities and differences among the cases.

Data reduction

Voss et al. (2002) suggest that essential to effective case research is the coding of observations. In detail, it is crucial to reduce data into categories (Miles and Huberman, 1994). Indeed, coding observations into categories and comparing each observation with others in the same category allow the researcher to develop theoretical properties of categories and to analyse the dimensions of properties (Voss et al., 2002). In the present research data has been coded following the scheme suggested by Strauss and Corbin (1990).

Data display

Miles and Huberman (1994) refer to data display as a *"visual format that presents information systematically, so the user can draw valid conclusions and take needed action"*. Matrices and networks are the main categories of data displays. Matrices are defined as *"the crossing of two or more main dimensions or variables (often with sub variables) to see how they interact"*, whereas networks as *"a series of nodes connected by links ... that re-creates the plot of events over time, as well as showing the complex interaction of variables"* (Miles and Huberman, 1994).

In the present research data displays are used for both within-case and cross-case analysis to explore, describe and explain purposes. In detail, as the research aims to develop a provisional model, according to the study of Miles and Huberman (1994) both matrices and networks have been used to display data.

Quality design criteria

Construct validity, internal validity, external validity and reliability constitute the set of quality design criteria commonly used to establish the research quality.

Construct validity

Yin (2003) refers to *construct validity* as the research quality design criteria ensuring the establishment of appropriate operational measures for the theoretical concepts being researched. To enhance construct validity Riege (2003) suggests researchers *"to make efforts* *to refrain from subjective judgements during the periods of research design and data collection"*.

In the present research the construct validity is ensured through the use of multiple sources of evidence in the data collection enabling triangulation of interview tapes and documents (Flick, 1992), and the establishment of a chain of evidence in the data collection using verbatim interview transcripts.

Internal validity

Riege (2003) refers to *internal validity* as the research quality design criteria estimating *"the confidence with which inferences about real-life experiences can be made … demonstrating that the inquiry was carried out in a way which ensures credibility"*.

In the present research the internal validity of case studies is ensured through the use of within-case analysis and cross-case pattern matching (Miles and Huberman, 1994), the display of collected data to assist explanation building (Miles and Huberman, 1994), and the cross-check of the results to ensure internal coherence of findings (Yin, 2003).

External validity

Yin (2003) refers to the *external validity* as the research quality design criteria estimating *"whether a study's findings are generalizable beyond the immediate case study"*. In detail, while quantitative research aims at statistical generalisation, case studies rely on analytical generalisation, whereby particular findings are generalised to some broader theory (Reige, 2003).

In the present research the external validity is enhanced through the definition of the research scope, the design of the research sample, and the comparison of case studies evidence with the extant literature. In detail, as previously discussed, the research scope is limited to the metal and electronic manufacturing industry helping to achieve reasonable analytical generalisations within research boundaries. Further, the designed sample is believed to be representative of how high performing companies with similar characteristics to the ones of the cases behave enabling the generation of theory related to 3D Concurrent Engineering practices among high performers.

Reliability

Yin (2003) refers to *reliability* as the research quality design criteria ensuring that *"if a later investigator followed the same procedures as described by an earlier investigator and conducted the same case study all over again, the later investigator should arrive at the same findings and conclusions"*. Hence, a case study is reliable if the same findings and conclusions can be obtained by another researcher who conducts the case repeating the original procedures. Further, Yin (2003) suggests that tactics to ensure reliability are either the use of a *case study protocol* or the development of a *case study database*.

In the present research the reliability of case studies is ensured through a rigorous case study protocol including case objective, selection criteria, sample description, respondents overview, data collection method, data analysis techniques and interview blueprint. In addition, to enhance the reliability of case studies the data collection and the data analyses have been personally performed avoiding misunderstandings of findings.

8.2. Operationalization

In the next sections the operational measures adopted to operationalize the constituent elements of the research model are discussed.

Product Development process architecture measures

As discussed in the section *"Defining the product development process architecture"*, development activities and activities' interdependencies determine the process architecture (Browning and Eppinger, 2002). In detail, according to the study of Sanchez (2000), development activities are either tightly or loosely coupled determining respectively integral or modular product development process architectures (i.e., a system of tightly or loosely coupled development activities). Hence, the form (i.e., modular or integral) of the product development process architecture has been measured decomposing the process into its activities and assessing the level of activities' dependence. Pooled interdependency among development activities determines modular architectures. Whereas, sequential interdependency determines modular architectures if sequential activities are decoupled (i.e., activities are loosely coupled). Otherwise, if sequential activities are not decoupled (i.e., activities are tightly coupled), sequential interdependency determines integral architectures. Finally, reciprocal interdependency among development activities determines integral architectures.

Further, as the level of activities' dependence might differ considering development activities in charge of a single function rather than activities in charge of different functions, the form of the product development process architecture has been measured assessing the level of activities' dependence within product design activities and across product, process and supply chain design activities. For instance, the level of dependence among development activities in charge of product design might be dissimilar to the level of dependence among activities in charge of different functions (i.e., product design, process design and supply chain). As a consequence, the form of a product development process architecture might be modular considering product design activities, whereas integral considering dependences between product design activities and process or supply chain design activities.

Level of dependence among development activities

Product design activities	*Loosely coupled* *Modular architecture*	*Tightly coupled* *Integral architecture*	*Tightly coupled* *Integral architecture*
	Product design activities	Process design activities	Supply Chain design activities

Figure 19. Example of dependences among development activities and of process architectures forms.

Table 5 presents a summary of the measures adopted to assess the form of the product development process architecture.

Measures of the form of the product development process architecture
• The level of dependence (i.e., pooled, sequential and reciprocal) among product design activities (i.e., activities in charge of product engineers). • The level of dependence among development activities in charge of product engineers, process engineers and supply chain professionals.

Table 5. Measures of the form of the product development process architecture

Integration measures

As discussed in the chapter *"Concurrent engineering: a matter of integration"*, integration is a construct of communication and collaboration (Kahn, 1996). In detail, communication is the process by which information is transferred from one individual or a function to another, whereas collaboration is the process by which several individuals with different and complementary skills work together (Kahn and McDonough, 1997). Hence, integration consists in communication if development activities are carried out separately by individuals and functions interacting through information transfer. Otherwise, if development activities are carried out collectively by individuals and functions working side by side, integration consists in collaboration. As the difference between communication and collaboration is to be found in the collective transformation of information, integration has been measured decomposing the product development process into its activities and assessing the extent to which individuals and functional areas work side by side to execute joint development activities. In detail, it has been assessed the extent to which design engineers participated together in design activities as well as the extent to which process engineers and/or supply chain professionals worked side by side with design engineers on product, process and/or supply chain design activities. For instance, in the case that product engineers design a component (with or without prior information from process engineers) and then transfer information about the component to process engineers who accordingly design the production equipment, integration consists in communication. Indeed, product design and process design activities are carried out separately. On the contrary, in the case that product and process engineers collectively design the component along with the production equipment, integration consists in collaboration.

Table 6 presents a summary of the measures adopted to assess the extent to which integration consists in communication and/or collaboration.

Measures of integration
• The extent to which product design engineers participate together (i.e., work side by side) in product design activities (i.e., in the designing of several product modules or components). • The extent to which functions (i.e., product design, process design and supply chain) work together in development activities that traditionally were considered the preserve of a unique function.

Table 6. Measures of integration

Integration mechanisms measures

As discussed in the chapter *"Integration mechanisms"* strategic, technological and organizational mechanisms enable and facilitate integration among individuals and functions involved in the product development process.

In detail, the configuration of integration mechanisms (i.e., the set of integration mechanisms implemented by an organization) determines the extent to which strategic, technological and organizational mechanisms are capable of enabling communication and/or collaboration. Hence, in the present research a detailed look at the configuration of integration mechanisms has been taken observing the implemented mechanisms and assessing the capability of the configuration to enable communication and/or collaboration.

Strategic mechanisms

As discussed in the section *"Strategic mechanisms"*, unambiguously communicated strategies and common goals facilitate integration giving guidelines for decision making to individuals involved in the product development process.

In detail, a complementary perspective on strategies and goals across specialists along with an active use of strategies and goals in decision-making processes facilitate integration. For instance, whereas product engineers, process engineers and supply chain professionals execute development activities toward common goals, integration in product development is facilitated. Indeed, common goals might be seen as common decision drivers toward which product engineers, process engineers and supply chain professionals converge on trade off decisions. Hence, it has been measured the extent to which strategies and goals were complementary rather than contrasting across functions involved in the product development process (i.e., product design, process design and supply chain). Further, it has also been measured the extent to which strategies and goals drove trade-off decisions across product engineers, process engineers and supply chain professionals facilitating integration in the product development process.

Table 7 presents a summary of the measures adopted to assess the strategic mechanisms implemented to integrate individuals and functions.

Measures of integration by strategic mechanisms
• The extent to which strategies (e.g., markets and technologies the firm would focus on) are complementary rather than contrasting across individuals and functions.
• The extent to which goals (e.g., time objective, cost objective, percentage of sales to be generated in the next years) are complementary rather than contrasting across individuals and functions.
• The extent to which strategies and goals drive trade-off decisions across product design, process design and supply chain functions.

Table 7. Measures of integration by strategic mechanisms

Technological mechanisms

Humanware mechanisms such as technical knowledge, social skills and managerial skills facilitate integration enhancing the understanding across specialists of disciplines' perspectives, requirements and constraints. Whereas, software mechanisms facilitate integration regulating process workflows and allowing specialists to access, distribute, store and retrieve project information (e.g., product, parts, process information). In addition, within software mechanisms, group collaboration technologies such as QFD, FMEA and DfX lead specialists involved in the product development process to work together exchanging, processing and adapting information. Hence, it has been measured aspects related to technical knowledge, social skills, managerial skills, computer-aided software and group collaboration technologies.

Concerning knowledge and skills, distinctions have been made among technical, social and managerial aspects. With regards to technical knowledge, it has been measured the extent to which specialists (i.e., product engineers, process engineers and supply chain professionals) comprehend constraints related to development activities considered the preserve of other functions. Further, with regard to social skills, it has been assessed the extent to which specialists communicate and collaborate across functions. Finally, with regard to managerial skills, it has been evaluated the extent to which specialists select and achieve goals, take and share responsibilities, and monitor and correct development activities.

Whereas, concerning software mechanisms, distinctions have been made between computer-aided software and group collaboration technologies. With regards to computer-aided software, it has been measured the extent to which software (e.g., CAD, ACM, PDM, PLM, EDB, EDI) is used to facilitate integration. Further, with regard to group collaboration technologies, it has been assessed the extent to which groupware, online team spaces, discussion databases, QFD, FMEA and DfX are used to facilitate communication and/or collaboration among specialists.

Table 8 presents a summary of the measures adopted to assess the technological mechanisms implemented to integrate individuals and functions.

Measures of integration by technological mechanisms
• The extent to which technical knowledge enable specialists (i.e., product engineers, process engineers and supply chain professionals) to comprehend constraints related to development activities considered the preserve of other functions.
• The extent to which social skills enable specialists to communicate and collaborate across functions.
• The extent to which managerial skills enable specialists to select and achieve goals, to take and share responsibilities, and to monitor and correct development activities.
• The extent to which training is used to enhance technical, social and managerial knowledge and skills.
• The extent to which computer aided software (e.g., CAD, ACM, PDM, PLM, EDB, EDI) is used to facilitate integration.
• The extent to which collaboration technologies (e.g., groupware, online team spaces, discussion databases, QFD, FMEA, DfX) are used to facilitate integration.

Table 8. Measures of integration by technological mechanisms

Organizational mechanisms

As discussed in the section *"Organizational mechanisms"*, suitable organizational arrangements enable integration in product development processes. In the present research standardization, formalization, direct supervision, formal mutual adjustment, informal mutual adjustment and dedicated team integration mechanisms have been operationalized to determine the extent to which organizational arrangements are used to enable communication and collaboration across specialists involved in product development processes.

Standardization facilitates integration specifying in advance the content and/or the result of the work along with the knowledge required to perform development activities. Hence, it has been assessed the extent to which work processes, outputs and knowledge were standardized.

Formalization facilitates integration structuring in advance the content of the product development process, for instance, articulating roles and activities each specialist has to fulfil. Hence, it has been measured the extent to which organizational processes, procedures and instructions were codified and enforced.

Direct supervision facilitates integration ensuring a proper link among specialists involved in the product development process. Project leaders, defined as the *"linking pins"*, exert direct supervision in project planning and in decisions making by means of authority. Hence, to investigate direct supervision, it has been assessed how project leaders exert authority over projects. Further, the extent to which project leaders exerted authority in project planning and in decision making has been evaluated measuring the freedom of specialists in planning development activities and in making project decisions.

Formal mutual adjustment mechanisms facilitate integration ensuring the management of the interface among specialists involved in the product development process. For instance, liaison personnel and review meetings ensure the visibility of disciplines' requirements and constraints across functions assuring fit among product, manufacturing process and supply chain parameters. Hence, it has been assessed the extent to which organizations used liaison personnel and review meetings to enable and facilitate integration.

Informal mutual adjustment mechanisms facilitate integration providing specialists with the opportunity to form interpersonal relationships removing organizational barriers and promoting close collaboration in development activities. For instance, face-to-face meetings and co-location of resources bring together individuals from different functions allowing specialists to react directly to information received from others and, in turn, to collaborate closely. Hence, it has been assessed the extent to which organizations used face-to-face meetings and co-location of resources to enhance close collaboration.

Dedicated teams facilitate integration increasing technical information available from different disciplines to design products. Hence, it has been assessed the extent to which firms adopted organizational arrangements such as cross-functional teams, self-contained groups and transition teams to enhance integration.

Table 9 presents a summary of the measures adopted to assess the organizational mechanisms implemented to integrate individuals and functions.

Measures of integration by organizational mechanisms
• The extent to which work processes, outputs and knowledge are standardized. • The extent to which organizational processes, procedures and instructions are codified and enforced. • The extent to which specialists are independent in planning development activities and making project decisions. • The extent to which organizations use liaison personnel and review meetings. • The extent to which organizations use face-to-face meetings and co-location arrangement. • The extent to which organizations establish cross-functional teams, self-contained groups and transition teams.

Table 9. Measures of integration by organizational mechanisms

Product Development organizational form measures

As discussed in the section *"Emerging organizational forms of product development"*, viewing together the location and the ownership of specialists involved in the product development process allows to recognize different forms of organization (Eppinger and Chitkara, 2006). Hence, it has been assessed the location and the ownership of product engineers, process engineers and supply chain professionals involved in the product development process.

Table 10 presents a summary of the measures adopted to assess the form of the product development organization.

Measures of product development organizational form
• The location of product engineers, process engineers and supply chain professionals involved in the product development process. • The ownership of product engineers, process engineers and supply chain professionals involved in the product development process.

Table 10. Measures of product development organizational form

Product architecture measures

As discussed in the section *"Elements constituting the research model"*, the system of product functional components and components' interdependencies determine the product architecture (Voordijk et al., 2006; Fixson, 2005; Fine, 1998; Ulrich, 1995).

In detail, functional components are either tightly or loosely coupled determining respectively integral or modular product architectures (i.e., a system of tightly or loosely coupled functional components). Hence, the form (i.e., modular or integral) of the product architecture has been measured decomposing the product into its functional components and assessing the level of components' dependence. Interchangeable, autonomous, and individually upgradeable functional components characterized by standard interfaces (i.e., loosely coupled components) determine modular architecture. On the contrary, interdependent components (i.e., tightly coupled components) determine integral architecture, in which a change in a component requires changes in other components for a correct functioning of the product. Table 11 presents a summary of the measures adopted to assess product architecture.

Measures of the product architecture
• The extent to which product functional components are interchangeable, autonomous, and individually upgradeable (i.e., the extent to which functional components are either loosely or tightly coupled).
• The extent to which components interfaces are standardized.

Table 11. Measures of the product architecture

Product innovativeness measures

As discussed in the section *"Elements constituting the research model"*, product innovativeness refers to the degree of discontinuity in marketing and/or technological processes (Goldenberg et al. 1999; Kessler and Chakrabarti, 1999). Building on the study of Goldenberg et al. (1999), Garcia and Calantone (2002) propose an operationalization of product innovativeness based on a macro/micro discontinuity and a marketing/technological discontinuity. In detail, macro and micro discontinuities refer to product innovations identified respectively as new to the industry or to the market or new to the company or to the customer. Whereas, marketing and technological discontinuities refer to product innovations requiring respectively a new marketplace to evolve or a shift in the state of technology embedded in the product. Viewing together the dimensions of discontinuity (i.e., macro vs. micro and marketing vs. technological), Garcia and Calantone (2002) provide a typology for classifying innovation envisioning three types of product innovativeness: radical, really new, and incremental (*see section "Product innovativeness"*).

According to the study of Garcia and Calantone (2002), in the present research product innovativeness has been assessed whether the product innovation concerns a macro and/or micro discontinuity or a marketing and/or technological discontinuity. Hence, it has been measured the extent to which the product is perceived new to the industry or to the market and to the company or to the customer along with the extent to which the product required a new marketplace to evolve and a shift in the embedded technologies.

Table 12 presents a summary of the measures adopted to assess the product innovativeness.

Measures of the product innovativeness
• The extent to which the product is perceived new to the industry.
• The extent to which the product is perceived new to the company.
• The extent to which the product is perceived new to the market.
• The extent to which the product is perceived new to the customer.
• The extent to which the product required a new marketplace to evolve.
• The extent to which the product required a shift in the state of embedded technologies.

Table 12. Measures of the product innovativeness

8.3. Case study format

The format in which case studies will be presented consists of a case study introduction section, followed by a case study description and within-case analysis section. In the present chapter the content of each section is examined.

Case study introduction

In the introduction section, general information will be provided about the company, the interviewees and the products. Further, an overview of the production process, the supply chain, and the innovation process will be given with the aim of providing insights on the context in which each company operates.

Case study description and within-case analysis

In the case study description and within-case analysis section, descriptions of the designed product, the product development organization, the product development process, the integration process, and the integration mechanisms will be provided. Further, the aforesaid descriptions will give insights into the elements constituting the conceptual model and enable the analysis on how each element was designed within a specific case.

In detail, the description of the designed product will provide insights on the mapping from product functions to components and the level of components dependence leading to analyse the architecture of the product. The description of the organization in charge of designing the product will provide insights on the location and the ownership of product, process and supply chain specialists leading to analyse the form of the product development organization. The description of the product development process will provide insights on activities' dependence within product design and across product, process and supply chain design leading to analyse how the process architecture was designed within a specific case. The description of the integration process will provide insights on the extent to which specialists executed design activities separately instead of collectively leading to analyse whether the integration process was constituted of communication or of collaboration. Finally, the description of the integration mechanisms will provide insights on the strategic, technological, and organizational mechanisms leading to analyse how integration mechanisms was configured within a specific case.

9. *Company Alpha CASE STUDY AND WITHIN-CASE ANALYSIS*

9.1. Introduction

Company profile

Company *Alpha* is one of the world's largest semiconductor companies with net revenues of US$ 10.35 billion in 2010 and US$ 2.44 billion in Q3 2011. Offering one of the industry's broadest product portfolios, company *Alpha* serves customers across the spectrum of electronics applications with innovative semiconductor solutions by leveraging its vast array of technologies, design expertise and combination of intellectual property portfolio, strategic partnerships and manufacturing strength.

The Company has particular strengths in Multimedia, Power, Connectivity and Sensing technologies and its sales re well balanced among the industry's major sectors: Telecom (28%), Automotive (17%), Consumer (10%), Computer (14%), Industrial (9%) and Distribution (22%). Company *Alpha* is among the world leaders in many different fields, including semiconductors for industrial applications, inkjet printheads, MEMS (Micro-Electro-Mechanical Systems) for portable and consumer devices, MPEG decoders and smartcard chips, automotive integrated circuits, computer peripherals and wireless. Company *Alpha* serves its customers with five main blocks of products, namely: power devices; MEMS and advanced analog ICs; microcontrollers; ASICs / ASSPs; platforms for digital consumer applications and for wireless.

Company *Alpha* was created in 1987 by the merger of two long-established semiconductor companies based in Italy and in France, and has been publicly traded since 1994. The group has approximately 53,000 employees, 12 main manufacturing sites, advanced research and development centers in 10 countries, and sales offices all around the world.

Since its creation, Company *Alpha* has maintained an unwavering commitment to R&D. Almost one quarter of its employees work in R&D and product design and in 2010 the Company spent almost 23% of its revenue in R&D. Among the industry's most innovative companies, Company *Alpha* owns around 20,000 patents and pending patent applications. The Company draws on a rich pool of chip fabrication technologies, including advanced CMOS (Complementary Metal Oxide Semiconductor), mixed-signal, analog and power processes, and is a partner in the International Semiconductor Development Alliance (ISDA) for the development of next-generation CMOS technologies.

To provide its customers with an independent, secure and cost-effective manufacturing machine, company *Alpha* operates a worldwide network of front-end (wafer fabrication) and back-end (assembly and test and packaging) plants. Company *Alpha*'s principal wafer plants are presently located in Agrate Brianza and Catania (Italy), Crolles, Rousset and Tours (France), and in Singapore. The wafer plants are complemented by world-class assembly-and-test facilities located in China, Malaysia, Malta, Morocco, Philippines and Singapore.

Interviewees' profile

In company *Alpha*, the technical program manager (twice) and the industrialization program manager (twice) were interviewed.

The technical program manager belongs to the technical department of the BCD power division. He is involved as project leader in planning and monitoring activities related to the development and the evaluation of BCD integrated circuits. Previously, he worked in the technical department as design engineer.

The industrialization program manager belongs to the product management department of the BCD power division. She is involved as project leader in monitoring activities related to the prototype delivery, the qualification and the production rump up of BCD integrated circuits. Previously, she worked in the R&D department as process engineer in the CVD (chemical vapour deposition) treatment of silicon.

Product technology overview

Company *Alpha* offers a wide range of discrete and smart power products and has a solid worldwide leadership position in this field. It is one of the world's leading suppliers of discrete power devices with a product range including power transistors, EMI filtering and signal conditioning, diodes, protection devices, thyristors and AC switches.

Company *Alpha* offers two families of smart power technologies: VIPower is a family of proprietary *Alpha* technologies in which a discrete power structure is integrated with analogical and digital control and diagnostic circuitry, resulting in a device that combines the robustness of discrete technology with integrated control and diagnostic circuitry. The second is *Alpha*'s BCD technology combines bipolar, CMOS and DMOS processes, allowing additional system functions, such as voltage regulators, communication interfaces, as well as multiple-load drivers, to be integrated along with logic circuitry in a single device.

Product overview

BCD Power Devices are standard devices widening the field of application for system oriented technologies. Typical examples include switching regulator for hard disk drives, lamp drivers for automotive applications and motor drivers of various types.

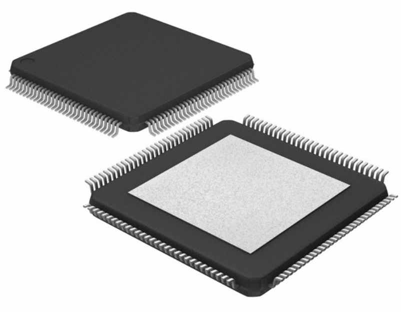

Figure 20. BCD Power Device.

Production process overview

The power device production process comprises 4 stages: the fabrication, the enhanced voltage stress test, the packaging and the final test.

The fabrication stage consists of a sequence of deposition and lithography processing steps during which the integrated circuits are fabricated on an 8-inch silicon disc called wafer. In order to produce power devices, the wafer goes through the deposition and the lithography cycle from 30 to 40 times. During the deposition steps, chemical vapor deposition technology (CVD) is used to depose materials such as metals and dielectrics on the wafer. Whereas, during the lithography steps, photolithography technology is used to selectively remove parts of the deposed material from the wafer. Through photolithography, the wafer is coated with a chemical called photoresist. The photoresist is exposed to short wavelength light by a stepper, a machine that aligns and moves a mask. Exposing selected portions of the wafer, photolithography transfers a geometric pattern from the mask to the wafer. The unexposed portions of the wafer are etched by a developer solution removing the deposed material that is not protected by the photoresist.

Once the fabrication process is completed, the wafer is subjected to the enhanced voltage stress test (EWS) to determine electric specifications and to verify whether the integrated circuits reflect customer's requirements.

Passed the EWS tests, the wafer, on which there are about 2.500 integrated circuits, is sawed into an individual die. Dies are then picked and let into the packaging process. Plastic packaging involves assembling the die onto the link frame, connecting the die pads to the pins on the package, and sealing the die.

Once the packaging process is completed, power devices are subjected to the final test to verify whether electric specifications have not been altered by the package and to determine whether the die-to-pin operation has been performed correctly.

Passed the final test, the power devices are ready to be supplied to customers' production plants.

Supply chain overview

In order to provide BCD Power Devices customers with an independent, secure and cost-effective manufacturing machine, Company *Alpha* operates a worldwide network of fabrication, EWS and packaging plants.

Worldwide manufacturers of silicon supply wafers to company *Alpha* and subcontractors production plants of BCD Power Devices. The fabrication of power devices is assigned to two *Alpha* production plants located in Italy and to two subcontractors located respectively in Germany and in France.

Production plants supply integrated circuits to EWS plants. The EWS test is performed in two *Alpha* production plants provided with EWS equipment located respectively in Italy and in Singapore.

EWS plants supply EWS tested integrated circuits to packaging plants. The packaging is assigned to two *Alpha* packaging plants located respectively in Philippines and in Malaysia and to two subcontractors located respectively in Singapore and in Taiwan.

Packaging plants supply power device to final test plants. The final test is assigned to two equipped *Alpha* packaging plants located respectively in Philippines and in Malaysia and to one subcontractor located in Singapore.

The power devices are then supplied to customers' production plants located in Thailand and in Malaysia.

Figure 21. BCD Power Device plants.

Innovation process overview

The radical innovation process leading to the development of a new technological knot starts on average every 5 years. The development of a new technological knot takes on average 5 years during which the Technical Research & Development Team designs the components of new generation power devices. Released the libraries of components, the development of a new generation power device takes on average 3 years from the receipt of the customer request for quotation to the production rump up. About ten distinct new generation devices are concurrently developed starting from the same libraries of components.

Manufactured the new generation devices, incremental innovation processes lead to improve power devices performance and/or to reduce power devices production costs. The development of a higher performing power device takes on average 2 years from the receipt of the customer request for quotation to the production rump up.

Innovation processes are evaluated on the capacity to complete a specific project on time, within budget and according to the product quality and reliability standard.

9.2. Case study and within-case analysis

The unit of analysis

The case study is based on the development of a BCD Power Device starting from a new technological knot.

The developed BCD Power Device provided improvements to the existing technology in the existing market refining existing product, production and supply chain systems. Hence, as the innovation caused marketing and technological discontinuity at the company and at the customer level, the developed BCD Power Device represented an incremental innovation.

The power device

The BCD Power Device is an integrated circuits powering and controlling the read-write head and the disk of hard disk drives.

The power device comprises standard blocks (e.g., the spindle motor block, the voice coil motor block - VCM -, the dual-stage actuator block - DSA -). Each block fulfils a specific function of the power device. Blocks are individually upgradable and characterized by a low level of dependence. Interfaces among blocks are defined in advance in standard specifications. As such, a specific block might be comprised in power devices designed to meet distinct technical requirements.

Each block of the power device is obtained combining standard components (e.g., CMOS components, DMOS components) selected from the libraries developed by the Techncial Research & Development Team.

As power devices include one-to-one mapping from product functions to blocks and blocks are individually upgradable and characterized by low level of dependence and standard interfaces, the product architecture is modular.

The power device development organization

The power device development organization comprised resources fully owned by company *Alpha* organization and drawn from multiple functions and different countries. Although the development team included resources belonging to the marketing, research and development, production engineering, operation, quality and reliability, and testing departments, the focus is on the organization of product engineers, process engineers and supply chain professionals.

Product engineers, in charge of the design of power device's blocks, belonged to the research and development department and were located in Italy and in Singapore. In detail, 10% of the engineers were based in Italy and 90% in Singapore. The technical program manager, responsible for the planning and the monitoring of design activities, was based in Italy.

Process engineers, in charge of the design of fabrication and packaging processes, belonged to the operation department and were located in Italy and in France. In detail, front-end process engineers responsible for the development of the fabrication process were located in Italy, whereas back-end process engineers responsible for the development of the packaging process were located in France.

Supply chain professionals, in charge of the design of front-end and back-end power device supply chain, belonged to the operation department and were located in Italy.

The industrialization program manager, responsible for the planning and the monitoring of production rump up activities, was based in Italy.

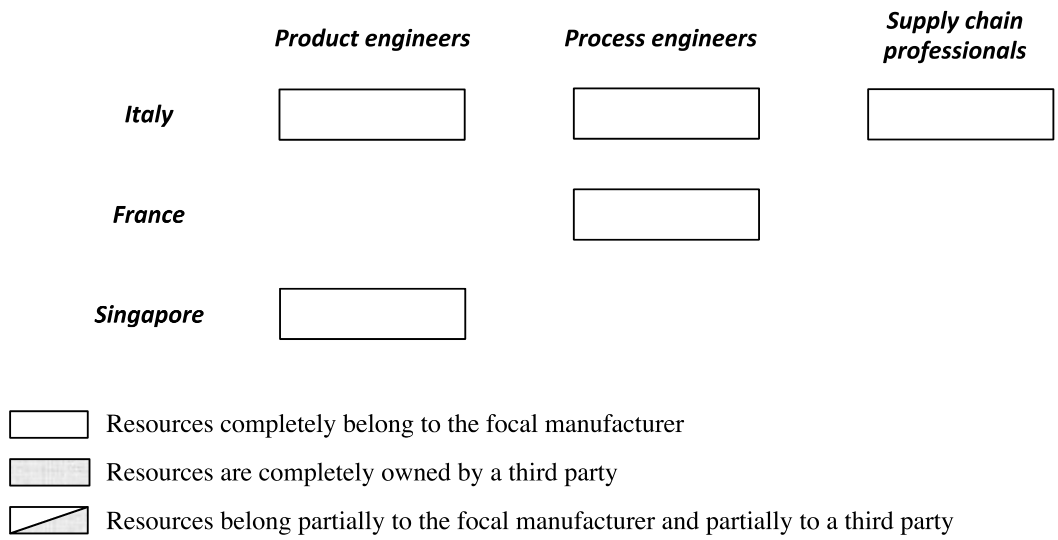

Figure 22. BCD Power Device: the product development organization.

As product engineers, process engineers and supply chain professionals belonged to company *Alpha* and were located offshore, the power device product development organizational form is global captive.

The power device development process

In radical innovation projects the technological knot development process precedes the product development process.

In the technological knot development process, technical R&D engineers design libraries of components and process engineers design front-end production processes (i.e., fabrication process). Technical R&D engineers design components of the technological knot and characterize interfaces among components. Concurrently front-end process engineers design the fabrication process. Designed the fabrication process, standard components are produced on wafers and tested. Passed the tests, standard components are released in the technological knot libraries.

Since technical R&D engineers release the libraries of components, the power device is developable. The product development process is organized according to the stage-gate model. It includes five stages: specification definition phase, design phase, prototype phase, qualification phase, and production phase; and three gates: design start (Gate 1), device full in specification (Gate 2), and start production (Gate 3).

Each gate is associated with a specific internal document. The *design start* gate is associated with the new product request (NPR) document, the *device full in specification* gate with the design approval certificate (DAC), and the *start production* gate with the product quality certificate (PQR).

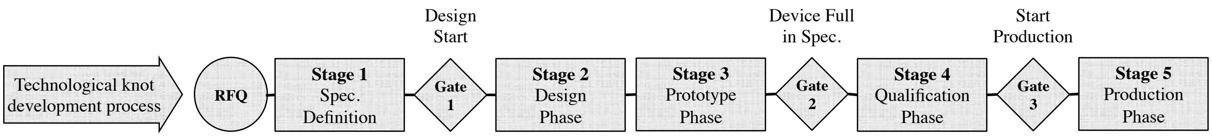

Figure 23. BCD Power Device development process.

Although stages are represented in a sequential view in figure 23, development activities and even stages overlap.

Request for quotation

The power device development process started with the customer request for quotation (RFQ). The RFQ included a list of product features and requirements on which the product development team estimated technical and financial feasibility. The receipt of the RFQ initiated stage 1.

Stage 1 - Specification definition phase

The specification definition phase consisted in assessing device technical requirements and in estimating costs and times to develop the integrated circuit. If company *Alpha* got the customer design award, stage 1 would result in the new product request (NPR) document, including product and project definition. Concerning the product definition, the NPR included: definition of the target market, specification of the product positioning strategy, and definition of product concept, features and specifications (e.g., technical, pin out, and packaging specifications). Whereas, concerning the project definition, the NPR included: definition of the project plan (e.g., definition of project milestones and project schedule, identification of project resources), and estimation of project execution time and costs.

Approved the NPR document, the design start gate was opened and the power device development process would go on with stage 2.

Stage 2 - Design phase

The design phase consisted in designing the power device to get full specifications and in developing the masks to fabricate integrated circuits on wafers.

The technical program manager decomposed the design phase into development activities and defined the activities schedule. Among development activities, product development activities aimed at designing the power device, whereas masks development activities aimed at designing fabrication masks. Concerning product development activities, each activity aimed at designing a block of the power device and was assigned to a product engineer. The product engineer was in charge of developing the drawings of the block and simulating the functioning. As interfaces among blocks were defined in advance in standard specifications, product development activities were characterized by a low level of dependence. However, as several blocks had a certain level of interdependency, product development activities related to those blocks were characterized by a higher level of dependence. The technical program manager assigned product development activities to product engineers according to the level of interdependency: independent product development activities were assigned to product engineers based either in Italy or in Singapore, whereas interdependent product development activities were assigned to product engineers based in the same office to avoid problems arising from resources dispersion. Concerning masks development activities, each activity aimed at designing a set of masks and at sequencing the masks to determine the order of the lithography steps in the fabrication process. Layout engineers were in charge of designing and sequencing the masks combining the drawings of blocks. The drawings and the sequence of masks were then released to the operation department. Supplied the masks to the fabrication plants, power device full in specification samples were produced to be tested.

Concurrently to the design of blocks and masks, production processes and supply chain were designed. The industrialization program manager decomposed the design of production processes and supply chain into design activities and defined the activities schedule. Front-end process engineers were in charge of refining the fabrication process designed in the technological knot development process, back-end process engineers were in charge of designing the packaging process, and supply chain professionals were in charge of designing the power device supply chain determining the make or buy strategy, the plant-product assignment, and the capacity of production and packaging plants. Process design activities were characterized by a low level of dependence with product and masks design activities as production processes specifications were defined in advance in the technological knot development process. Similarly, supply chain design activities were characterized by a low level of dependence with product and masks design activities as product materials and production technologies (i.e., development activities outputs influencing power device supply chain) were defined in advance in the NPR document.

Stage 3 - Prototype phase

The prototype phase consisted in designing the power device test program. Concurrently to product and masks development activities, prototype activities aimed at developing the test program including the device functionality evaluation, the bench evaluation, and the drive evaluation. Stage 3 resulted in the design approval certificate (DAC) including product specifications and test program definition. Concerning product specifications, the DAC included: full technical specifications of the power device and full technical specifications of the fabrication masks. Whereas, concerning test program definition, the DAC included: definition of the device functionality evaluation, of the bench evaluation, of the drive evaluation, and of the test program.

Approved the DAC, the device full in specification gate was opened and the product development process would go on with stage 4.

Stage 4 - Qualification phase

The qualification phase consisted in verifying power device functionality and reliability. Quality and reliability engineers performed functionality evaluation, bench evaluation, drive evaluation, test program, parameters analysis, reliability test, and yielded analysis on power devices. If quality and reliability tests passed, stage 4 would results in the product qualification certificate (PQC) including product quality and reliability performance.

Approved the PQC, the device full in specification gate was opened and the product development process would go on with stage 4.

Stage 5 - Production phase

The production phase consisted in ramping up the production of the designed power device. The power device was manufactured and monitored to meet corporate standard and was available through regular standard commercial system.

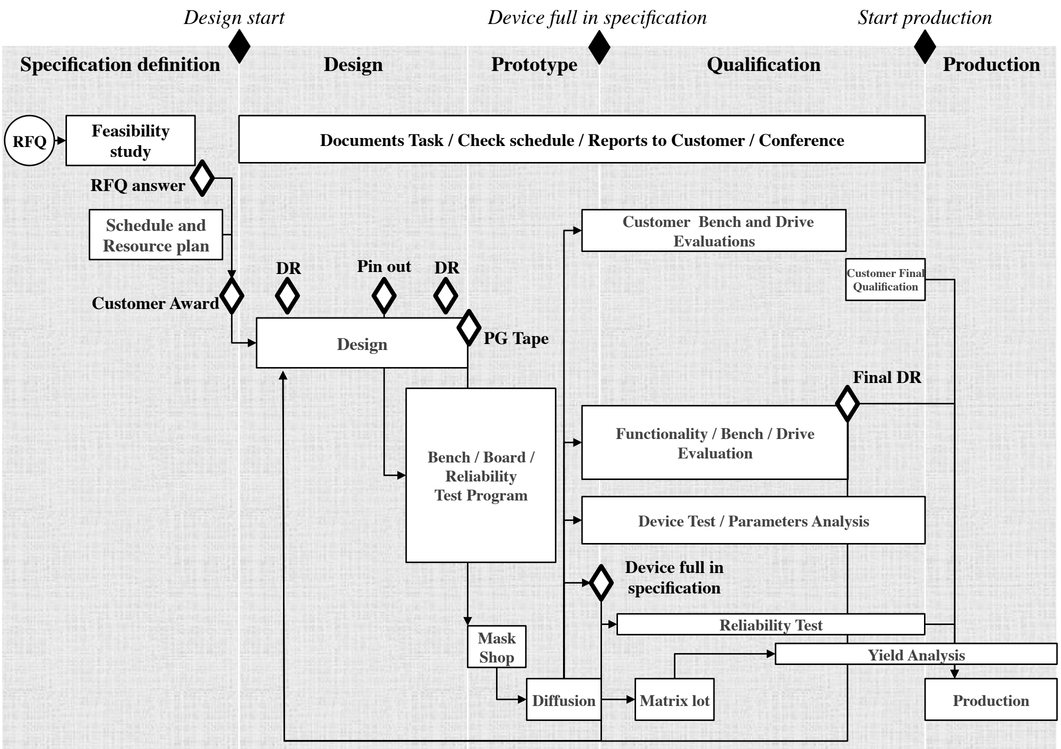

Figure 24. Main activities in the development of the BCD Power Device.

The power device development process architecture

Assessing the level of activities dependence within product design activities and across product, process and supply chain design activities in the design phase, the form of the product development process architecture appears modular. In fact, as product and masks development activities were characterized by a low level of dependence, the product development process architecture was modular within development activities. Similarly, as production process and supply chain design activities were characterized by a low level of dependence with product and masks development activities, the product development process architecture was modular across product, process and supply chain design activities.

Level of dependence among development activities

Product design activities	*Loosely coupled* *Modular architecture*	*Loosely coupled* *Modular architecture*	*Loosely coupled* *Modular architecture*
	Product design activities	Process design activities	Supply Chain design activities

Figure 25. BCD Power Device: the product development process architecture.

Integration in the power device development process

Product engineers did not participate together in development activities. Indeed, each development activity was assigned to a product engineer who was responsible for designing the drawings of a specific block of the power device.

Similarly, process engineers and supply chain professionals did not work side by side with product engineers. Product, process and supply chain development activities were carried out separately as the required outputs of each activity was defined in standard specifications in the form of design rules and standard documentations (e.g., the NPR document, the DAC certificate).

Hence, integration in the power device development process consisted in communication as development activities were carried out separately by individuals and functions interacting through information transfer.

Integration mechanisms adopted in the power device development process

Strategic integration mechanisms

A complementary perspective on product development strategies and goals across product development resources was ensured through the NPR document presented in a plenary meeting at the beginning of the project.

The NPR document set project goals and made them clear and shared to everyone involved in the product development process. In detail, the NPR document defined: target market, product positioning strategy, product concept, features, and specifications, project plan, target cost, and time-to-market.

Product and project goals specified in the NPR document enhanced integration across resources involved in the product development acting as common drivers toward which product engineers, process engineers and supply chain professionals converged on trade off decisions.

Technological integration mechanisms

Humanware

Product engineers, process engineers and testing engineers had similar theoretical background (e.g., electronics engineering, physics) enhancing the ability to comprehend constraints related to development activities considered the preserve of other functions. Further, multifunctional trainings on-the-job (e.g., working in more than one function) were regularly organized to let individuals understand goals perspectives, and priorities of other functions reducing the misunderstanding due to differences in thoughts.

Product development team members established collaborative personal relationships enhancing cross-functional integration, building interpersonal trust, and supporting the exchange of technical knowledge across functions. Further, training on European and Asian cultural values and behaviours were regularly organized to let individuals from different countries understanding each other.

Resources involved in the power device development process were responsible for their own development activities. Product engineers, process engineers and supply chain professionals estimated the time to complete each development activity, took responsibilities on activities timeline, and monitored and corrected their own activities.

Software

Core communication technologies, including e-mails, teleconferences, and videoconferences, were regularly adopted across the resources involved in the product development process to discuss on power device development issues.

Enterprise communication technologies were adopted to support product engineers in designing power device, so as to formalize the power device development process workflow giving project management release control over project gates, and to allow resources involved in the product development to access, distribute, store and retrieve information concerning products, production processes, and plants. In detail, designing and simulation software were adopted to support product engineers and test engineers in developing devices and test programs. Project management software was adopted to develop project plan, to assign resources to tasks, to track project progress, to manage the budget and to analyse resources workload. Customized software was adopted to formalize the power device development process workflow storing information related to the NPR, the DAC, and the PQR documents and to give project management release control over the design start, the device full in specification, and the start production gates. Company databases were used to store project documentations (e.g., technical drawings, NPR document, DAC certificate, PQR certificate, meeting minutes).

Concerning group collaboration technologies, the failure mode and effects analysis (FMEA) were executed on the design, the fabrication and the packaging processes. However, specialists did not work together in developing FMEA: product engineers worked on the design process FMEA, front-end process engineers worked on the fabrication process FMEA, and back-end process engineers worked on the packaging process FMEA.

Organizational integration mechanisms

Standardization

Product development workflows and development activities outputs were specified in standard procedures and documents. Content of activities was specified in the project plan produced in the specification definition stage of the product development process. Similarly, outputs of activities were specified in the NPR document.

A standard project reporting workflow was adopted to provide visibility of the project status to the product development team by a tight monitoring of project base line, of resources allocation and workload, and of design change notification.

Formalization

A program management formal procedure was adopted to pursue customer satisfaction by planning, organizing, directing and controlling the company resources in order to complete the project on time, within the budget and according to the company quality standard.

The project plan, including a detailed schedule of activities and articulating specialists roles and responsibilities, was set up as the product development started and regularly reviewed as development activities evolved. It constituted the synthesis of the work requirements needed to have the project finalized within a given timing schedule and according to fixed targets.

Project milestones were aimed at discussing about the most critical project issues and approving product, process, test and supply chain design proposals. Once approved and signed, project milestones provided an efficient method for generating project report and for leaving project traceability.

Direct Supervision

The technical and the industrialization program managers coordinated and integrated activities across multiple functional lines within the policies, the procedures and the directives of the organization. Program managers exerted direct supervision in decision-making, having a significant responsibility on critical and trade-off decisions, and in project planning, scheduling and monitoring development activities.

Formal mutual adjustment

Design review meetings were held weekly with the aim of monitoring the development activities status and discussing on design issues. Product development resources involved in design review meetings were product engineers and layout engineers. The technical program manger organized, coordinated, and validated design review meetings collecting technical documentation of the project.

Test review meetings were held weekly to coordinate product development activities with test program development activities in order to ensure an acceptable fit between the product design and the test program. Product development resources involved in test review meetings were product engineers and testing engineers.

Core review meetings were held weekly with the aim of monitoring the progress of the project and identifying and solving critical issues. Core review meetings aimed at ensuring an acceptable fit among product, process and supply chain parameters integrating distinct knowledge and experience into design, prototype, qualification and manufacturing activities.

The technical program manager coordinated core review meetings in the design phase, whereas the industrialization program manager coordinated the meetings from the prototype phase to the production phase.

Dedicated teams

The product development team was a cross-functional team including resources belonging to the marketing, research and development, production engineering, operation, quality and reliability, and testing departments.

Integration mechanisms		
Strategic	Strategic	Complementary perspective on product development strategies and goals. Clear and shared project and product goals.
Technological	Humanware	Electronics and physics technical background. Personal attitudes towards cross-functional integration. Personal attitudes in taking responsibilities on activities. Multifunctional and multicultural training.
	Software	Basic technologies (e.g., e-mail, teleconferences). Designing and simulation software. Project management software. Project documentation databases. Failure mode and effects analysis (FMEA).
Organizational	Standardization	Standard product development workflows. Standard product development activities outputs.
	Formalization	Formal program management procedures. Detailed project plan. Project milestones.
	Direct supervision	Program managers exerting direct supervision in project planning and in decision-making.
	Formal mutual adjustment	Design review meetings. Test review meetings. Core review meetings.
	Dedicated teams	Cross-functional team.

Table 13. Integration mechanisms in the power device development process.

10. Company Beta CASE STUDY AND WITHIN-CASE ANALYSIS

10.1. Introduction

Company profile

Company *Beta* is a world leader in the manufacturing of flow-pack packaging systems with turnover of EU€ 46 millions in 2010.

Offering complete solutions for medium and high-speed lines capable to manage every kind of product typology starting from the last processing station to the overwrapping equipment, company *Beta* serves customers across the food industry (90%), the pharmaceutical industry and the cosmetic industry (10%). Particularly, it offers standard or customized solutions in the following branches: monotype and assorted industrial patisserie, biscuits, breakfast products and confectionery, sweet and salted snacks, coffee capsules for automatic and semiautomatic machines, fresh and frozen food, drugs, medical devices, cosmetics, products for personal and housing hygiene.

Company *Beta* was created in 1960. For many years the company has been developing flow-pack packaging technology for the Italian market in the food and pharmaceutical industries. Progressively the range of solutions has been expanding to upstream and downstream steps for flow-packer. The opening of a manufacturing plant in Brazil and commercial offices abroad, the foundation of a robotic division and the acquisition of an Italian brand represent the milestones of an international group capable to manage the entire packaging process with highly customized solutions. The group has approximately 300 employees, of which 70 work in the R&D department, 3 operating plants (2 in Italy and 1 in Brazil), 1 foreign distributor, and 42 agencies covering 58 countries in Europe, North and South America, Asia, Australia and Africa.

The Italian operating plants concentrate technical and production skills in the major application sectors (e.g., bakery, confectionery, fresh food, and cosmetic), including the specific fields of accumulation, conveying and orientation lines for bakery, fresh products, and frozen food. The Brazilian plants operates in the manufacturing, commercialization and technical assistance for flow-pack entry level packaging systems and acts in the development of flow-wrapping solutions and of automatic lines with loaders of latest generation.

The expertise in manufacturing flow-pack wrapping machinery, automated loaders, conveyor systems, air insertion systems and secondary packaging solutions allowed the group to become a reference partner of important multinational corporations. Sales abroad exceed the 80% of consolidated turnover.

To regularly face up to the technological challenge, the 3% of the company turnover is annually re-invested in R&D. The 25% of employees contributes to innovation producing 90 system patent registrations. The innovation efforts are directed to the packaging of fresh and frozen food, the engineering based on sanitary design international standards, and the compatibility of the systems with polymeric and cellulosic packaging materials of the latest generation, produced with renewable resources.

Interviewees' profile

In company *Beta*, the project leader (twice), the mechanical designer (twice), and the project manager (once) were interviewed.

The project leader belongs to the R&D department. He is involved as project leader in coordinating product development projects across functions and plants managing the interface among design, manufacturing, supply chain and marketing specialists.

The mechanical designer belongs to the R&D department. He is responsible for product standardization. He is involved in product development projects designing flow-pack packaging modules and components according to standard specifications.

The project manager belongs to the project management department. She is involved in planning and monitoring design activities related to the development of flow-pack packaging systems.

Product overview

Flow-pack packaging systems are standard or customized solutions for the packaging process, starting from processing lines up to the overwrapping of products with different forms and characteristics, special packaging and packaging materials, and a wide range of opening and re-closing solutions for wrapping and overwrapping applications.

Technical solutions for the packaging process include pre-packaging, packaging, and secondary packaging modules. Pre-packaging modules include accumulation and buffering systems, distribution and feeding devices, and vertical and horizontal automatic loaders. Whereas, packaging modules include horizontal flow wrappers and secondary packaging modules include multi axis manipulators.

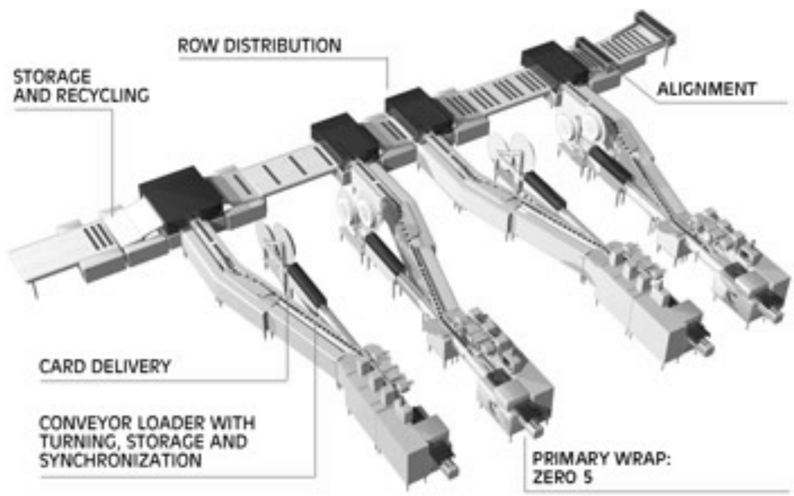

Figure 26. Flow-pack packaging system.

The processing line (i.e., the production line) is the interface of flow-pack packaging systems. Products coming out from the processing lines are stored in accumulation and buffering modules operating in FIFO mode. Products are then ordered in lines and rows on distribution and feeding systems (e.g., loading conveyors with continuous or intermittent motion) feeding one or more wrapping lines. Optional feeding devices form packs containing one or more products (e.g., one on top of the other, side by side, one behind the other, or combinations of these, with or without card). Distribution and feeding systems are connected to automatic loaders feeding flow wrappers or to product recycle station. Finally, flow wrappers package the products for sale.

Production process overview

The power device production process comprises 5 stages: the fabrication, the pre-assembly, the pre-test, the system assembly, and the test run.

The fabrication stage consists of a sequence of mechanical processing steps during which mechanical components are fabricated.

Once the fabrication of mechanical parts is completed, manufactured and supplied components are assembled to realize every modules of the flow-pack packaging system (e.g., the accumulation and buffering module, the distribution module, the automatic loader module, and the flow wrapper module).

Pre-assembled modules are subject to stand-alone functioning pre-test aimed at verifying whether a specific module operates correctly.

Passed the pre-test, modules are assembled, supplied accessories (e.g., weighing system, metal-detector system) are integrated in modules, and electric cables are wired to realize the complete flow-pack packaging system.

Once the system assembly is completed, the flow-pack packaging system is subjected to the test run. The test run is composed of two phases: the vacuum test and the final test. In the vacuum test, the system is tried out without any products to verify whether it operates correctly. Whereas, in the final test, the system is tried out with products to verify whether it reflects customers’ requirements.

Passed the test run, the flow-pack packaging system is ready to be supplied to customers’ production plants.

Supply chain overview

In order to provide customers with the widest range of flow-pack solutions and assistance, company *Beta* operates a worldwide network of operating plants, parts distributors and commercial agencies.

Worldwide manufacturers supply mechanical parts and system accessories (e.g., weighing system, metal-detector system) to company *Beta* operating plants located in Italy and in Brazil. Each operating plant is capable to manage the complete production process from the fabrication stage to the test-run. The machine tool departments, divided in three sub-departments different for working typology, are equipped with milling cutters and working centres, turning and grinding machines. Whereas, the assembly departments are equipped to pre-assembly the modules, to assembly the complete system, and to perform the pre-test and the test run.

In detail, the operating holding plant is based in Prato Sesia (Italy); the operating plant specialized in the fields of accumulation, conveying and orientation lines for bakery, fresh products, and frozen food is based in Torino (Italy); and the operating plant specialized in the manufacturing, commercialization and technical assistance for flow-pack entry level packaging systems is based in Sao Paulo (Brazil).

Company *Beta* supply chain network includes a part distributor based in Atlanta (US) to assures assistance to North America customers and 42 commercial agencies covering 58 countries in Europe, North and South America, Asia, Australia and Africa.

Figure 27. Flow-pack packaging system plants and distributors.

Innovation process overview

As the core of the flow-pack packaging system is the packaging module (i.e., the flow wrapper module), radical innovation processes essentially lead to the development of new flow wrappers. The radical innovation process starts on average every 6 years and takes from 2 to 6 months during which the R&D department design the new generation flow wrapper.

Incremental innovation process leads to improve flow-pack packaging system performance and/or to reduce system costs. The development of a higher performance flow-pack packaging system starts whenever a customer requires a solution having distinct performance compared to previously designed system.

Innovation processes are evaluated on the capacity of company *Beta* to complete a specific project on time, within budget and according to system quality requirements.

10.2. Case study and within-case analysis

The unit of analysis

The case study is based on the development of a complete flow-pack packaging system including a distributor module, an automatic loader module, and a horizontal flow wrappers module.

The developed flow-pack packaging system was an incremental innovation as it provided improvements in the existing technology and in the existing market.

The flow-pack packaging system

The developed flow-pack packaging system was equipped with a row-distributing module, an in-line loading module, and a horizontal flow wrapper module.

The row-distributing module consists in a conveyor belt system connecting the processing line to the in-line loading system. The function of the row-distributing module is to order products received from the processing line in rows and to distribute rows orderly.

The in-line loading module consists in a series of belt conveyors connecting the row-distributing module to the horizontal flow wrapper module. The function of the in-line loading module is to receive the products from the row-distributing module and to feed the horizontal flow-wrapping machine.

The horizontal flow wrapper module consists in a wrapping machine packaging products in single packs.

Therefore, the flow-pack packaging system comprises standard modules (i.e., the distribution module, the automatic loader module, and the flow wrapper module). Each module fulfils a specific function of the system. Modules are individually upgradable and characterized by a low level of dependence. Interfaces among modules are defined in advance in standard specifications. As such, a specific module might be comprised in distinct flow-pack packaging systems.

Each module of the flow-pack packaging system is obtained combining mechanical and electrical components. On average, the 70% of components in a specific module (e.g., the flow wrapper) are standard, and the 30% are customized to satisfy customers’ requirements. However, even if the 70% of mechanical and electrical parts are standard in a specific module, components are not individually upgradable and are characterized by a high level of dependence.

As flow-pack packaging system include one-to-one mapping from product functions to modules and modules are individually upgradable and characterized by low level of dependence and standard interfaces, the system architecture is modular.

On the contrary, at the module level, as a specific module include complex mapping from module functions to components and components are not individually upgradable and characterized by high level of dependence, the module architecture is integral.

The packaging system development organization

The flow-pack packaging system development organization comprised resources fully owned by company *Beta* and drawn from multiple functions and different countries. Although the development team included resources belonging to the sales, technical production, and logistic departments, the focus is on the organization of product engineers, process engineers and supply chain professionals.

Product engineers, in charge of the design of the flow-pack packaging system modules, belonged to the technical department and were based both in Italy (at the operating holding plant) and in Brazil.

Process engineers, in charge of the design of mechanical fabrication and assembly processes, belonged to the production department and were based both in the Italian operating holding plant and in the Brazilian operating plant.

Supply chain professionals, in charge of the design of flow-pack packaging system supply chain (e.g., selecting raw materials and accessories suppliers, defining sourcing arrangements with suppliers), belonged to the logistic department and were located both in Italy and in Brazil.

The project leader, responsible for the coordination of the product development project across functions and operating plants, and the project manager, responsible for the planning and the monitoring of development activities, were based in Italy at the operating holding plant.

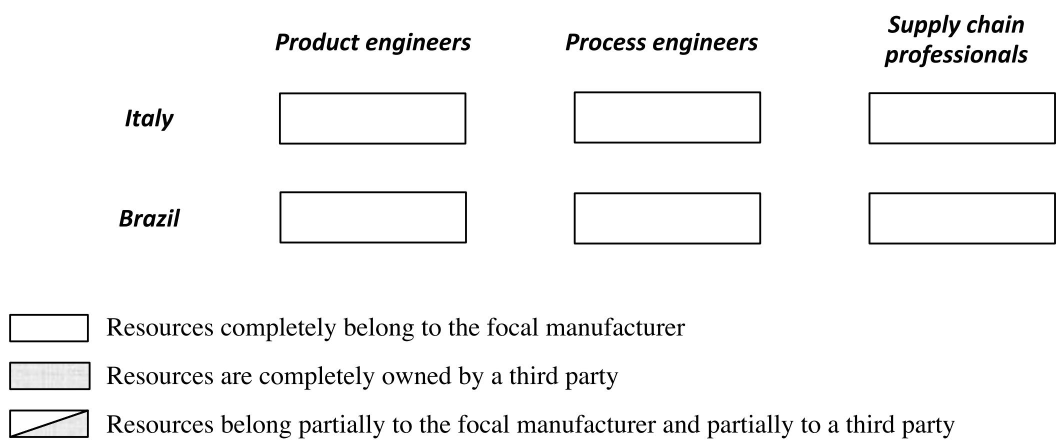

Figure 28. Flow-pack packaging system: the product development organization.

As product engineers, process engineers and supply chain professionals belonged to company *Beta* and were located offshore, the flow-pack packaging system development organizational form is global captive.

The packaging system development process

The flow-pack packaging system product development process is organized according to the stage-gate model. It includes six stages: offer definition phase, pre-design phase, design phase, fabrication phase, module assembly phase and system assembly phase; and three gates: offer award gate (Gate 1), fabrication and module assembly gate (Gate 2), and system assembly gate (Gate 3).

Although stages are represented in a sequential view in figure 29, development activities and even stages overlap.

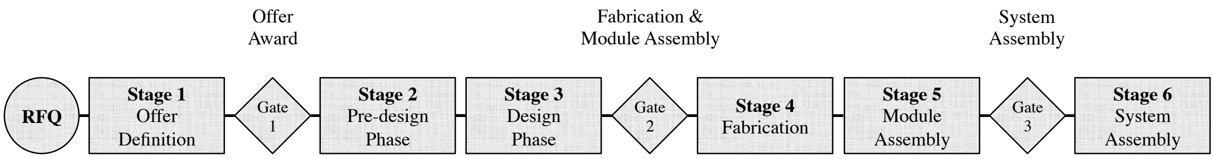

Figure 29. Flow-pack packaging system development process.

Request for quotation

The flow-pack packaging system development process started with the customer request for quotation (RFQ). The RFQ included a list of system features and requirements (e.g., packaging speed, number of product included in a single pack, specification of secondary pack) on which the product development organization estimated technical and financial feasibility. The receipt of the RFQ initiated stage 1.

Stage 1 - Offer definition phase

The offer definition phase consisted in assessing the system technical requirements and in estimating the system industrial cost.

The chief engineer officer was in charge of assessing system technical feasibility and of identifying a system solution to meet customer requirements.

Based on the identified system solution, the industrialization department designed the flow-pack packaging system layout and the PrePiCo department (i.e., budgeting, planning and accounting department) estimated the system industrial cost. Modules and accessories costs were estimated based on previously projects. The project management department supported the PrePiCo estimating the cost of supplied components and accessories.

The offer definition phase resulted in the RFQ answer approved by the sales director and the chief engineer officer and discussed with the customer. Company *Beta* got the customer offer award and the development process went on with stage 2.

Stage 2 - Pre-design phase

The pre-design phase consists in presenting the acquired job order to the managers of the departments involved in the development process and in assigning the development of the flow-pack packaging system to operating plants.

The pre-design phase started with a pre-design meeting in which the sales director, the chief engineer officer, the operating director, the project leader, the project manager, the electrical manager, the test manager, and the planning manager participated. In the meeting the sales director and the chief engineer officer presented the acquired job order to the manager of the departments involved in the development process.

Directors and managers assigned the development of system modules to the operating plants. Across distinct modules, development activities aiming at designing modules, supply processes, production processes and assembly processes were characterized by a low level of dependence as interfaces were defined in standard specifications. Hence, the development of each module of the system was assigned to an operating plant according to where technical expertise resides: the row-distributor module and the in-line loading module were assigned to the Italian operating holding plant, whereas the flow wrapper module to the Brazilian operating plant. In addition, directors and managers assigned the responsibility of the complete system to the Brazilian operating plant.

Assigned the responsibility and the development of the flow-pack packaging system to operating plants, the product development process went on with stage 3.

Stage 3 - Design phase

The design phase consisted in designing each module of the flow-pack packaging system to get full specifications.

The project leader specified modules features and decomposed the design of each module into module development activities defining the schedule. Module development activities aiming at designing components and parts (e.g., the wrapper basement part, the wrapper web part, the wrapper weld part) of a specific system module were assigned to a team of product engineers based in the same operating plant. As components and parts were not 100% standard (70% of components in a specific module are standard, and the 30% are customized to satisfy customers' requirements), module development activities were characterized by a high level of dependence.

Concurrently to the design of components and parts, process engineers and supply chain professionals designed supply, production and assembly processes of the module. Process and supply chain design activities related to novel components were characterized by a high level of dependence with module development activities (e.g., the design of the wrapper basement part was characterized by a high level of dependence with the design of the wrapper assembly process, the design of the wrapper pneumatic part was characterized by a high level of dependence with the selection of the pneumatic control unit supplier). Process engineers and supply chain professionals in charge of designing supply, production and assembly processes of a specific module were based in the same operating plant of product engineers responsible for the designing of the same module (e.g., process and supply chain design related to the wrapper machine was assigned respectively to process engineers and supply chain professionals based in Brazil).

Concerning the in-line loading module of the system, module development activities were assigned to Italian product engineers, whereas supply, production and assembly processes design activities were assigned to Brazilian specialists as the fabrication of components and the assembly of the module were planned to be executed in the Brazilian operating plant. On that circumstance, during the design phase, the Brazilian specialists moved to the Italian operating holding plant to participate at the design activities of the in-line loading module.

Stage 3 resulted in a set of drawings defining system modules specifications. Drawings were subjected to the approval of the chief engineer officer. Approved the drawings, the fabrication and module assembly gate was opened and the product development process went on with stage 4.

Stage 4 - Fabrication phase

The fabrication phase consisted in producing mechanical components and parts constituting the system modules.

In detail, the row-distributor mechanical components were fabricated in the Italian operating holding plant, whereas the in-line loading and the flow wrapper mechanical components were produced in the Brazilian operating plant.

Fabricated the mechanical components and parts, the product development process went on with stage 5.

Stage 5 - Module assembly phase

The module assembly phase consisted in assembling each module of the flow-pack packaging system and in verifying module functionality.

Fabricated components and supplied accessories were assembled to produce system modules. Assembled modules were subjected to stand-alone functioning tests aimed at verifying whether the module operated correctly.

In detail, the row-distributor module was assembled and tested in the Italian operating holding plant, whereas the in-line loading module and the flow wrapper module were assembled and tested in the Brazilian operating plant.

Tested module functionality, the system assembly gate was opened and the product development process went on with stage 6.

Stage 6 - System assembly phase

The system assembly phase consisted in assembling the flow-pack packaging system and in verifying system functionality.

To produce the complete flow-pack packaging system, modules were assembled, supplied accessories were integrated in modules and electric cables were wired. As the Brazilian operating plant was in charge of assembling the system, the row-distributor module was shipped in Brazil.

Completed the system assembly, the test run was performed. Tested system functionality, the flow-pack packaging system was available to the customer.

The flow-pack packaging system development process architecture

Across distinct modules, assessing the level of dependence of design activities (i.e., system design, supply chain design, fabrication and assembly processes design activities) aiming at developing different modules of the system, the form of the product development process architecture appears modular. In fact, design activities related to distinct modules were characterized by a low level of dependence as module interfaces were defined in standard specifications.

On the contrary, within a specific module, assessing the level of dependence of design activities aiming at developing a specific module of the system, the form of the product development process architecture appears integral. In fact, as module components and parts were not 100% standard, design activities related to a specific module were characterized by a high level of dependence.

Hence, the flow-pack packaging system development process architecture is considered modular across distinct modules, whereas, within a specific module of the system, it is considered integral.

Level of dependence among development activities

Product design activities		Product design activities	Process design activities	Supply Chain design activities
	Across distinct modules	*Loosely coupled* *Modular architecture*	*Loosely coupled* *Modular architecture*	*Loosely coupled* *Modular architecture*
	Within a specific module	*Tightly coupled* *Integral architecture*	*Tightly coupled* *Integral architecture*	*Tightly coupled* *Integral architecture*

Figure 30. Flow-pack packaging system: the product development process architecture.

Integration in the packaging system development process

Across distinct modules, product engineers responsible for the design of different modules did not participate together in development activities (e.g., product engineers in charge of the design of the row-distributor module and product engineers in charge of the design of the flow wrapper module did not participate together in development activities). Similarly, supply and production processes specialists responsible for a specific module did not work side by side with product engineers in charge of the design of a different module (e.g., supply, production and assembly specialists of the row-distributor module did not work side by side with product engineers in charge of the design of the flow wrapper module). Hence, across distinct modules, design activities were carried out separately as modules interfaces were defined in standard specifications in the form of design rules.

On the contrary, within a specific module, product engineers participated together in development activities (e.g., product engineers in charge of designing different parts of the row-distributor module participated together in development activities). In fact, module development activities were assigned to product engineers who were based in the same operating plant. Similarly, supply and production processes specialists responsible for a specific module worked side by side with product engineers in charge of the design of the same module (e.g., concerning the in-line loading module, Brazilian specialists moved to the Italian operating plant to work side by side with Italian product engineers).

Hence, across distinct modules, integration consisted in communication as development activities were carried out separately by individuals and functions interacting through information transfer. On the contrary, within a specific module, integration consisted in collaboration as development activities were carried out together by individuals and functions working side by side.

Integration mechanisms adopted in the packaging system development process

Strategic integration mechanisms

A complementary perspective on product development strategies and goals across the product development organization was ensured through the pre-design meeting during which project goals were clearly set and shared to everyone involved in the development process.

Product and project goals specified in the pre-design meeting enhanced integration across resources involved in the product development acting as common drivers toward which product engineers, process engineers and supply chain professionals converged on trade off decisions.

Technological integration mechanisms

Humanware

Specialists involved in the product development process had a significant expertise on flow-packaging system enhancing the ability to comprehend constraints related to development activities considered the preserve of other functions.

Product development team members established collaborative personal relationships enhancing cross-functional integration, building interpersonal trust, and supporting the exchange of technical knowledge across functions.

Resources involved in the power device development process were responsible for their own development activities timeline.

Software

Core communication technologies, including e-mails, teleconferences, and videoconferences, were regularly adopted across the resources involved in the product development process to discuss on flow-pack packaging system development issues.

Enterprise communication technologies were adopted to support product engineers in designing mechanical and electrical components of the system. Project management software was adopted to develop the project plan and to track project progress.

Organizational integration mechanisms

Standardization

Across operating plants, product development work processes were standardized through the use of standard forms and data dictionary (e.g., the use of standard cartouche, the use of standard technical terms in drawings information).

Across distinct modules, design rules concerning the design of module interfaces were defined in advance allowing product engineers based in distinct operating plants to assure the fit among modules interfaces. As the responsibility of the entire system was in charge of the Brazilian operating unit, Brazilian product engineers were responsible for defining interfaces design rules. Within a specific module, design rules concerning the design of components were defined to maximize the percentage of standard components constituting a module of the flow-pack packaging system and to avoid the proliferation of customized parts.

Formalization

The project plan, including a detailed schedule of activities, was set up as the product development started and regularly reviewed as development activities evolved. It constituted the synthesis of the work requirements needed to have the project finalized within a given timing schedule and according to fixed targets.

Project milestones were aimed at discussing about the most critical project issues and approving flow-pack packaging system proposals. The chief engineer officer was responsible for the approval of project milestones.

Direct Supervision

The project leader exerted direct supervision in decision-making, having the responsibility on critical and trade-off decisions related to system requirements, system design, and production processes design.

The project manager coordinated functions involved in the system development process supervising, monitoring and correcting design activities. Having full responsibility for project times and costs, the project manager developed the project plan and exerted direct supervision in decision-making to comply with project goals.

Formal mutual adjustment

Progress review meetings were held weekly with the aim of monitoring the progress of the project and identifying and solving critical issues. The project manger coordinated progress review meetings collecting information related to project activities status from Italian and Brazilian specialists involved in the system development process.

The project leader acted as a product champion having the responsibility to manage the interface among technical, production and logistic functions promoting communication (e.g., transfer information related to the status of module design, transfer drawings of modules interface, transfer information related to critical issues affecting the entire system) among specialists assigned to distinct modules.

Informal mutual adjustment

Specialists involved in the development of a specific module of the flow-pack packaging system held face-to-face meeting daily. Informal communication among team members working together on a specific module was adopted to coordinate activities, solve system-assembly interface problems, and maintain focus on the project.

Co-location was adopted to put together specialists involved in the development of a specific module from different functions and countries with the aim of removing organizational and cultural barriers, and of promoting close collaboration in development activities. For instance, concerning the in-line loading module, Brazilian specialists moved to the Italian operating plant to work side by side with Italian product engineers achieving better system design and lower cost production.

Dedicated teams

The system development team was a cross-functional team including resources belonging to the sales, technical, production, and logistic departments.

Integration mechanisms		
Strategic	Strategic	Complementary perspective on product development strategies and goals. Clear and shared project and product goals.
Technological	Humanware	Significative expertise in flow-pack packaging system. Personal attitudes towards cross-functional integration. Personal attitudes in taking responsibilities on activities.
	Software	Basic technologies (e.g., e-mail, teleconferences). Mechanical and electronic design software. Project management software.
Organizational	Standardization	Standard forms and data dictionary. Interfaces design rules. Standard components design rules.
	Formalization	Detailed project plan. Project milestones.
	Direct supervision	Project leader exerting direct supervision in decision-making Project managers exerting direct supervision in project planning.
	Formal mutual adjustment	Progress review meetings. Product champion.
	Informal mutual adjustment	Face-to-face meetings. Co-location.
	Dedicated teams	Cross-functional team.

Table 14. Integration mechanisms in the flow-pack packaging development process.

11. Company Gamma CASE STUDY AND WITHIN-CASE ANALSIS

11.1. Introduction

Company profile

Company *Gamma* is a world leader in the field of automotive disc brake technology with net revenues of EU€ 1.075,3 million in 2010 and EU€ 1.254,5 in 2011. The company operates on both the original-equipment market, focusing on the supply of braking systems, and in the aftermarket. Company market is represented by cars, motorbikes, commercial vehicles, racing cars and racing motorbikes manufacturers. Company sales are shared out the automotive industry's major sectors: Car (66,6%), Commercial vehicle (14,5%), Motorcycle (10,7%), Racing (5,4%), Passive safety equipment (2,1%) and others (0,7%).

The company's product offering for car and commercial vehicle applications includes brake discs, brake callipers, the side-wheel module, and the braking system, including integrated engineering services. Manufacturers of motorbikes are also offered brake discs, brake callipers, brake pumps, lightalloy wheels and braking systems. In the car aftermarket, the company offers approximately 1.300 product codes for European vehicles.

Company *Gamma* was created in 1961. The company started to produce brake discs for cars in 1964 and brake systems for motorcycles in 1972, while in 1975 the company ventured into motor sports competitions, supplying its own braking systems for racing cars. Through technological innovation and continuous research into materials and manufacturing processes, Company *Gamma* has become one of the world's most prestigious brands. In 1995, the group was listed on the Milan stock exchange and inaugurated a strategy for growth and internationalisation, which would soon lead the company to exceed a billion Euros in turnover. Currently, the group operates with 35 plants in 15 different countries and a workforce of more than 6.000 employees of which around 10% are engineering staff and product specialists working in R&D.

Company *Gamma* has an unwavering commitment to R&D. The company invests 4.8% of its turnover in R&D. Product specialists and technicians work out of the R&D Centre at the science and technology park, hosting companies, research centres, laboratories, high-tech manufacturing concerns and services dedicated to innovation. The expertise of engineers and product specialists working in the science and technology park is enriched by the range of complimentary skill-sets within the park, covering everything from mechanics to electronics, and also taking in chemistry, material physics and thermo-mechanical and fluid-dynamic simulations.

To provide its customers with a responsiveness and cost-effective manufacturing machine, company *Gamma* operates a worldwide network of production plants. In detail, company *Gamma* production plants are presently located in Italy, Germany, Spain, Great Britain, Poland, Czech republic, Slovak republic, India, China, Japan, Brazil, Mexico, and United States. The production plants network is complemented by a network of commercial agencies located in Italy, Germany, France, Spain, Great Britain, Sweden, Poland, Slovak republic, India, China, Japan, Brazil, Mexico, and United States.

Interviewees' profile

In company *Gamma,* the project director (twice) and the operation director (twice) were interviewed.

The project director is the chief of the commercial vehicles business unit project management department. He is involved as project director in managing business initiatives including braking systems development projects.

The operation director is the chief of the commercial vehicles business unit operation department. In braking systems development projects, he is involved as operation director in supervising development activities related to the production process design, the assembly process design, and the production rump up of brake discs and cast iron hydraulic calipers.

Commercial and industrial vehicles business units

Company *Gamma* is a leader in the world commercial vehicle braking system market and operates in the OEM and spare parts sectors. The company applies its technological know-how and experience to work for the professional sector, producing braking systems for commercial and industrial vehicle.

Commercial and industrial vehicles, whether light (up to 6 tonnes), medium (from 6 to 16 tonnes) or heavy (over 16 tonnes), demand superior braking power as the braking system is subjected to repeated, frequent loads in varying road conditions. The work demanded of a braking system and the heat that it must dissipate during braking are directly proportional to the mass of the vehicle and the speed it is travelling at when braking starts. The brakes therefore have to work hardest when the vehicle is fully loaded and at maximum operating speed. As a result, the braking system is subject to more stress than other vehicles, making it the more crucial that it be suitable for the application.

Company *Gamma* responds to these requisites by supplying manufacturers in the commercial and industrial vehicles segment with braking systems that set the standards for quality, reliability and durability.

Product overview

Light commercial and industrial vehicles braking systems consists of brake discs and cast iron hydraulic calipers.

Concerning the brake discs, company *Gamma* designs and manufactures a range of cast iron discs sized appropriately to increase resistance to the thermo-mechanical stresses that occur on heavy vehicles. For critical applications such as industrial vehicles, the company uses pillar venting technology, developed and patented by the group's Research and Development Centre. Company *Gamma* discs with pillar venting technology improve material distribution, increase heat exchange surface area and produce greater air turbulence in the ventilation gap reducing cooling times and minimizing thermal cracks. The discs produced for light commercial vehicles are around 280 mm diameter components weighing approximately 9 Kg.

Concerning the calipers, company *Gamma* designs and manufactures single-piston and dual-pistons front and rear floating hydraulic calipers made from cast iron. To achieve reliability, integrity and safety for the entire lifetime of the vehicle, the components of the caliper must be engineered to exacting standards preventing weather corrosion. For instance, the design of the seals determines the system capability of preventing infiltration and corrosion.

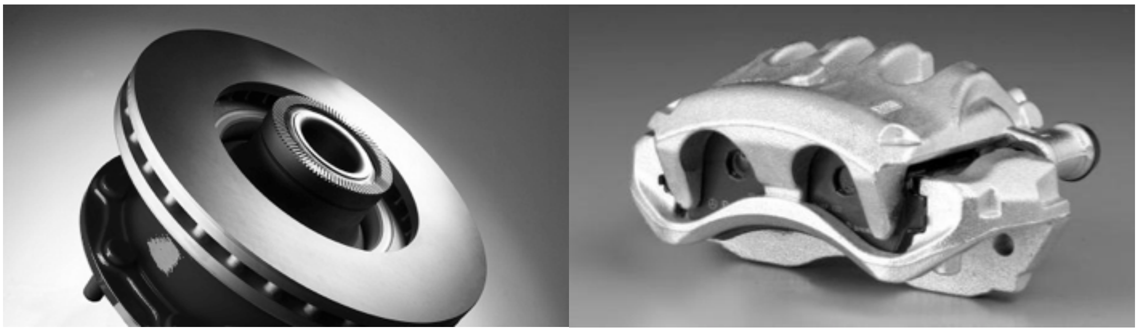

Figure 31. Commercial vehicle braking system.

Production process overview

The cast iron hydraulic caliper production process comprises 4 stages: the cast, the machining, the assembly and the test.

The cast stage consists in a permanent mould casting process through which untreated iron caliper components (e.g., the cylinder body, the mounting bracket) are fabricated. In detail, the casting process consists in heating the iron alloy until it liquefies and in pouring the liquefied alloy into a mould. The alloy poured into the mould solidifies taking the untreated shape of an iron caliper components.

Cast untreated components are then machined. The machining process consists in removing material from cast untreated components to achieve the definitive geometry. Computer numerical control (CNC) milling machines, drill presses and other cutting machines are used to process cast untreated components.

Once the machining of iron components is completed, fabricated and supplied (e.g., the piston seal, the piston, the piston boot, the boot ring, bleeder cap) components are assembled to realize the cast iron hydraulic caliper. Assembly tasks are carried out on a dedicated assembly line made up of several workstations.

Assembled calipers are finally tested. The test is carried out automatically in the last workstation of the assembly line.

Passed the test, cast iron hydraulic calipers are ready to be supplied to customers' production plants.

Supply chain overview

Company *Gamma* operates a worldwide network to provide light commercial vehicles braking system customers with an efficient and responsiveness manufacturing machine.

Around 70 worldwide manufacturers supply caliper components (e.g., the untreated cylinder body, the untreated mounting bracket, the piston seal, the piston, the piston boot, the boot ring, bleeder cap) to company *Gamma* production plants located in Poland and in China.

Calipers production plants are capable to manage the production process from the machining stage to the test stage. Machine tool departments are equipped with CNC milling machines, drill presses and other cutting machines used to process untreated cast components; assembly departments are equipped with assembly lines made up of several workstations through which the caliper is assembled and tested.

Polish and Chinese plants supply braking systems to customers' production plants respectively located in Europe (essentially in Germany) and in Asia.

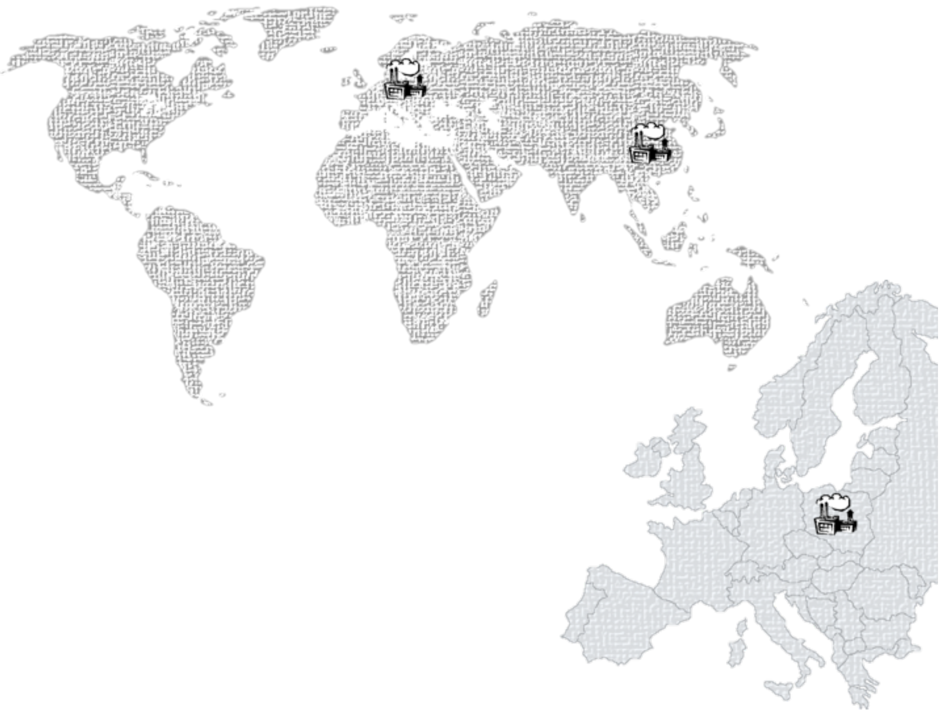

Figure 32. Cast iron hydraulic calipers plants.

Innovation process overview

The innovation process leads to improve cast iron hydraulic caliper performance and/or to reduce caliper costs innovating components materials, fabrication methods and production processes (e.g., machining and assembly processes).

The development of a higher performance cast iron hydraulic caliper starts whenever a customer requires a solution having distinct performance compared to previously designed calipers. The innovation process takes on average 2 years during which the commercial vehicles business unit is in charge of designing the caliper along with the machining and the assembly processes.

Innovation processes are evaluated on the capacity of company *Gamma* to complete a specific project on time, within budget and according to caliper quality requirements.

11.2. Case study and within-case analysis

The unit of analysis

The case study is based on the development of a cast iron hydraulic caliper designed for light commercial vehicles.

The developed cast iron hydraulic caliper was an incremental innovation as it provided improvements in the existing technology and in the existing market.

The cast iron hydraulic caliper

The developed cast iron hydraulic caliper comprises metal and rubber components. On average, the 40% of components is standard, whereas the 60% is customized to meet customer requirements and specifications. In fact, as the caliper constitutes a module of the vehicle, it has to be designed according to customer requirements defined taking into account specifications of others commercial vehicle modules interacting with the caliper module.

The 40% of standard components mainly includes supplied parts, such as the bleeder cap and the bleeder screw. However, even if the caliper comprises standard components, designed parts are not individually upgradable and are characterized by a high level of dependence.

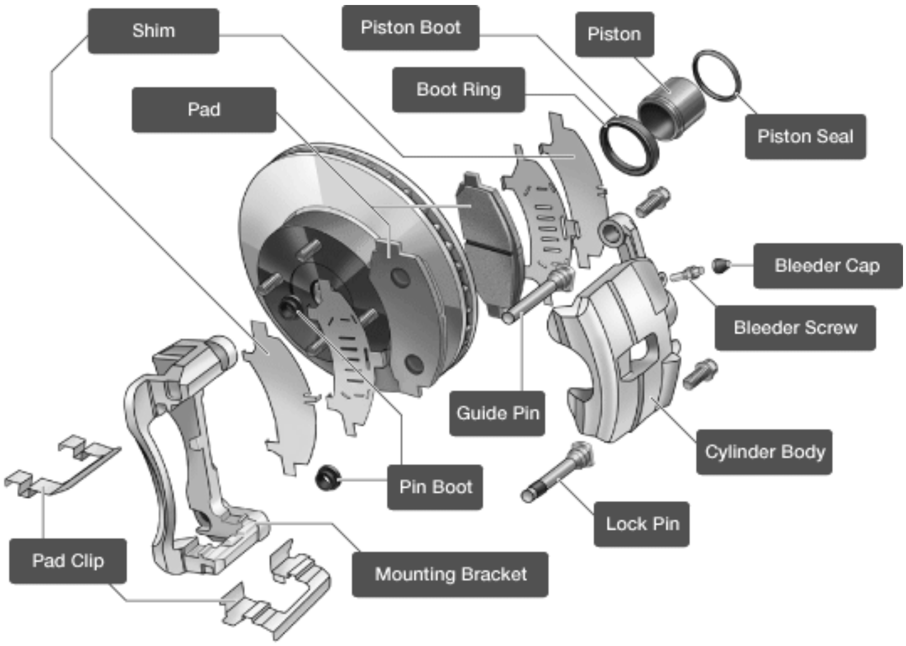

Figure 33. Major components of a cast iron hydraulic caliper.

As the caliper includes complex mapping from product functions to components and components are not individually upgradable and characterized by high level of dependence, the product architecture is integral.

The caliper development organization

The cast iron hydraulic caliper development organization comprised resources fully owned by company *Gamma* and drawn from multiple departments based in Italy.

Although the development team included resources belonging to the sales, technical development, technology development, operation, purchase and quality departments, the focus is on the organization of product engineers, process engineers and supply chain professionals.

Product engineers, in charge of the design of caliper components, belonged to the technical development department of the commercial vehicles business unit and were based in Italy.

Process engineers, in charge of the design of the machining and the assembly processes, belonged to the operation department of the commercial vehicles business unit and were based in Italy.

Supply chain professionals, in charge of the design of the caliper supply chain (e.g., selecting components suppliers, defining sourcing arrangements with suppliers), belonged to the purchase department and were based in Italy. The purchase department is a centralized function in company *Gamma* assisting the business units.

The project leader, in charge of managing the product development team including product engineers, process engineers, quality engineers, and supply chain professionals (e.g., purchase and logistics specialists), belonged to the project management department and was based in Italy.

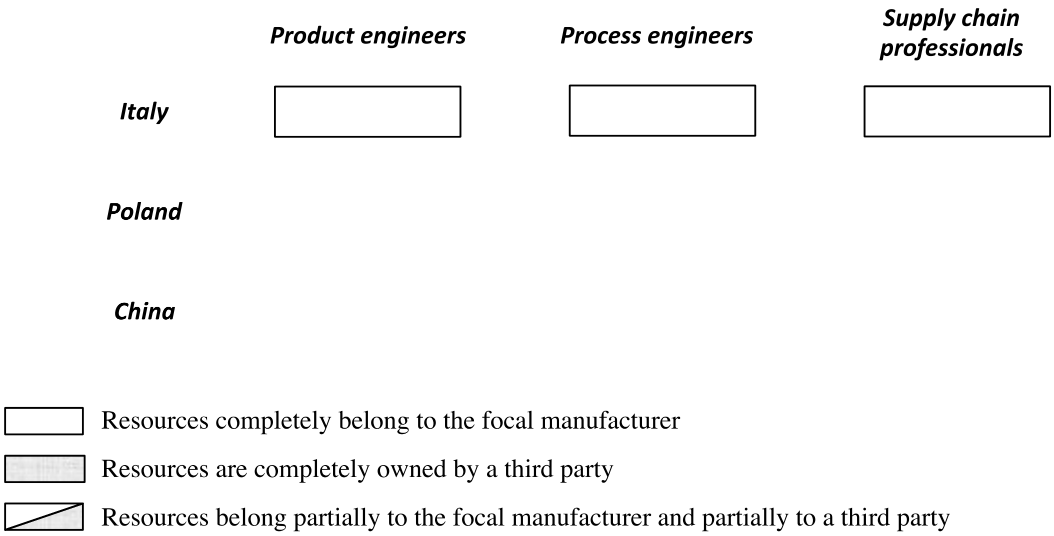

Figure 34. Cast iron hydraulic caliper: the product development organization.

As product engineers, process engineers and supply chain professionals belonged to company *Gamma* and were located onshore, the cast iron hydraulic caliper development organizational form is local.

The caliper development process

The cast iron hydraulic caliper product development process, known as *Butterfly*, is organized according to the APQP stage-gate model. It includes five stages: planning phase, product design and development phase, process design and development phase, product and process validation phase, and production phase; and four gates: project initiation (Gate 1), program approval (Gate 2), prototype start (Gate 3), and product launch (Gate 4).

At each gate the results of the previous stages are evaluated and included in a predefined internal document. Whether the results of the stage satisfy the evaluation criteria, the specific internal document is approved and the product development process goes on with the next stage.

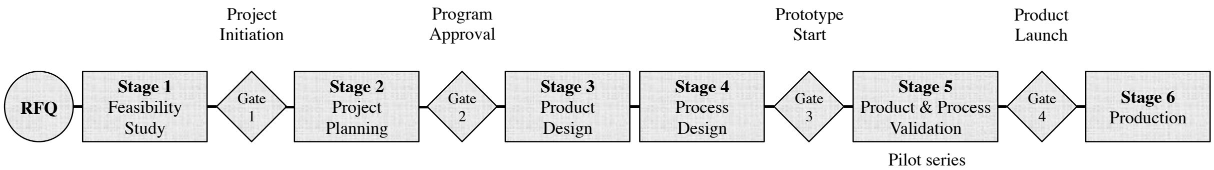

Figure 35. Cast iron hydraulic caliper development process.

Although stages are represented in a sequential view in figure 35, development activities and even stages overlap.

Request for quotation

The cast iron hydraulic caliper development process started with the customer request for quotation (RFQ). The RFQ included a list of product features and requirements (e.g., braking distance with empty load, braking distance with full load) on which the product development organization estimated technical and financial feasibility. The receipt of the RFQ initiated stage 1.

Stage 1 - Feasibility study

The feasibility study consisted in assessing technical and financial feasibility in respect of customer requirements. Concerning the financial feasibility study, each department involved in the development process was in charge of estimating project costs: the technical development department was in charge of estimating design costs; the operation department was in charge of estimating production costs; the technology development department was in charge of estimating production equipment costs; and the purchase department was in charge of estimating supplied components costs.

The feasibility study resulted in an internal document including product preliminary specifications and product industrial cost. Approved the internal document, the RFQ answer was delivered to the customer. Got the customer offer award, the project initiation gate was opened and the development process went on with stage 2.

Stage 2 - Project Planning

The project planning phase consisted in defining the project plan in terms of activities schedule, milestones, and resources planning. Approved the project plan, the program approval gate was opened and the product development process went on with stage 3.

Stage 3 - Product Design and Development

The product design and development phase consisted in designing the cast iron hydraulic caliper to get full specification.

The chief of the technical research and development department assigned product design activities to product engineers: an engineer was in charge of the design of the exterior components (e.g., the cylinder body, the mounting bracket) and an engineer was in charge of the design of the interior components (e.g., the piston).

Product engineers gathered detailed technical data on the commercial vehicle (e.g., vehicle acceleration, vehicle weight, vehicle barycentre) to refine caliper technical requirements preliminarily defined in the feasibility study.

Refined caliper requirements were discussed in the technical review meeting with the customer and revised where necessary. Approved the requirements, product engineers designed caliper components. Besides, the design of the supplied untreated iron caliper components (e.g., the cylinder body, the mounting bracket) were performed in co-design with cast suppliers. As caliper components were not standard (on average 60% of caliper components are customized to meet customer requirements and specifications), product design activities were characterized by a high level of dependence.

Concurrently to the design of caliper components, supply chain professionals were in charge of selecting suppliers and defining sourcing arrangements. Supply chain design activities related to supplied caliper components were characterized by a high level of dependence with design activities (e.g., the design of the untreated cylinder body was characterized by a high level of dependence with the selection of the untreated cylinder body supplier).

Stage 3 resulted in a set of drawings defining caliper components specifications. Drawings were subjected to the approval of the chief of the technical development and research department.

Stage 4 - Process Design and Development

The process design and development phase consisted in designing the machining and assembly processes of the cast iron hydraulic caliper.

Concurrently to the design of the caliper, a process engineer was in charge of designing the machining and the assembly processes. Process design activities were characterized by a high level of dependence with product design activities, as the output of product design was the input of process design and, in turn, the output of process design was the input of product design (e.g., the design of the cylinder body extremely influenced the design of both the machining and the assembly processes, and vice versa).

Designed the working sequence and estimated machining's cycle times, technology engineers designed production equipment (e.g., milling tools, cutting tools, machines retainers) required to process untreated caliper components.

Stage 4 resulted in an internal document including caliper, machines, tools and assembly line specifications. Approved product and process specification, the prototype start gate was opened and the product development process went on with stage 5.

Stage 5 - Product and Process Validation

The product and process validation phase consisted in verifying caliper, machines, machining tools and assembly line functionality and reliability.

Prototypes of the caliper and the machining tools were developed to test product and production processes. After refining prototypes according to test results, a pilot series was produced to definitely validate the caliper, the machining process and the assembly process.

Stage 5 resulted in an internal document including caliper, machining and assembly performance. Validated the product and the production processes, the product launch gate was opened and the product development process went on with stage 6.

Stage 6 - Production

The production phase consisted in ramping up the production of the designed cast iron hydraulic caliper. The calipers were manufactured and tested to meet corporate quality standard and were available to customers.

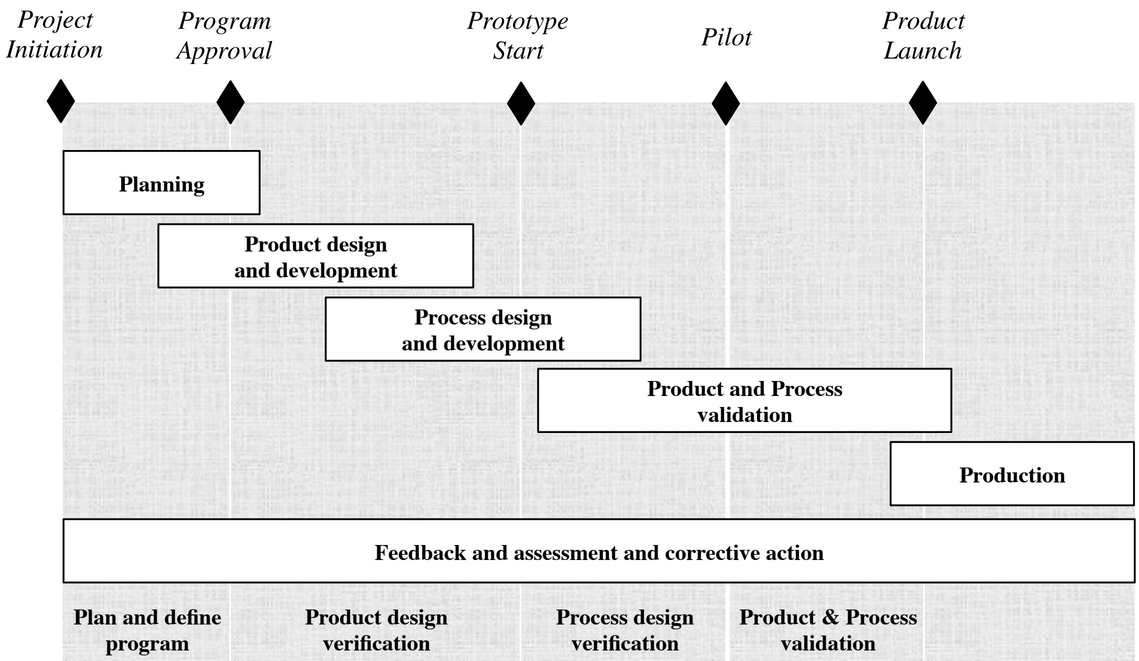

Figure 36. APQP product development process model.

The cast iron hydraulic caliper development process architecture

Assessing the level of activities dependence within product design activities and across product, process and supply chain design activities in the design and development phase, the form of the product development process architecture appears integral. In fact, as caliper components design activities are characterized by a high level of dependence, the product development process architecture is integral within product design activities. Similarly, as production process and supply chain design activities are characterized by a high level of dependence with caliper components design activities, the product development process architecture is integral across product, process and supply chain design activities.

Level of dependence among development activities

Product design activities	*Tightly coupled* *Integral architecture*	*Tightly coupled* *Integral architecture*	*Tightly coupled* *Integral architecture*
	Product design activities	Process design activities	Supply Chain design activities

Figure 37. The cast iron hydraulic caliper: the product development process architecture.

Integration in caliper development process

Product engineers participated together in design activities (e.g., product engineers in charge of designing exterior components of the caliper participated worked together with product engineers in charge of designing interior components of the caliper). In fact, design activities were assigned to product engineers based in the same open office. Similarly, process engineers and supply chain professionals worked side by side with product engineers. Besides, process engineers were based in the same open office of product engineers.

Hence, integration in the cast iron hydraulic caliper development process consisted in collaboration as design activities were carried out together by individuals and functions working side by side.

Integration mechanisms adopted in caliper development process

Strategic integration mechanisms

A complementary perspective on product development strategies and goals across the product development organization was ensured through the output of the feasibility study defining caliper requirements and caliper industrial cost. In fact, the internal document including the feasibility study results was approved by the chief of each department and shared to everyone involved in the development process clearly setting project goals.

Product and project goals specified in the internal document enhanced integration across resources involved in the product development acting as common drivers toward which specialists converge on trade off decisions.

Technological integration mechanisms

Humanware

Specialists involved in the product development process had a significant expertise on cast iron hydraulic caliper enhancing the ability to comprehend constraints related to design activities considered the preserve of other functions.

Product development team members established collaborative personal relationships enhancing cross-functional integration, building interpersonal trust, and supporting the exchange of technical knowledge across functions.

Software

Core communication technologies, including e-mails and teleconferences were adopted across specialists involved in the development process to discuss on caliper design issues.

Enterprise communication technologies were adopted to support product engineers in designing caliper components.

Concerning group collaboration technologies, the failure mode and effects analysis (FMEA) were executed on the design, the machining and the assembly processes. In detail, specialists involved in the project worked together in developing the FMEA analysis.

Organizational integration mechanisms

Standardization

Product development workflow was specified in advance according to standard procedures. Project milestones, deliverables and formal documents (e.g., documents including technical specifications, documents reporting the results of development stages) were defined at the beginning of the project.

Formalization

A program management formal procedure was adopted to complete the project on time and within the budget by planning, organizing, and supervising resources involved in the caliper development process.

The project plan, including a detailed schedule of activities, was set up as the product development started and regularly reviewed as designing activities evolved. It constituted the synthesis of the work requirements needed to have the project finalized within a given timing schedule and according to fixed targets.

Project milestones were aimed at discussing about the most critical project issues and approving product, machining process, assembly process, and supply chain proposals.

Direct Supervision

The project manager coordinated functions involved in the caliper development process supervising, monitoring and correcting design activities. Being responsible for project times and costs, the project manager developed the project plan and exerted direct supervision in decision-making to comply with project goals.

Formal mutual adjustment

Design review meetings were held regularly with the aim of monitoring design activities status and discussing on design issues. Specialists involved in design review meetings were product engineers, process engineers and quality specialists. The project manager coordinated design review meetings collecting technical documentation.

Project review meetings were held semi-weekly with the aim of monitoring the progress of the project and identifying and solving critical issues. Every department involved in the project participated regularly to project review meetings. The project manger coordinated project review meetings collecting information related to project activities status.

Informal mutual adjustment

Specialists involved in the development of the caliper held face-to-face meeting daily. Informal communication among team members working together on the caliper was adopted to coordinate designing activities and maintain focus on the project.

Co-location was adopted to put together specialists involved in the development of the caliper from different functions with the aim of removing organizational barriers and of promoting close collaboration in designing activities. In fact, product engineers and process engineers worked together in the same open space.

Dedicated teams

The caliper development team was a cross-functional team including resources belonging to the sales, technical development and research, technology development, operation, and purchase departments.

Integration mechanisms		
Strategic	Strategic	Complementary perspective on product development strategies and goals. Clear and shared project and product goals.
Technological	Humanware	Significative expertise in cast iron hydraulic caliper. Personal attitudes towards cross-functional integration.
	Software	Basic technologies (e.g., e-mail, teleconferences). CAD software. Collaborative FMEA.
Organizational	Standardization	Standard product development workflow.
	Formalization	Formal program management procedures. Detailed project plan. Project milestones.
	Direct supervision	Project manager exerting direct supervision in project planning and in decision-making.
	Formal mutual adjustment	Design review meetings. Progress review meetings.
	Informal mutual adjustment	Face-to-face meetings. Co-location. Open space.
	Dedicated teams	Cross-functional team.

Table 15. Integration mechanisms in the cast iron hydraulic caliper development process.

12. CROSS-CASE ANALYSIS

The cross-case analysis has been performed to look for similarities and differences among the cases. In detail, similarities and differences have been analysed among product architectures, product development organizations, product development process architectures, integration processes, and integration mechanisms.

12.1. Units of analysis

The unit of analysis of each case is the development of a product come in market on time and within budget. Company *Alpha* case study was based on the development of a BCD Power Device, whereas company *Beta* case study was based on the development of a flow-pack packaging system, and company *Gamma* case study was based on the development of a cast iron hydraulic caliper.

According to the choice of modelling the Product Innovativeness as a control variable, the products developed by company *Alpha*, *Beta*, and *Gamma* constituted an incremental innovation providing improvements in the existing company technology and in the existing company market. In fact, it has been opted to investigate development processes in which designed products have similar degree of innovativeness avoiding the effect of product innovativeness on the configuration of the elements enabling 3D concurrent engineering.

12.2. Similarities and differences in product architectures

The product architecture has been measured decomposing the product developed by each company into its functional components and assessing the mapping from product functions to components and the level of components dependence.

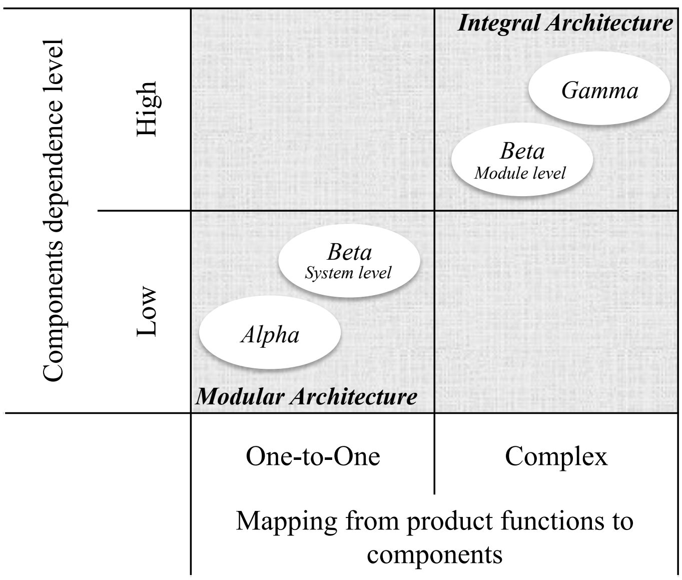

Figure 37. Product architecture matrix.

The BCD power device architecture is modular (company *Alpha*). In fact, the power device includes one-to-one mapping from product functions to blocks (the power devices comprises standard blocks fulfilling a specific function of the product) and blocks are individually upgradable and characterized by low level of dependence and standard interfaces.

The flow-pack packaging system architecture is modular at the system level (company *Beta - System level* -), though integral at the module level (company *Beta - Module level* -). In fact, the flow-pack packaging system includes one-to-one mapping from product functions to modules (the flow-pack packaging system comprises standard modules fulfilling a specific function of the system) and modules are individually upgradable and characterized by low level of dependence and standard interfaces. Whereas, at the module level, a specific module of the system includes complex mapping from module functions to components (a specific module of the system comprises mechanical and electrical components tightly coupled) and components are not individually upgradable and characterized by high level of dependence.

The cast iron hydraulic caliper architecture is integral (company *Gamma*). In fact, the caliper includes complex mapping from product functions to components (the caliper comprises metal and rubber components tightly coupled) and components are not individually upgradable and characterized by high level of dependence.

12.3. Similarities and differences in product development organizations

The product development organizational form has been assessed observing the location and the ownership of product engineers, process engineers and supply chain professionals involved in the product development process of each company.

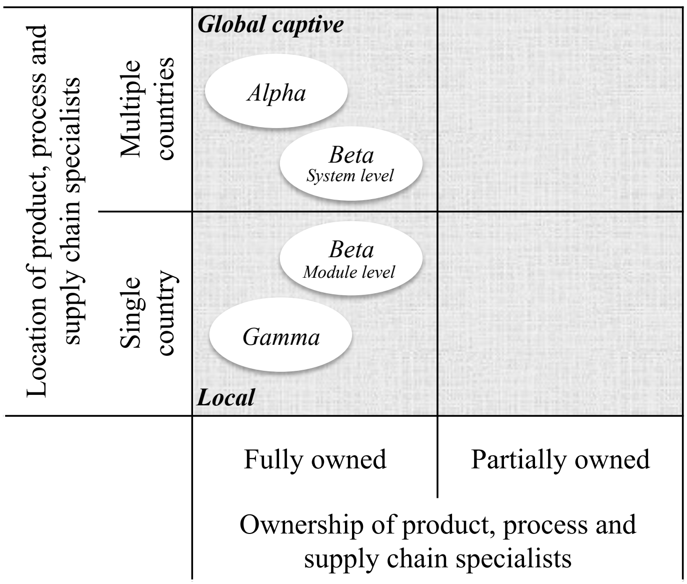

Figure 38. Product development organization matrix.

The power device development organization was global captive (company *Alpha*). Specialists were fully owned by company *Alpha* and based in different countries: product engineers were based in Italy and in Singapore, process engineers were based in Italy and in France, and supply chain professionals were based in Italy.

The flow-pack packaging system development organization was global captive at the system level (company *Beta* - *System level* -), though local at the module level (company *Beta*

- *Module level* -). In fact, at the system level, specialists were fully owned by company *Beta* and based in different countries: product engineers, process engineers and supply chain professionals were based in Italy and in Brazil. Whereas, at the module level, specialists were based in the same country: specialists in charge of the row-distributor module were based in Italy, specialists in charge of the in-line loading module were based in Italy, and specialists in charge of the wrapper module were based in Brazil.

The cast iron hydraulic caliper development organization was local (company *Gamma*). Specialists were fully owned by company *Gamma* and based in the same country: product engineers, process engineers, and supply chain professionals were based in Italy.

12.4. Similarities and differences in product development process architectures

The product development process architecture has been measured assessing the level of activities' dependence within product design activities and across product, process and supply chain design activities of each case.

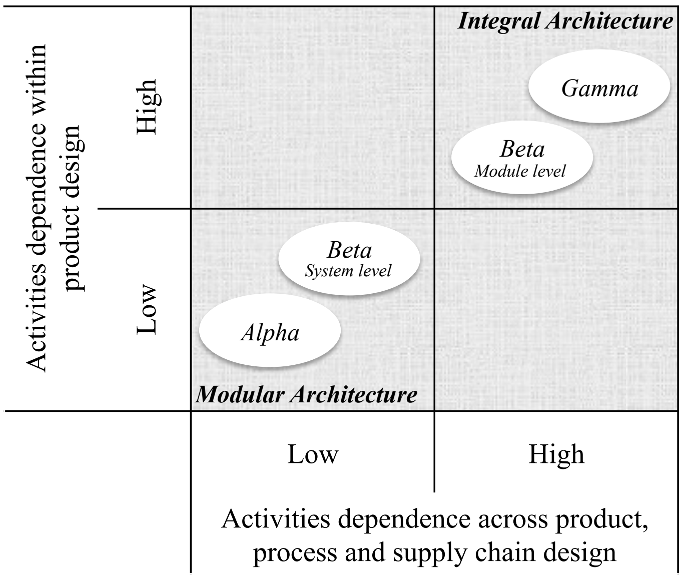

Figure 39. Process development architecture matrix.

The BCD power device development process architecture is modular (company *Alpha*). In fact, within product design and across product, process, and supply chain design, activities were characterized by a low level of dependence as interfaces among power device blocks, specifications of production processes, and power device materials and production technologies were defined in advance in standard specifications.

The flow-pack packaging system development process architecture is modular at the system level (company *Beta - System level* -), though integral at the module level (company *Beta - Module level* -). In fact, at the system level (i.e., across distinct modules), design activities (both within product design and across product, process, and supply chain design) related to distinct modules were characterized by low level of dependence as module interfaces were defined in advance in standard specifications. Whereas, at the module level (i.e, within a specific module), design activities (both within product design and across product, process, and supply chain design) related to a specific module were characterized by high level of dependence, as module components were not standard.

The cast iron hydraulic development process architecture is integral (company *Gamma*). In fact, within product design and across product, process, and supply chain design, activities were characterized by high level of dependence, as caliper components were not standard.

12.5. Similarities and differences in integration processes

The integration process form has been measured decomposing the product development process into its activities and assessing the extent to which specialists worked side by side to execute joint design activities.

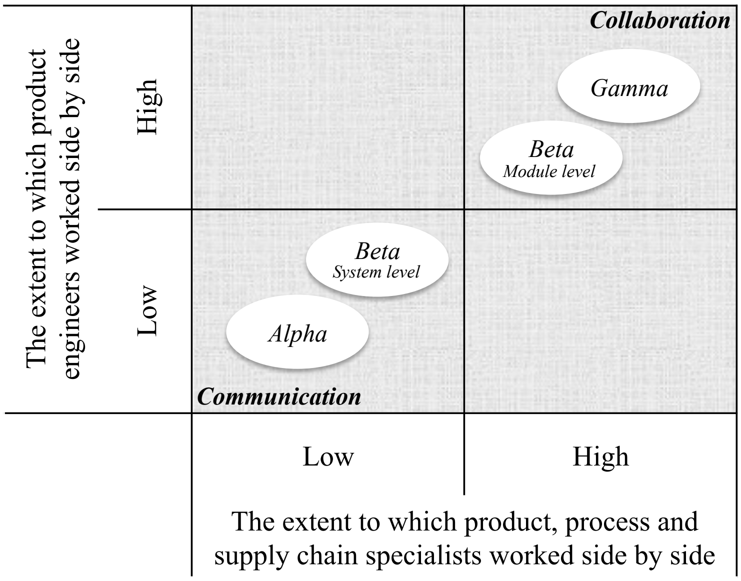

Figure 40. Integration process form matrix.

The BCD power device integration process consists in communication (company *Alpha*). In fact, as the required output of activities was defined in standard specifications in the form of design rules and standard documentations, design activities were carried out separately by individuals and functions interacting through information transfer.

The flow-pack packaging system integration process consists in communication at the system level (company *Beta - System level* -), though in collaboration at the module level (company *Beta - Module level* -). In fact, at the system level (i.e., across distinct modules), as modules interfaces were defined in standard specifications in the form of design rules, design activities were carried out separately by individuals and functions interacting through information transfer. Whereas, at the module level (i.e., within a specific module), as module components were not standard, design activities were carried out together by individuals and functions working side by side.

The cast iron hydraulic caliper integration process consists in collaboration (company *Gamma*). In fact, as caliper components were not standard (i.e., components specifications were not definable in advanced in the form of design rules), design activities were carried out together by individuals and functions working side by side.

12.6. *Similarities and differences in integration mechanisms*

The configuration of integration mechanisms has been observed assessing the strategic, technological, and organizational mechanisms implemented by each company.

Strategic integration mechanisms

A complementary perspective on product development strategies and goals across the product development organization along with an active use of goals in trade off decisions were ensured in each case study.

Each company set project goals and made them clear and shared to everyone involved in the product development process. Besides, project goals enhanced integration acting as common drivers toward which specialists converge on trade off decisions.

Technological integration mechanisms

Humanware

In each case study, technical knowledge, social skills and managerial skills were common characteristics among specialists belonging to the product development organization.

In every company, specialists had a significant technical expertise on the designed product enhancing the ability to comprehend constraints related to activities considered the preserve of other functions. Further, specialists established collaborative personal relationships enhancing cross-functional integration, building interpersonal trust, and supporting the exchange of knowledge across functions. Finally, specialists took and shared responsibility for design activities, and monitored and corrected their own and others' tasks when required.

Software

In each case study, core communication technologies, including e-mails, teleconferences and videoconferences were regularly adopted across specialists involved in the development process to discuss on product design issues.

Enterprise communication technologies were extensively adopted in company *Alpha* to support product engineers in product design activities (e.g., designing and simulation software), so as to formalize the product development process workflow giving project management release control over project gates (e.g., project management software), and to allow resources involved in the product development to access, distribute, store and retrieve information concerning products, production processes, and plants (e.g., company databases). Whereas, in company *Beta* and in company *Gamma* enterprise communication technologies were adopted to essentially support product engineers in product design activities and project managers in project planning activities. Company *Beta* also adopted enterprise communication technologies to allow specialists based in distinct operating plants accessing, distributing, storing and retrieving data (e.g., technical drawings) on product modules and module components.

Group collaboration technologies (e.g., the failure mode and effects analysis) were just adopted in company *Gamma* to prompt specialists involved in the project to work together.

Organizational integration mechanisms

Standardization

In each case study, standard work processes were established to standardize product development procedures.

Standard outputs were defined by companies *Alpha* and *Beta* to decouple design activities related to product blocks and system modules. In detail, in company *Alpha*, the outputs of design activities were specified in advance in the NPR document including product, production process and supply chain specifications. Whereas, in company *Beta*, the outputs of module interfaces design activities were specified in advance in the form of design rules.

Formalization

In each case study, a project plan, including a detailed schedule of activities and articulating specialists roles and responsibilities, was set up as the product development process started and regularly reviewed as design activities evolved. Further, project milestones were established to prompt specialists to discuss about critical project issues and to approve product, process and supply chain design proposals.

Direct supervision

In each case study, project managers were established to coordinate functions involved in the product development process supervising, monitoring and correcting design activities. Being responsible for project times and costs, project managers exerted direct supervision in decision-making and in project planning to comply with project goals.

Formal mutual adjustment

In each case study, review meetings were held regularly to monitor project design activities status and identify and solve critical issues ensuring an acceptable fit among product, production process, and supply chain parameters.

In company *Beta*, a product champion was established to manage the interface among technical, production and logistic functions promoting communication among specialists assigned to the design of distinct system modules.

Informal mutual adjustment

Face-to-face informal communication among team members working together on a specific system module or on the entire product was ensured daily in company *Beta* (among specialists in charge of designing a specific module) and in company *Gamma* to coordinate design activities and maintain focus on the project.

Similarly, co-location was adopted by company *Beta* and company *Gamma* to respectively put together specialists involved in the design of a specific system module or of the entire product with the aim of removing organizational and cultural barriers and promoting close collaboration in design activities.

Dedicated teams

In each case study, the product development team was a cross-functional team including specialists drawn from multiple company departments.

12.7. Cross-case analysis results

Similarities and differences in the elements of the research conceptual model (i.e., the product architecture, the product development organization, the product development process architecture, the integration process, and the integration mechanisms) among cases have been displayed in the following table.

Case	Product Architecture	Product Development Organization	Product Development Process		Integration Process	Integration mechanisms (differences)
			Process Architecture	Design Activities Assignment		
Alpha	Modular	Global captive	Modular	- Design activities to specialists based in distinct countries - Interdependent product design activities to specialists based in the same country	Communication *Information transfer*	- Standard specifications specified in advance design activity outputs - Extensive use of enterprise communication technologies
Beta *System level*	Modular	Global captive	Modular	- Design activities related to distinct modules according to where technical expertise resides	Communication *Information transfer*	- Standard specifications specified in advance module interfaces design activity outputs - Adoption of software to manage product data - Product champion
Beta *Module level*	Integral	Local	Integral	- Design activities of a specific module to specialists based in the same operating plant	Collaboration *Working collectively*	- Co-location of specialists involved in the design of a specific system module - Face-to-face informal communication
Gamma	Integral	Local	Integral	- Design activities to specialists based in the same open space	Collaboration *Working collectively*	- Collaborative FMEA - Co-location of specialists involved in the design of the product - Face-to-face informal communication

Table 16. Cross-case analysis results.

In the next sections the relations among the elements of the research conceptual model are analysed across cases.

Integration process and Integration mechanisms relations across cases

Assessing the relations between the integration process and the integration mechanisms, cross-case analysis results suggest that whereas the integration process consists in communication (case *Alpha* and case *Beta - System level -*), integration mechanisms comprise: (i) standard specifications defining in advance design activities outputs; (ii) enterprise communication technologies formalizing product development process workflows and allowing specialists to access, distribute and store product data; (iii) product champions promoting communication among specialists. On the contrary, whereas the integration process consists in collaboration (case *Beta - Module level -* and case *Gamma*), integration mechanisms comprise: (i) co-location of specialists involved in the product development; (ii) face-to-face informal communication; (iii) collaborative techniques (e.g., the FMEA).

Hence, as the requirements for working collectively decrease, integration mechanisms such as standard specifications, enterprise communication technologies, and product champions are essential to enable integration in the form of communication. On the contrary, as the requirements for working collectively increase, integration mechanisms such as co-location, face-to-face informal communication, and collaborative techniques are essential to enable integration in the form of collaboration.

PD process architecture and Integration / Integration mechanisms relations across cases

Assessing the relations between the PD process architecture, the integration process and the integration mechanisms, cross-case analysis results suggest that whereas the PD process architecture is modular (case *Alpha* and case *Beta - System level -*), the integration process consists in communication and the integration mechanisms comprise: standard specifications, enterprise communication technologies, and product champions. On the contrary, whereas the PD process architecture is integral (case *Beta - Module level -* and case *Gamma*), the integration process consists in collaboration and the integration mechanisms comprise: co-location, face-to-face informal communication, and collaborative techniques.

Hence, whereas the PD process architecture is modular, requirements for working collectively decrease and configured integration mechanisms enable integration in the form of communication. On the contrary, whereas the PD process architecture is integral, requirements for working collectively increase and configured integration mechanisms enable integration in the form of collaboration.

Product architecture and PD process architecture relations across cases

Assessing the relations between the product architecture and the PD process architecture, cross-case analysis results suggest that whereas the product architecture is modular (case *Alpha* and case *Beta - System level -*), the PD process architecture is modular. On the contrary, whereas the product architecture is integral (case *Beta - Module level -* and case *Gamma*), the PD process architecture is integral.

Product development organization and 3D-CE elements relations across cases

Assessing the relations between the PD organization and the 3D-CE elements (i.e., the PD process architecture, the integration process, and the integration mechanisms), cross-case analysis results suggest that whereas the PD organization is global captive (case *Alpha* and case *Beta - System level -*), the PD process architecture is modular, the integration process consists in communication and the integration mechanisms comprise: standard specifications, enterprise communication technologies, and product champions. On the contrary, whereas the PD organization is local (case *Beta - Module level -* and case *Gamma*), the PD process architecture is integral, the integration process consists in collaboration and the integration mechanisms comprise co-location, face-to-face informal communication, and collaborative techniques.

Hence, whereas the PD organization is global captive, the PD process architecture is modular, requirements for working collectively decrease and configured integration mechanisms enable integration in the form of communication. On the contrary, whereas the PD organization is local, the PD process architecture is integral, requirements for working collectively increase and configured integration mechanisms enable integration in the form of collaboration.

CONCLUSIONS AND DISCUSSIONS

In the next chapters the research question is answered discussing how high performing companies configure product development process architecture, integration process and integration mechanisms to facilitate 3D-CE in product development practices depending on product development organizational form and on product architecture. Further, observations derived from the case studies are discussed. Then, the managerial implications and the theoretical contributions of the research are advanced and discussed. Finally, research limitations and further research directions are presented.

13. CONCLUSIONS

It does not matter how optimum production process and supply chain parameters are, if product parameters basically do not fit with the production process and supply chain design, optimum service and cost are not achievable. Hence, aligning product, process and supply chain parameters is essential to leverage production process and supply chain capability, to improve product development performance and, beyond that, to enhance company growth.

Aligning product, process and supply chain parameters implies to combine product design issues with production and supply chain considerations. The three-dimensional concurrent engineering (3D-CE) is widely recognized as the approach to product development leading to combine cross-functional design issues through the simultaneous and coordinated design of products, production processes and supply chains.

However, as organizations exploit distinct product development practices ranging from local to global product development, a dearth in the academic literature consists in explaining how 3D-CE should be facilitated according to distinct product development practices. Tackling the dearth, a widely exploration of the academic literature drew out the product development process architecture, the integration process and the integration mechanisms as the elements facilitating 3D-CE, whereas the product development organizational form and the product architecture as the elements affecting 3D-CE in product development practices. Hence, the results of the research explain how high performing companies configure product development process architecture, integration process and integration mechanisms to facilitate 3D-CE in product development practices depending on product development organizational form and on product architecture.

In the next sections the results of the research are discussed starting from how each element facilitating 3D-CE in product development practices is configured depending on the product architecture and the product development organization.

How high performing companies configure the PD process architecture depending on the product architecture and the PD organizational form

Case study results suggest that high performing companies, exploiting global PD practices in a context where the product architecture is modular and the PD organization is global captive, design modular product development process architectures (case *Alpha* and case *Beta - System level -*).

On the contrary, high performing companies, exploiting local PD practices in a context where the product architecture is integral and the PD organization is local, design integral product development process architectures (case *Beta - Module level -* and case *Gamma*).

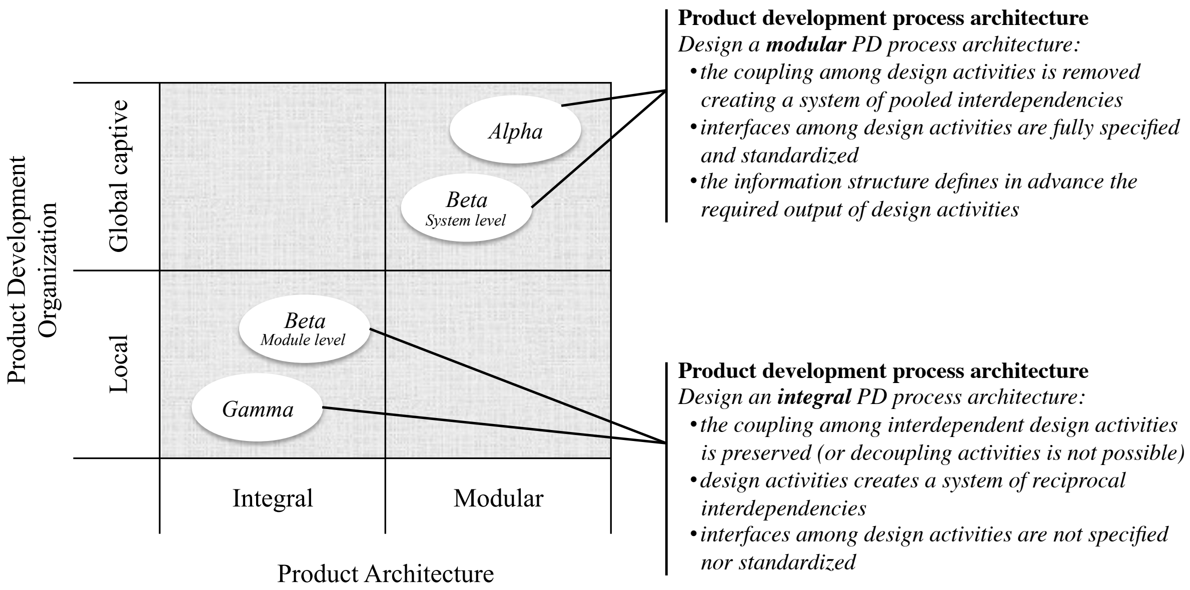

Figure 41. Research results: focus on product development process architectures.

In case *Alpha* and in case *Beta - System level -*, the companies, designing a modular product development process architecture, established a system of pooled interdependent design activities in which interfaces among activities related to the design of the power device and the design of distinct packaging system modules were fully specified and standardized. Hence, specifying in advance the required output of design activities, the companies decoupled interdependent activities allowing specialists to perform design tasks separately interacting through information transfer.

On the contrary, in case *Gamma* and in case *Beta - Module level -*, the companies, designing an integral product development process architecture, established a system of reciprocal interdependent design activities in which the coupling among activities related to the design of the hydraulic caliper and the design of a specific packaging system module was preserved. Hence, as activities were tightly coupled, specialists performed design tasks collectively working side by side.

In conclusion, organizations, operating in a context where the product architecture allows to decouple design activities and exploiting global product development practices in which resources are geographically dispersed, should design the product development process architecture as modular as possible minimizing requirements for working collectively and, in turn, allowing specialists to perform design tasks separately. On the contrary, organizations, operating in a context where the product architecture requires to preserve the coupling across design activities, should design an integral product development process architecture preserving requirements for working collectively and, in turn, exploiting local product development practices in which resources are co-located.

How high performing companies configure the integration process depending on the product architecture and the PD organizational form

Case study results suggest that high performing companies, exploiting global product development practices in a context where the product architecture is modular and the PD organization is global captive, configure an integration process consisting in communication (case *Alpha* and case *Beta - System level* -).

On the contrary, high performing companies, exploiting local product development practices in a context where the product architecture is integral and the PD organization is local, configure an integration process consisting in collaboration (case *Beta - Module level* - and case *Gamma*).

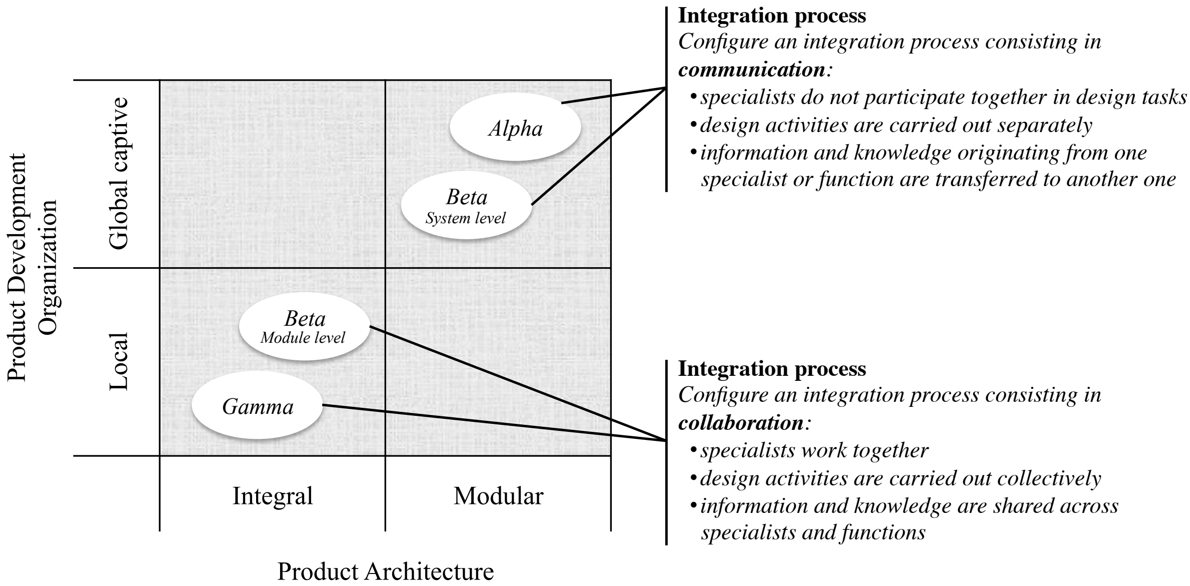

Figure 42. Research results: focus on integration processes.

In case *Alpha* and in case *Beta - System level* -, the companies, configuring an integration process consisting in communication, established a process in which information and knowledge were transferred from specialists to specialists. As the companies decoupled design activities, there was no need for on-going adjustment among tasks, consequently specialists assigned to a specific module communicated relevant information to specialists assigned to a distinct module when required (e.g., specialists in charge of the design of a specific packaging system module communicated relevant information to specialists in charge of the design of a distinct module when required). Hence, to establish an integration process consisting in communication, specialists did not have to work together, instead to perform design activities separately interacting through information transfer.

On the contrary, in case *Beta - Module level* - and in case *Gamma*, the companies, configuring an integration process consisting in collaboration, established a process in which information and knowledge were mutually shared across specialists satisfying the need of on-going adjustment among design activities (e.g., the design of the caliper required on-going adjustment with the design of the machining and the assembly processes). Hence, to establish an integration process consisting in collaboration, the companies led specialists to work together performing design activities collectively.

In conclusion, organizations, operating in a context where the product architecture allows to minimize the need of on-going adjustment among design activities and exploiting global product development practices in which resources are geographically dispersed, should configure the integration process on communication minimizing the need of mutually share information and, in turn, allowing specialists to perform design tasks separately. On the contrary, organizations, operating in a context where the product architecture requires on-going adjustment among design activities, should configure the integration process on collaboration preserving the need of mutually share information across specialists and, in turn, exploiting local product development practices in which resources perform design activities collectively.

How high performing companies configure integration mechanisms depending on the product architecture and the PD organizational form

Case study results suggest that high performing companies, exploiting global product development practices in a context where the product architecture is modular and the PD organization is global captive, implement integration mechanisms capable of enabling integration in the form of communication (case *Alpha* and case *Beta - System level* -).

On the contrary, high performing companies, exploiting local product development practices in a context where the product architecture is integral and the PD organization is local, implement integration mechanisms capable of enabling integration in the form of collaboration (case *Beta - Module level* - and case *Gamma*).

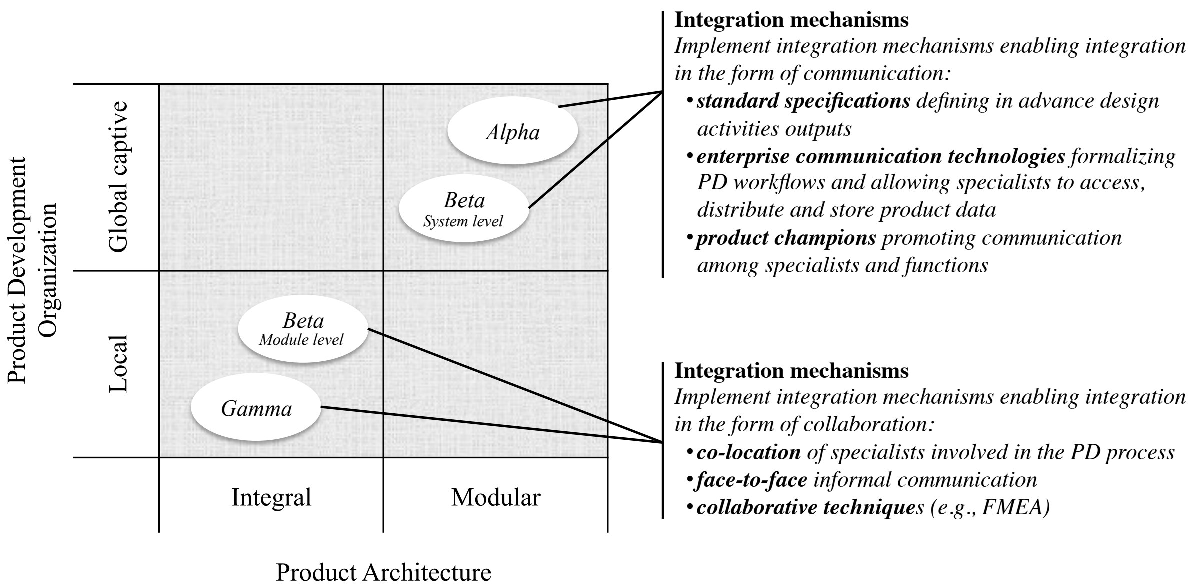

Figure 43. Research results: focus on integration mechanisms.

In case *Alpha* and in case *Beta - System level* -, the companies, implementing integration mechanisms comprising standard specifications, enterprise communication technologies, and product champions, enabled and facilitated integration in the form of communication. In detail, as the companies established an integration process consisting in communication, the implemented integration mechanisms comprise: (i) standard specifications defining in advance design activities outputs; (ii) enterprise communication technologies formalizing product development process workflows and allowing specialists to access, distribute and store product data; and (iii) product champions promoting communication among specialists. Hence, the companies, implementing integration mechanisms capable of enabling integration in the form of communication, facilitated integration across specialists performing design activities separately.

On the contrary, in case *Beta - Module level* - and in case *Gamma*, the companies, implementing integration mechanisms comprising co-location, face-to-face informal communication, and collaborative techniques, enabled and facilitated integration in the form of collaboration. In detail, as the companies established an integration process consisting in collaboration, the implemented integration mechanisms comprise: (i) co-location of specialists involved in the product development; (ii) face-to-face informal communication; and (iii) collaborative techniques (e.g., the FMEA). Hence, the companies, implementing integration mechanisms capable of enabling integration in the form of collaboration, facilitated integration across specialists performing design activities collectively.

In conclusion, strategic, humanware, formalization, direct supervision, and dedicated team integration mechanisms are configured and implemented in each company designing a product. Whereas, the extent to which software, standardization, formal mutual adjustment and informal mutual adjustment mechanisms are implemented depends on the product architecture and the PD organizational form. In fact, organizations, operating in a context where the product architecture allows to configure an integration process consisting in communication and exploiting global product development practices in which resources are geographically dispersed, should implement integration mechanisms capable of enabling integration in the form of communication. Whereas, organizations, operating in a context where the product architecture requires to configure an integration process consisting in collaboration and exploiting global product development practices in which resources are geographically dispersed, should implement integration mechanisms capable of enabling integration in the form of collaboration.

How high performing companies configure PD process architecture, integration process and integration mechanisms to facilitate 3D-CE in product development practices depending on PD organization and on product architecture

In summary, case study results suggest that high performing companies, exploiting global product development practices in a context where the product architecture is modular and the PD organization is global captive, facilitate 3D-CE (i) designing a modular PD process architecture, (ii) configuring an integration process consisting in communication, and (iii) implementing integration mechanisms capable of enabling integration in the form of communication (case *Alpha* and case *Beta - System level* -).

On the contrary, high performing companies, exploiting local product development practices in a context where the product architecture is integral and the PD organization is local, facilitate 3D-CE (i) designing an integral PD process architecture, (ii) configuring an integration process consisting in collaboration, and (iii) implementing integration mechanisms capable of enabling integration in the form of collaboration (case *Beta - Module level* - and case *Gamma*).

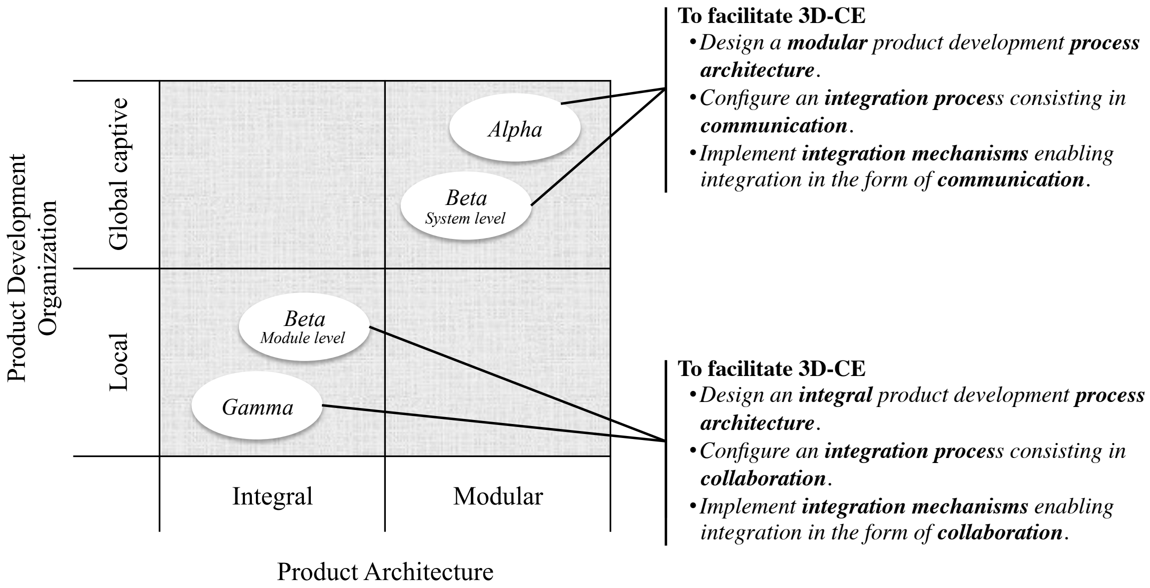

Figure 44. Research results.

In conclusion, organizations, operating in a context where the product architecture allows to decouple design activities and exploiting global product development practices, should design a modular PD process architecture determining a system of pooled interdependent activities. Cut down the need of on-going adjustment among design activities, an integration process consisting in communication should be configured establishing a process in which information is transferred from specialists to specialists, instead of being mutually shared across specialists. Finally, configured the integration process on communication, integration mechanisms capable of enabling communication across specialists performing design activities separately should be implemented.

On the contrary, organizations, operating in a context where the product architecture requires to preserve the coupling among design activities and exploiting local product development practices, should design an integral PD process architecture determining a system of reciprocal interdependent activities. Preserved the need of on-going adjustment among design activities, an integration process consisting in collaboration should be configured establishing a process in which information is mutually shared across specialists. Finally, configured the integration process on collaboration, integration mechanisms capable of enabling collaboration across specialists performing design activities collectively should be implemented.

14. DISCUSSIONS

Differences and similarities in the observed products

In the present research, it has been chosen to include in the sample firms operating in similar industries (i.e., organizations positioned in the 25-28 ISIC range: manufacturer of fabricated metal products, manufacturer of electronic products, manufacture of electrical equipment, and manufacture of machinery and equipment). However, even though the three organizations belong to similar industries, the observed products differ. As a matter of fact, the BCD power device, the flow-pack packaging system, and the cast iron hydraulic caliper are physically completely different products.

Although the products present distinct physical characteristics, from a conceptual perspective the BCD power device, the flow-pack packaging system, and the cast iron hydraulic caliper are similar. The BCD power device comprises blocks (e.g., the spindle motor block, and the voice coil motor block) and, in turn, each block is obtained combining electrical components. The flow-pack packaging system comprises modules (e.g., the row-distributing module, and the in-line loading module) and each module is obtained combining mechanical and electrical components. Finally, similarly to the power device and the packaging system, the cast iron hydraulic caliper is obtained combining metal and rubber components. Hence, to be designed, each observed product requires the development of its components, whether electrical, mechanical, metal, or rubber, and the integration of those components in order to obtain product blocks, modules and/or the product itself depending on the product architecture. As a consequence, even though the object of the design activities differs across cases, those activities might be considered conceptually similar.

These observations suggest that, even though the products appear completely different, design activities performed to develop each product are conceptually similar, so the configuration of the 3D-CE approach might not be influenced by the aforesaid dissimilarities.

Would case studies suggest any relations between 3D-CE and performance?

Although the choice to exclusively include in the research sample high performing organizations (i.e., organizations leading the market segment in terms of market share and product performance and having outstanding manufacturing and supply chain capabilities) and to investigate product development projects in which the product comes into market on time and within budget is coherently with the aim of observing effective 3D-CE practices, case studies observation does not provide any evidence on the relations between the 3D-CE and performance indicators. However, as discussed in the section *"Benefits of the 3D-CE approach in product development"*, in theory and in practice it is well established that effective 3D-CE approaches improve product development performance and leverage production process and supply chain capabilities such as time-to-market reduction, development cost reduction, product quality improvement, delivery lead time reduction, and production and logistic cost reduction. Therefore, it has been assumed that effective 3D-CE and, in turn, the fit of the elements enabling 3D-CE with the contextual elements leads to higher performance in terms of time, cost and quality, thus considering of limited interest to perform research about the relations between the 3D-CE and performance indicators.

Would case studies suggest any relations between 3D-CE and supply chain structure?

Observation derived from case studies indicates that the organizations included in the research sample operate in global supply chain networks in which suppliers, manufacturers and distributors are geographically spread (Hieber, 2002). Company *Alpha* purchases wafers from worldwide manufacturers of silicon and operates a worldwide network of fabrication, EWS and packaging plants. Similarly, company *Beta* purchases mechanical parts and system accessories from worldwide manufacturers and operates a worldwide network of operating plants, parts distributors and commercial agencies. Likewise, company *Gamma* purchases caliper components from around 70 worldwide manufacturers and operates a worldwide network of production plants.

However, even though each observed organization operates in a global supply chain network, the 3D-CE approach established in cases *Alpha* and *Beta – System level* – differs from the one established in cases *Beta – Module level* – and *Gamma*. In fact, the 3D-CE approach established in cases *Alpha* and *Beta – System level* – consists in designing a modular product development process architecture, configuring an integration process consisting in communication, and implementing integration mechanisms comprising standard specifications, enterprise communication technologies, and product champions. Whereas, the 3D-CE approach established in cases *Beta – Module level* – and *Gamma* consists in designing an integral product development process architecture, configuring an integration process consisting in collaboration, and implementing integration mechanisms comprising co-location of specialists, face-to-face informal communication, and collaborative techniques.

These arguments suggest that the supply chain structure appears not to be related to the 3D-CE approach established in product development practices. In fact, it is here inferred that the product development organizations might be either local or global captive whether an organization operates in a local or a global supply chain network. Hence, as the 3D-CE approach differs according to the product development organization, it might not be affected by the supply chain structure.

Would case studies suggest any relations between 3D-CE and global team challenges?

As discussed in the section *"From co-located cross-functional teams to global cross-functional teams"*, teams constituted by members working and living in distinct countries face physical distance and cultural diversity which, in turn, might increase communication complexity, slow decision-making and create conflicting responsibilities (McDonough et al., 2001; Gupta and Wilemon, 1998).

Observation derived from case studies suggests that organizations, exploiting global product development practices, face global team challenges configuring a 3D-CE approach able to cut down the need of on-going adjustment among design activities and, in turn, to let specialists perform design activities separately. Hence, it is here inferred that designing a modular product development process architecture, configuring an integration process consisting in communication, and implementing integration mechanisms comprising standard specifications, enterprise communication technologies, and product champions enable organization to face challenges arising from the global dispersion of product, process and supply chain specialists.

Would case study observation be replicated across distinct product innovativeness?

In the present research, according to the choice of modelling the product innovativeness as a control variable, each observed product constitutes an incremental innovation providing improvements in the existing company technology and in the existing company market. As a consequence, case studies observation does not provide any evidence on how the observed phenomenon would be replicated across distinct level of product innovativeness.

However, as discussed in the section *"Factors influencing the configuration of integration mechanisms"*, the uncertainty associated with radical innovative products is much higher than in the case of incremental products, because as the degree of newness increases, the amount of relevant experience and knowledge decreases, which then enhances the degree of uncertainty surrounding the project. In turn, a higher degree of uncertainty makes the choice of product design parameters more sensitive to the choice of process and supply chain parameters and vice versa.

Hence, it is here inferred that the uncertainty associated with high degree of innovativeness requires to preserve the coupling among design activities leading specialists to constantly consider the impact of product parameters on process and supply chain parameters and vice versa. In fact, as the required output of product, process and supply chain design activities is not specifiable in advance, due to the higher degree of uncertainty, development tasks require on-going adjustments and adaptation so that specialists having different and complementary technical skills need to work together sharing design information and knowledge. On the contrary, the uncertainty associated with low degree of innovativeness does not require to preserve design activities interdependence as the impact of product parameters on process and supply chain parameters and vice versa is definable in advance, for instance, in the form of design rules. Hence, whether the required output of design activities is specifiable in advance, development tasks do not require on-going adjustments so that specialists might work separately interacting through information transfer.

These arguments suggest that the product innovativeness might affect the configurations of the elements enabling the 3D-CE in product development practices. Indeed, concerning radical innovations, requirements to preserve the coupling among product, process and supply chain design activities might lead to design a product development process architecture consisting in interdependent design activities. Further, needs to on-going adjustments and adaptation among design activities might induce organizations to configure an integration process letting specialists work collectively, and, in turn, to implement integration mechanisms capable of enhancing the share of functional expertise and of technological knowledge across team members. On the contrary, concerning incremental innovations, opportunities to decouple design activities might lead to design a product development process architecture consisting in pooled interdependent design activities. Further, possibilities to minimize the needs of on-going adjustments among design activities might lead to configure an integration process letting specialists work separately, and, in turn, to implement integration mechanisms capable of enhancing the transfer of information across team members.

Would case study observation be replicated across industries?

In the present research, according to the choice of observing organizations operating in similar industries, case studies observation does not provide any evidence on how the observed phenomenon would be replicated across industries.

However, building on a few studies, (Jacobides, 2005; Baldwin and Clark, 2000; Schilling, 2000), it is here inferred that the industry might affect the organization of the resources involved in the product development process. For instance, industries operating in an integrated mode (e.g., vertically integrated) might determine local product development organization, whereas disintegrated industries might determine global product development organization increasing efficiency through the division of labour and aiming to obtain potential gains from specialization. Further, the industry might also affect the possibility to decompose the product into modules influencing the form of the product architecture. In fact, in certain industries (e.g., the paper industry), it is simply not possible to decompose the product that, in turn, presents an integral architecture.

These arguments suggest that the industry does not directly affect the configuration of the elements facilitating 3D-CE practices, while it might affect the product development organization and the product architecture, which, in turn, influence the 3D-CE approach.

The flexible stage-gate model

Observation derived from case studies proves the adoption of stage-gate product development process models by each organization included in the research sample. In particular, it is interesting to notice that each organization adopts a flexible stage-gate model (Cooper, 2008) in which activities and even stages overlap and, in turn, do not wait for complete information before moving forward. In fact, case studies observation suggests that the value of a stage-gate model is pre-eminently organizational: gates serve as go/kill decisions points and do not have to represent constraints for moving novel products from idea to launch hazarding the time-to-market (e.g., a gate might be opened even though parts and components drawings have not been completely released).

15. MANAGERIAL IMPLICATIONS

In the current section, through observation derived from the case studies, a two-steps process to establish an effective 3D-CE approach in product development practices is proposed, starting with defining the product development organization and followed by designing the 3D-CE approach.

Building on Tripathy and Eppinger (2011), the first step, *defining the product development organization*, consists in defining the location of product, process, and supply chain specialists involved in the product development process. Indeed, the product development organization is implicitly defined determining the location of design activities. The selection of the activities to be offshored is influenced by the product development intent (e.g., to meet market needs creating direct connections with existing and potential markets, to seek efficiencies redistributing design activities in low cost countries, or in regions where technical expertise reside) and by the product architecture. Hence, the product development organization is the output of an iterative process involving the analysis of the product development intent and the decomposition of the designed product. In fact, decomposing the product into pooled interdependent modules allows organizations to analyse the product development intent related to each module and, in turn, to select design activities to be either centralized or offshored (e.g., design activities related to modules requiring direct connection with a specific market should be assigned to specialists based close to the market, whereas design activities related to modules seeking cost savings should be assigned to specialists based in low cost countries). Hence, in a context where the product architecture allows to decompose the product and the product development intent requires to geographically distribute specialists (e.g., specialists in charge of the design of innovative module are based where the technical expertise reside, whereas specialists in charge of the design of standard module are based in low cost counties), the product development organization should be global comprising resources located in distinct countries. On the contrary, in a context where the product architecture does not allow the decomposition of the product, design activities should be centralized and, in turn, the product development organization should be local comprising specialists based in a specific region according to the overall product development intent (e.g., whereas the overall intent is to increment knowledge on a certain technology, specialists involved in the product development process might be located where the sought expertise reside).

The second step, *designing the 3D-CE approach*, consists in configuring processes and mechanisms facilitating 3D-CE consistently with the product development organization. First the product development process architecture should be designed, and then the integration process and the integration mechanisms should be configured.

The design of the product development process architecture as well as being consistent with the product development organization is also influenced by the product architecture. In fact, as emerged from the case studies, whereas the product architecture allows to decompose the product into independent modules, the product development process architecture is designable modular. Hence, in a context where the product development organization is global and the product architecture is modular, the product development process architecture should be decomposed into pooled interdependent activities in order to minimize the need of on-going adjustment among design activities related to distinct modules. On the contrary, in a context where the product development organization is local and the product architecture is integral, the product development process architecture should be designed preserving the coupling among design activities in order to exploit co-location of specialists.

The configuration of the integration process and the integration mechanisms as well as being consistent with the product development organization is also influenced by the product development process architecture. In fact, as emerged from the case studies, the design of the product development process architectures determines design activities interdependencies and, in turn, the requirements of the integration process and the integration mechanisms (e.g., whereas the product development process architecture allows to decompose the process into independent design activities, the integration process should consist in communication and integration mechanisms should be capable of enabling integration in the form of communication). Hence, in a context where the product development organization is global and the product development process architecture has been designed modular, the integration process should be formed on communication and integration mechanisms should be configured to enable communication across specialists performing design activities separately. On the contrary, in a context where the product development organization is local and the product development process architecture has been designed integral, the integration process should be formed on collaboration and integration mechanisms should be configured to enable collaboration across specialists performing design activities collectively.

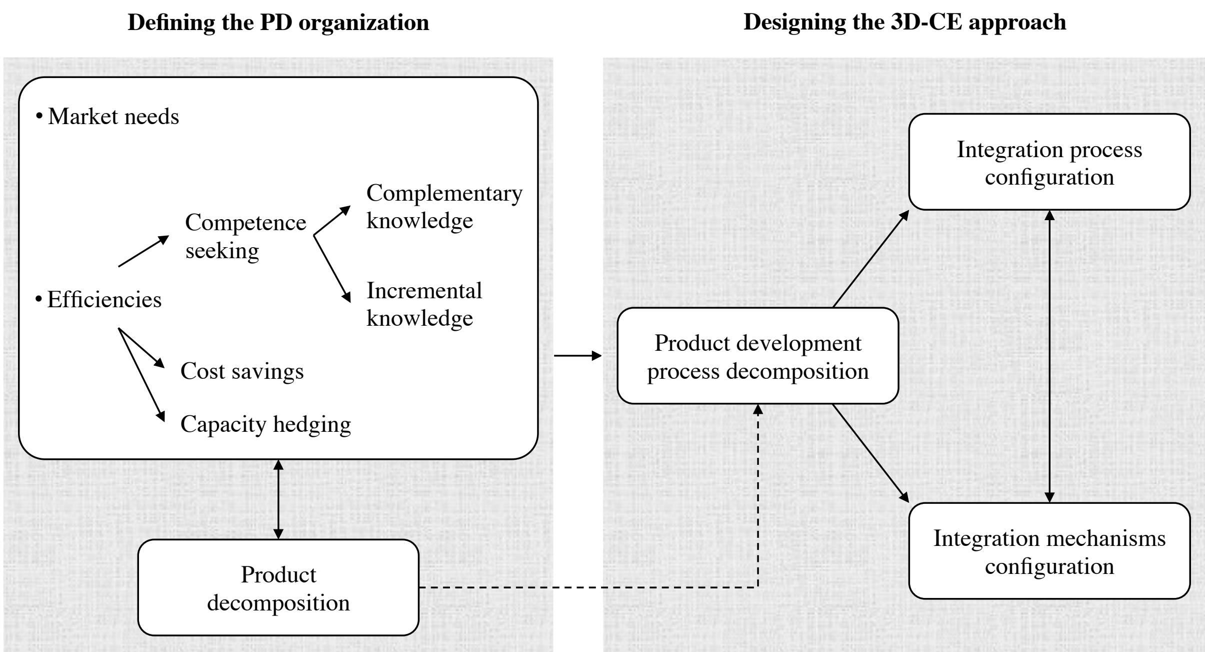

Figure 45. Steps toward designing the 3D-CE approach in product development practices.

In conclusion, distinct product development practices require tailored 3D-CE approach consistently designed with the nature of the product development organization.

16. THEORETICAL CONTRIBUTIONS

The research contributes to the academic literature concerning the global product development (Tripathy and Eppinger, 2011; Eppiger and Chitkara, 2009) and the integration of product development and supply chain management (Pero et al., 2010; Ellram et al., 2008; Hoek and Chapman, 2007; Fine 1998) addressing how high performing organizations facilitate 3D-CE according to distinct product development practices. In fact, as the reviewed academic discussion on GPD practices has been about what it is, why it should be done and how it should be deployed and the discussion on integration in GPD practices has been about how integration mechanisms allow building trust, encouraging collective goals and promoting motivation among global team members, how to design and implement effective 3D-CE in product development practices has been poorly investigated. Further, the research still contributes to theory as observations derived from the cases lead to formulate testable research propositions on how the elements facilitating and affecting 3D-CE are related to each other. Following, research propositions are introduced and discussed.

P1a. Integration in the form of communication is associated with integration mechanisms comprising standard specifications, enterprise communication technologies, and product champions, and vice versa.
P1b. Integration in the form of collaboration is associated with integration mechanisms comprising co-location of specialists, face-to-face informal communication, and collaborative techniques, and vice versa.

In the academic literature, several research studies (De Luca and Atuahene-Gima, 2007; McDonough et al., 2001; McDonough and Kahn, 1999; Paashuis and Boer, 1997; Kahn, 1996) suggest the existence of a correspondence between the extent to which the integration process consists in communication or in collaboration and the integration mechanisms designed and implemented to enable integration. Further, case studies provide support to the proposition proving that the configuration of integration mechanisms is related to the configuration of the integration process. In fact, in case *Alpha* and in case *Beta - System level* -, the integration process consisted in communication, decreasing the requirements for working collectively, and integration mechanisms comprised standard specifications, enterprise communication technologies, and product champions. On the contrary, in case *Beta - Module level* - and in case *Gamma*, the integration process consisted in collaboration, increasing the requirements for working collectively, and integration mechanisms comprised co-location, face-to-face communication, and collaborative techniques.

P2a. Modular PD process architectures are associated with integration in the form of communication along with integration mechanisms capable to enable communication.
P2b. Integral PD process architectures are associated with integration in the form of collaboration along with integration mechanisms capable to enable collaboration.

In the academic literature, Sanchez (2000) suggests that the product development process architecture might influence the correspondence between the information processing requirements of integration (i.e., the extent to which integration consists in communication and/or in collaboration processes) and the information processing capabilities of integration mechanisms (i.e., the configuration of integration mechanisms capable of enabling integration in term of communication and/or collaboration processes). Further, case studies provide support to the proposition proving that the product development process architecture is both related to the configuration of integration mechanisms and the configuration of the integration process. In fact, in case *Alpha* and in case *Beta - System level* -, in which the product development process architecture was modular, the integration process consisted in communication and integration mechanisms comprised standard specifications, enterprise communication technologies, and product champions. On the contrary, in case *Beta - Module level* - and in case *Gamma*, in which the product development process architecture was integral, the integration process consisted in collaboration and integration mechanisms comprised co-location, face-to-face communication, and collaborative techniques.

P3a. Modular product architectures are associated with modular PD process architectures.
P3b. Integral product architectures are associated with integral PD process architectures.

In the academic literature, Sanchez (2000) suggests that the product architecture might affect the product development process architecture determining the interdependence patterns of design activities. Further, case studies provide support to the proposition proving that the product development process architecture varies in relation to the product architecture. In fact, in case *Alpha* and in case *Beta - System level* -, in which the product architecture was modular, the product development process architecture was designed modular too. On the contrary, in case *Beta - Module level* - and in case *Gamma*, in which the product architecture was integral, the product development process architecture was designed integral.

P4a. Global PD organizational forms are associated with modular PD process architectures, integration in the form of communication and mechanisms capable to enable communication.
P4b. Local PD organizational forms are associated with integral PD process architectures, integration in the form of collaboration and mechanisms capable to enable collaboration.

In the academic literature, several research studies (Kleinschmidt et al., 2007; Eppinger and Chitkara, 2006; Barczak and McDonough, 2003; McDonough and Kahn, 1999) suggest that the product development organizational form might affect the design of the product development process architecture, the configuration of the integration process, and the configuration of the integration mechanisms. Further, case studies provide support to the proposition proving that the product development process architecture, the configuration of the integration process and the configuration of the integration mechanisms vary in relation to the nature of the product development organization. In fact, in case *Alpha* and in case *Beta - System level* -, in which the product development organization was global, the product development process architecture was designed modular, the integration process consisted in communication and integration mechanisms comprised standard specifications, enterprise communication technologies, and product champions. On the contrary, in case *Beta - Module level* - and in case *Gamma*, in which the product development organization was local, the product development process architecture was designed integral, the integration process consisted in collaboration and integration mechanisms comprised co-location, face-to-face communication, and collaborative techniques.

17. LIMITATIONS AND FURTHER RESEARCH DIRECTIONS

As the present study conducts to develop a provisional model to explain how organizations establish effective 3D-CE approaches in distinct product development practices using qualitative data in the form of cases studies might reduce the potential contribution to the academic literature even though the research sample includes exclusively high performing organizations and case studies investigate product development projects in which the product come in market on time and within budget. Further, as the research sample includes organizations operating in the metal and electronic manufacturing industry and the product innovativeness is modelled as a control variable, the present research does not provide any evidence on how the observed phenomenon would be replicated across industries and distinct level of product innovativeness. Finally, as cases present either an integral product architecture with a local PD organization or a modular product architecture with a global PD organization, the present research does not provide any evidence on how the observed phenomenon would differ in opposite contexts (e.g., an integral product architecture with a global PD organization, and a modular product architecture with a local PD organization).

Concerning further research directions, there is the opportunity to mature the present research by testing inferred propositions on a larger sample, including organizations operating in distinct industries and investigating product development projects whether the product did not come in market on time and within budget or the designed products present distinct level of innovativeness. Extending the research sample, it is expected to observe organizations operating either in a context where the product architecture is integral and the PD organization is global captive or in a context where the product architecture is modular and the PD organization is local.

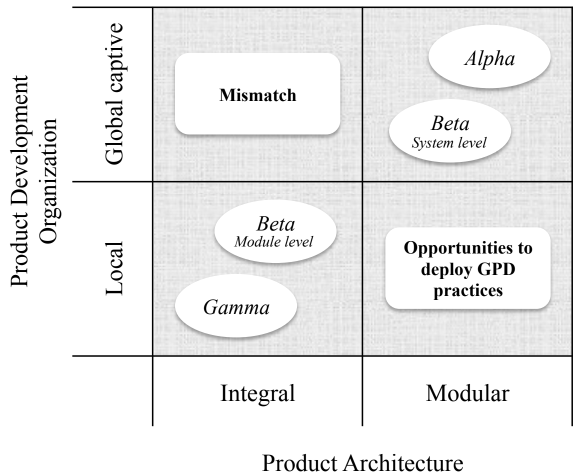

Figure 46. Product Architecture - PD Organization matrix.

In detail, concerning organizations situated in the upper left square of the matrix, it is expected to observe cases in which the product did not come in market on time and within budget as a mismatch between the product architecture and the information processing requirements related to global PD organization would be present. Whereas, concerning organizations situated in the lower right square of the matrix, it is expected to observe cases in which a proper product decomposition would give opportunities to deploy GPD practices.

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APPENDIX

INTERVIEW BLUEPRINT

Introduction

1. General description of interviewed position and background.
2. General description of products, manufacturing processes and supply chain.
3. General description of the most important product line (later on the Product Line).
4. Detailed description of the most important product (later on the Product) belonging to this line with the aim of assessing the extent to which product functional components are interchangeable, autonomous and individually upgradable and the extent to which components interface are standardized.
5. Detailed description of the Product manufacturing and assembly processes.
6. Detailed description of the Product supply chain.

Innovation process

(related to the Product Line)

7. What is the number of radical innovation projects managed over a year? What is the number of incremental innovation projects?
8. What are the differences between a typical incremental and a typical radical innovation project in terms of product development process structure (stages and gates) and content?
9. What is the average lead time for radical innovation projects? And for the incremental ones?
10. Concerning radical innovation projects, what is the number of centralized product development projects and the number of global projects?
11. What are the differences between a typical centralized project and a typical global project in terms of product development process structure (stages and gates) and content?
12. What is the average lead time for local projects? And for global projects?
13. What are the most important performance criteria used to evaluate product development projects?
14. Are product development projects generally run according to the planned lead times and to the fixed budget?
15. Did you generally noticed problems in terms of product development process and supply chain effectiveness and efficiency at the launch of products?

General description of the project

(related to a project in which the Product come in market on time and within budget)

16. Was the project a radical or an incremental innovation?
17. Did the development project run according to the planned lead times and to the fixed budget?
18. Did you noticed problems in terms of product development process and supply chain effectiveness and efficiency at the launch of the Product?

Organization of resources involved in the product development project

19. How were the resources involved in the product development process organized?
20. How was the rest of the organisation involved during the product development process?
21. What was the structure of the team (e.g., cross-functional team, self-contained team)?
22. What were the functions from which product development team members were drawn?

Organization of product engineers, process engineers and supply chain professionals

23. How was the design department function organized (number of resources, location of resources, responsibilities of resources)?
24. How were product engineers allocated to the project team?
25. How was the operation department organized (number of resources, location of resources, responsibilities of resources)?
26. How were process engineers allocated to the project team?
27. How is the supply chain management department organized (number of resources, location of resources, responsibilities of resources)?
28. How were supply chain professionals allocated to the project team?

Product development process

29. Can you describe the structure of the product development process?
30. Can you describe in detail the structure and content of each stage and gate?
31. Are you satisfied with your process model? Is the process in phase of being redesigned? Do you think it is proper to reassess the model? If yes, why and what would you change?
32. In the definition stage of the project plan, what were the logic and the criteria according to which the product development activities were decomposed and sequenced?
33. Which development activities were planned in sequence, which ones in overlap and which ones in parallel?
34. Was there a relationship between the way in which activities were sequenced and the interfaces among design activities?
35. Did the localization of the resources influence the way in which the new product development process architecture has been defined? If yes, how?
36. Did the level of interdependence among the development activities influence the way in which the new product development process architecture has been defined? If yes, how?
37. Did the level of product modularity influence the way in which the new product development process architecture has been defined? If yes, how?

Integration process

38. Did product design engineers participate together in product design activities?
39. Did product engineers, process engineers and supply chain professionals work together in development activities that traditionally were considered the preserve of a unique function?

Integration mechanisms adopted in the product development project
Strategic mechanisms

a. What were the strategic mechanisms used to facilitate integration among the resources involved in the product development process?
b. Was there a clear, visible and shared product development strategy in terms of markets and technologies the business unit should focus on? If yes, can you describe it?
c. Was there a clear, visible and shared project goal? If yes, what is the goal (e.g., target cost, % of sales to be generated in the next years with the new product development, % of profit)?
d. To what extent the perspective of product engineers, process engineers and supply chain professionals were complementary rather than conflicting?
e. Does the project goal drive trade-off decisions among product engineers, process engineers and supply chain professionals?
f. What were the decisions in which the project goal acted as a driver? On the contrary, what were the decisions in which the project goal did not act as a driver?

Technological mechanisms

Knowledge and skills

a. Did resources involved in the project understand specialist activities carried out by other functions? How did they acquire such knowledge?
b. Was the downstream function able to transfer its technical requirements to the upstream function in the product development process? How did the transfer occur?
c. Had project team resources been trained to develop the skills required to work in teams?
d. What were the main causes of conflicts among product engineers, process engineers and supply chain professionals? How were the conflicts solved?
e. How did resources involved in the project select goals? How did resources meet goals?
f. How did project resources take or share the responsibility for the activities aimed at meeting the goals?
g. How did resources involved in the project monitor and, if necessary, correct development activities?

Software

a. What computer software were used to support both development activities and integration among the resources involved in the project?
b. How did computer software support integration among different functions?
c. What were the prerequisites that guarantee the exploitation of the potential of computer software used?
d. Did you use other methods and/or management practices to support integration among the resources involved in the project?

Organizational mechanisms

Standardization and Formalization

a. Did you use standard work procedures to coordinate the integration among project team members?
b. Were the development activities outputs standardized?
c. What development activities were applied with standardization concepts?
d. What were the goals that were going to be meet through the standardization of work procedures and of development activities standards?
e. Did the model adopted for the product development process structure the way in which the project team resources interact?

Direct Supervision

a. What was the role of the top management during the project? What were the decisions made by the top management?
b. Was a project leader nominated? If yes, what was the function from which the project leader was drawn? What were the responsibilities and the objectives of the project leader across the different stages of the product development process?
c. Did the project leader act as a integrator among project team members?
d. What methods and/or management practices did the project leader use to coordinate the product development projects?
e. What were the decisions made by the project leader?
f. How did the project leader make decisions?
g. How did the project leader collect information on the status of the activities of the different functions involved in the project?

Mutual adjustments

a. Were there in the project team resources with liaison or product champion roles?
b. Did the coordination of project activities occur also through formal progress meetings? Were there different types of formal meetings? What was the frequency and what were the contents of each type of meeting? Who participates? How were they carried out?
c. Were there face-to-face meetings during the project? In what stages of the project?
d. What was the frequency of face-to-face meetings? Did their frequency depend on the project stage?

Dedicated teams

a. Were cross-functional teams adopted ?
b. Were transition teams used at the end of the project?