Effect of product lifecycle management on new product development performances: Evidence from the food industry

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Food industry is becoming more and more crucial for all kind of economies worldwide. Though, despite the higher attention this sector is gaining, there is still uncertainty on how to properly manage food New Product Development (NPD) process. In particular, it is not clear whether IT solutions and methods successfully ap-plicable to traditional manufacturing industries – in particular Product Lifecycle Management (PLM) solution-would have the same positive impact in the food industry. In this context, the present study starts from the belief that even in the food industry the NPD process can benefit from the implementation of a PLM solution. We introduce and test three propositions: (i) the implementation of a PLM solution is positively related to firm's process management capability, thus improves NPD performances; (2) the implementation of a PLM solution is positively related to firm's coordination capability, thus improves NPD performances; and (3) the usefulness of PLM functionalities differs for each NPD stage. The study is based on a multiple case study approach, with data gathered from several multinational food companies. Our results confirm the propositions were correct and specifically the implementation of PLM solutions in food companies positively affect process management and coordination capabilities, resulting in the improvement of overall NPD performance. Moreover, this paper dis-cusses which food NPD stages are affected by PLM solutions and how.

Keywords: New Product Development (NPD), New Food Development (NFD), Product Lifecycle Management (PLM), PLM solution, Process management capability Coordination capability, Food industry, Performance

1. Introduction

Nowadays the food sector is considered one of the most important sectors of the current economy and it has drawn the attention of different authorities and organizations [1]. Despite the importance of this sector being recognized globally, companies operating in the food industry still face many challenges in managing their products and competing in the market [2]. In fact, over the last years, an accelerated number of tasks have influenced food companies, pushing them to focus on innovation to maintain, or to gain competitive advantage [3]. In this context, there are different challenges affecting these companies and most of them are related to driving change and creating new demands on product development. Successful companies have to understand and to accept these challenges, and find ways to address them through processes and solutions focused on *new product innovation* and *development* [3,4].

New product success requires excellence in three categories: (i) reducing product development cycle time, (ii) increasing product development innovation and (iii) reusing company knowledge assets [3]. To achieve success in these three areas, companies must look to the factors that drive innovation: people, knowledge, and systems. The latter (systems) enables employees to efficiently leverage the company's expertise and knowledge, as well as to effectively generate big ideas and profitable products. Product Lifecycle Management (PLM) solution could be seen as a key driver of innovation and success [2,5–8]. Though, while successful applications of PLM solutions can be found since the late 1990s in the so-called *discrete* manufacturing industries – where automotive sector shows the greater number of adopters [9]-very little is known about the impacts of PLM solutions implementations in New Product Development (NPD) within *process* manufacturing kind of businesses, where food industry belongs to.

The present study starts from the assumption that, as it happens in NPD in discrete manufacturing industries, also the food NPD process can benefit from the implementation of a PLM solution. This idea originates from the peculiarities that characterize the food NPD process, as outlined in the following. In the food industry, safety is extremely

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relevant [10] especially because of the products vulnerability; e.g. dealing with natural products that are often perishable. Thus, they could become harmful if not managed in a timely and safe manner [11]. It seems then logical to consider as necessary to dispose of a huge number of real-time data about food properties during NPD (composition, state, temperature, etc.) that must be managed and combined with other information. The use of the PLM solution allows to maintain full traceability of accurate and complete product data through the entire product structure, from finished products down to ingredients and packaging materials. Moreover, providing a single, reliable source of technical product description, consents to reduce the risk of quality problems due to product content errors, and to support faster new product introduction. In addition, managing food safety risks across the product development process requires documented policies and procedures that describe how to deal with the product throughout its life cycle [12]. Recipes and formulas must be certified for compliance with regulations. Furthermore, the latter vary from country to country. Indeed, currently, there are myriad of laws, regulations, standards, processes, tools and technologies intended to ensure food safety. Government agencies continue to impose complex and ever-changing regulations on the industry. An example is the Hazard Analysis and Critical Control Points (HACCP) protocol [13], which follows a systematic approach to identify, evaluate and control steps in the process that are critical to food safety. As suggested by Granros [14], a fully automated HACCP protocol ensures that proper controls are developed and integrated into appropriate downstream processes and systems [14]. In this scenario, food companies have to meet all these requests by producing profitable products that are also nutritional balanced, flavorful, safe and appealing [10]. The proper use of the PLM solution supports companies to identify what regulations, policies and obligations are applicable to them. Furthermore, it allows to proactively ensure compliance throughout the product life cycle and fully integrate product quality and food safety into the process of developing and managing products.

Moreover, while retailers and food service operators are demanding improved productivity and lower prices from the industry, consumers have renewed concerns about food safety and are expecting new health and wellness products [15] calling for clearer and more accurate labels [10]. Thus, even in this case, the correct use of the PLM solution allows to ensure product integrity, with a real-time understanding of the impact on compliance, nutrition, and other product characteristics. This solution helps also to improve the communication with the final customer, fostering companies to develop and revise product packaging and labels more effectively, improving cross-functional tasks among technical, marketing, and design teams.

Since in the literature, almost no studies investigate the effect of PLM solutions on NPD performances in the food industry, this paper wants to cover that gap. The main idea in which this work is grounded is that even in the competitive and highly regulated food and beverage industry, an integrated PLM solution can improve the NPD performances, affecting both firms' *process management capability* and *coordination capability* (these two dimensions will be presented in the next section). Despite the growing importance assumed by PLM solutions in the scientific literature, not only few studies investigate the moderating effect of a PLM solution adoption for NPD performances [16], but also none of them is on food industry. Building on the pioneer work of Tai [16], with this study we are investigating how PLM solutions can improve NPD performances in the food industry, as well as at which stages of the food NPD process are affected by such solutions and how (which performance are influenced), since we expect different phases of NPD might require different data input and activities to be performed.

Not only literature lacks of studies able to explain the impact of PLM solutions on food NPD performance, but also food NPD process has not been clearly described yet. This is why with this research we want to first explore and schematize a generic food NPD process, that we call New Food Development (NFD) process. By doing that we are focusing on big enterprises, since large firms usually have a more formalized and structured NPD process, as well as a PLM solution can often represent an expensive investment usually only large firms can afford.

After an introduction of the conceptual background behind this study, and of the relative propositions (Section 2), we describe the research structure and explain the methodology used to conduct the study (Section 3). In Section 4, the findings of the research are presented and later discussed in Section 5. Finally, Section 6 concludes the paper, summarizing main contribution – both in term of knowledge and practice- of this research and outlining future and ongoing research directions.

2. Conceptual background and research model

2.1. IT solutions and NPD performance

The term 'life cycle' generally indicates the whole set of phases from 'its cradle to its grave'. Product life cycle can be defined by three main phases: Beginning of life (BOL) including design and manufacturing, Middle-of-life (MOL) including distribution, use and support and, and End-of-life (EOL) where products are retired in order to be recycled or disposed [17]. This paper focuses on the BOL phase, as it is recognized as the most adding value phase [18].

Creating an integrated product information environment is an important determinant of a company's capacity to manage the life cycle of their products [19]. Literature proposes various Information Technology (IT) solutions that can support NPD [20–22]. Laurindo and de Carvalho [23] studied the link of enhanced performance of the NPD process while increasing their use of IT applications. The results of the analysis showed a competitive advantage, understood as a reduction in development cycle time and development cost, and the increase of customer satisfaction, perceived as the executive perception of improvement in final product quality. Moreover, according to MacCormack, Verganti, and Iansiti [24], the effective use of IT in NPD to provide agility and responsiveness has become a source of competitive advantage. The positive impact of IT on NPD can be achieved in different ways, with tools such as databases, project management applications, design tools (like CAD/CAE/CAM) and interconnection between the different players in the development process [23]. Thus, the role of IT in NPD can vary from simple administrative support to an important strategic position [25].

2.2. PLM

The acronym PLM has been broadly adopted and defined by different communities with slightly different interpretations. One definition that sums up all the previous is the one of Terzi et al. [19], defining the PLM solution as a product-centric – life cycle oriented business model, supported by IT, in which product data are shared among actors, processes, and organizations in the different phases of the product life cycle for achieving desired performances and sustainability for the product and related services. As a technology solution, PLM is an integrator of tools and technologies that streamlines the flow of information through the various stages of the product life cycle and seeks to provide the right information at the right time and in the right context [19]. Such solution has come to signify what some call the 21st-century paradigm for product development [26] as it addresses the entire life cycle of a product and its intimately cross-functional nature [27].

PLM is made of several ICT tools, platforms and systems. A special impact of PLM is on BOL phase with a huge variety of tools and systems supporting the various design and development activities [18]. PLM solutions include integrated information systems that comprise different industrial software such as Computer-Aided technologies (CAx) integration, product data management, computer-integrated manufacturing, and configuration management systems [16]. Product development information are integrated into a single logical database to support the definition and standardization of the workflows and objects created and used during product development [28–31]. PLM systems support product information for firms [32], assisting them in managing the creation, variation, and exchange of product-related information during the NPD process [33,34].

The augmented awareness of the benefits deriving from the implementation of PLM solutions has encouraged firms to invest in PLM systems. Nevertheless, past studies have reported differing outcomes regarding the effects of PLM systems on NPD performance [32,35,36].

2.3. Research fundamentals

This paper investigates if PLM functionalities affects the development of process management and coordination capabilities, thereby improving specific NPD performances.

Tai [16] argued that the ability to control and improve NPD processes (i.e., *process management capability*) and coordinate NPD participants (i.e., *coordination capability*) are critical and direct sources of superior NPD performances. PLM systems theoretically provide firms with a platform to rationalize NPD processes, align NPD activities, and manage knowledge production and dissemination in NPD contexts.

Process management capability is defined as a firm's ability to effectively control and improve NPD management processes [37]. The concept can be further divided in process efficiency capability and process optimization capability [16]. The first refers to a firm's ability to rationalize NPD processes in order to control the duration and cost of NPD [32], and to increase the reliability of processing tasks. The second concerns the firm's ability to optimize NPD processes to identify and exclude nonvalue-added activities from projects and efficiently allocate resources for tasks [38]. We propose that process management capability is a crucial source of NPD performance, thus enabling firms to benefit from time and cost savings.

Coordination capability refers to a firm's ability to coordinate NPD participants to achieve its own NPD objectives [39]. NPD involves complex and interdependent activities that necessitate firms to engage in information sharing and alignment for effective coordination with the various NPD participants. Information sharing and alignment refers to the development of mechanisms that promote the exchange of accurate information among NPD participants, so enabling the implementation of effective NPD strategies [39]. Robust information sharing and alignment can lead NPD participants to make appropriate decisions and to synchronize the output of their NPD participants' production activities with a single NPD plan [16]. We propose that coordination capability is a crucial source of NPD performance, thereby establishing participating coordination mechanisms to manage and align information.

It is possible to summarize these arguments as follows:

- Strong/Weak process management capability means that the firms have/have not the ability to control and improve NPD management processes,
- Strong/Weak coordination capability means that the firms have/have not the ability to coordinate NPD participants to achieve its own NPD objectives.

2.4. Propositions development

The implementation of PLM systems may enable firms to control and manage NPD processes [33]. Firms adopting PLM solutions could rationalize NPD processes [16], thereby improving process efficiency capability (reducing the time and cost of developing new products). In fact, PLM systems provide a platform based on virtual product design that could enable firms to accelerate feasibility analysis and cut the costs of concept validation and product testing [16]. Firms adopting PLM solutions continually improve NPD process optimization capability. In fact, PLM functionalities may allow the maintenance of product information for design reuse in a database, reducing partial redundancy and providing functions for resource configuration management, able to adaptively allocate resources to various NPD tasks [28]. Accordingly, the first proposition (P1) is:

P1. *The implementation of a PLM solution is positively related to process management capability, thus improving NFD performances.*

Furthermore, PLM solutions could act as coordination platforms that facilitate interactions within NPD participants [35], enabling the sharing of updated product information and the alignment of NPD process activities. The implementation of a PLM system could enable the exchange of food product information with NPD participants at different hierarchical levels, from the strategic to the operational ones. PLM systems are designed to manage large quantities of data and knowledge and exchanging information and knowledge among product development participants, thus supporting collaborative work in product development processes and enabling the efficient integration of product development participants and all associated information [16]. This should simplify knowledge-driven decision and product information sharing throughout the NPD life cycle, providing the data and knowledge required for accurate and prompt decision-making and adjustments. According to these arguments, the second proposition (P2) is:

P2. *The implementation of a PLM solution is positively related to coordination capability, thus improving NFD performances.*

As recognized by different studies [40,41], the establishment of an a priori theoretical framework is a necessary step in a qualitative data research project such as the one presented in this paper. In this sense, based on the considerations found in the literature, the authors identified the main areas involved in the present study through a logical theoretical framework (see Fig. 1). The objective of the framework is to provide an overview about the logical connections existing among constructs.

Connections among these concepts should be considered only as logical connections. The purpose of the framework is to lay out an overview of the main concepts involved in the present research, and to illustrate how they are logically related: our aim is not to measure the quantitatively impact of each concept on the others.

Finally, we found a gap in the literature concerning the level of analysis: to date, (i) no studies indicate which NPD stages are affected by PLM functionalities, and (ii) which NPD performances (for each NPD stages) are affected by PLM functionalities. In NPD processes, each phase has its own characteristics, participants, rules, etc., thus the

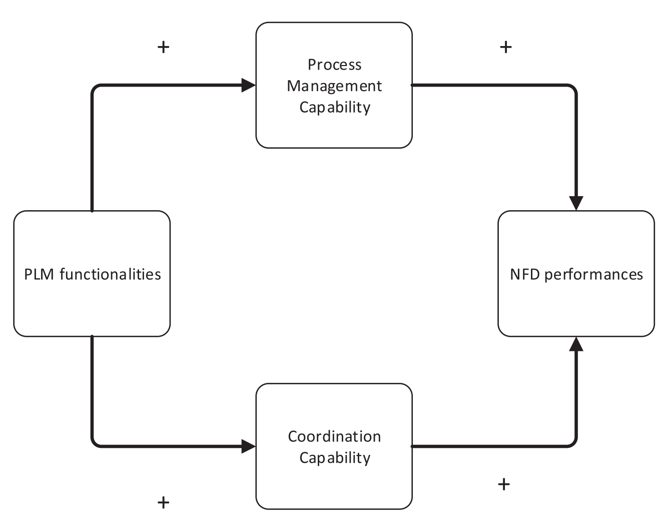

Fig. 1. The research model.

implementation of PLM functionalities in a NPD environment could lead to different effects for each stage. We believe that PLM systems, in a given industry, potentially does not affect all NPD stages in the same way, given the usefulness of PLM functionalities for each NPD stage and the needs of each NPD stage. We thus propose the following proposition:

P3. *The usefulness of PLM functionalities is different for each NFD stage.*

3. Methodology

3.1. Data collection

A two-stage multiple case study research methodology is adopted and implemented considering several multinational companies within the food industry. The first sample (sixteen multinational food firms) was identified and then analysed with the intention of developing a common NFD process for multinational food firms, as well as identifying performances which characterize this process and its phases. This preliminary stage represented the basis on which the next stage is grounded, aimed at confirming or denying the propositions. Then, for the second research stage, we considered (among firms considered in the first stage) only those that are currently using PLM functionalities to support their NFD process and activities. To do this, an Italian PLM supplier operating in the food sector helped to identify a group of companies belonging to the imposed constraints. This collaboration allowed us to have direct contact with its customers, which in turn streamlined the research process.

3.1.1. First sample of firms: multinational food firms

We followed a theoretical sampling to build our multiple case study research design so that the case analysis could assist in answering our research questions [42]. Accordingly, cases to be included in the first sample were selected based on the following criteria: (a) being a multinational food company; (b) being an innovative company; and (c) having a formalized and structured NPD process. Considering the general agreement that can be learnt from failure [43], this solicited a comparison among cases with different levels of performance, but also specifying the difference in food products. This research design allowed us to respect the maximum variation sampling principle, which suggests including extreme cases to obtain variations on dimensions of interest [44] and increase external validity.

According to Van de Ven and Poole [45], this study conceptualizes the process in terms of a sequence of stages based on the phase theory which attempts to identify the coherent periods of activity through which a process unfolds. This allows us to encapsulate essential rich process data in a simpler account of stepwise development or typical activities, a narrative describing the sequence of events on how development and change unfold. Cases were then analysed by combining retrospective and real-time orientations [46].

An interview protocol was established before data collection, and semi-structured interviews were conducted with key personnel from the candidate firms. Data was collected from both direct interviews (following a semi-structured protocol developed on the basis of the literature) and secondary sources (such as company briefings and internal reports) to provide data triangulation [47]. Before administering the interview protocol, candidate firms were identified by a number of different sources. These included expert opinion, past experience and knowledge of the research team.

Multiple interviews for each case allowed us to easily comply with investigator triangulation. The semi-structured protocol developed was previously validated and tested through a series of pilot cases to increase internal validity. Once the questionnaire had been validated and refined, it was emailed to the food companies, which have been answered through interviews. Results collected from the interviews have been elaborated and submitted to the company's managers for approval.

Following Eisenhardt [48], we analysed the data in two steps: the within-case analysis, and the cross-case analysis. As far as the former is concerned, its purpose is to provide an in-depth understanding and description of the phenomenon under investigation. Specifically, a within-case analysis represents the in-depth exploration of a single case as a standalone entity, and involves an intimate familiarity with a particular case in order to discern how the processes or patterns that are revealed in that case support, refute, or expand (a) a theory that the researcher has selected or (b) the propositions that the researcher has derived from a review of the literature and/or experience. The cross-case analysis divides the data by type across all cases investigated. Researchers then examines the data of that type thoroughly. When the evidence conflicted, deeper probing of the differences was necessary to identify the cause or source of conflict. In all cases, the researcher must treat the evidence fairly; to produce analytic conclusions answering the original "how" and "why" research questions. We used data to challenge and extend the theory [49]. During the repeated process of investigating the data, revising the theory, and returning to the data, the themes presented in this article eventually emerged. The results, presented in the next section, consist of a generic model of NFD process and its main measures of performance.

3.1.2. Second sample of firms: multinational food firms adopting a PLM solution

The second sample was obtained as a subset of firms belonging to the first one. At this stage, we considered only firms that adopted a PLM solution in managing their NPD process, thus obtaining a second sample of five firms out of the original sixteen. Again, data was collected from direct interviews involving different managers (belonging from both IT and R&D functions) for triangulation purposes. Once again, in line with Eisenhardt [48], we analysed the data in two steps: the within-case, and the cross-case. The result of this stage lead to unveil the impact of PLM functionalities on NFD activities, process management and coordination capabilities and NFD performances.

3.2. Data analysis

Data generated in the case studies were subject to content analysis, that breaks down case study data in order to analyse, conceptualise, and develop categories for the data. Qualitative content analysis is one of the numerous research methods used to analyse text data. Research using qualitative content analysis focuses on the characteristics of language as communication with attention to the content or contextual meaning of the text [50,51]. This aspect is very important for our research because standard names associated to the different topic under investigation have not been found. For example, the different interviews highlight that every food company gives different names for the NFD process phase. The same goes for performances, process management and coordination capabilities and PLM functionalities. According to Weber [52] qualitative content analysis goes beyond merely counting words to examining language intensely for the purpose of classifying large amounts of text into an efficient number of categories that represent similar meanings. The goal of content analysis is to provide knowledge and understanding of the phenomenon under study [52].

In this work, an inductive approach has been used because there is not enough former knowledge about the phenomenon, as realised from the literature review. According to Elo and Kyngäs [53], this process is represented by three main phases: (i) preparation, (ii) organizing and (iii) reporting.

- The preparation phase starts with selecting the unit of analysis. In the interviews, we identified three different unit of analysis: (i) the NFD process, (ii) the NFD process performances, and (iii) the PLM functionalities supporting the NFD process and impacting on the

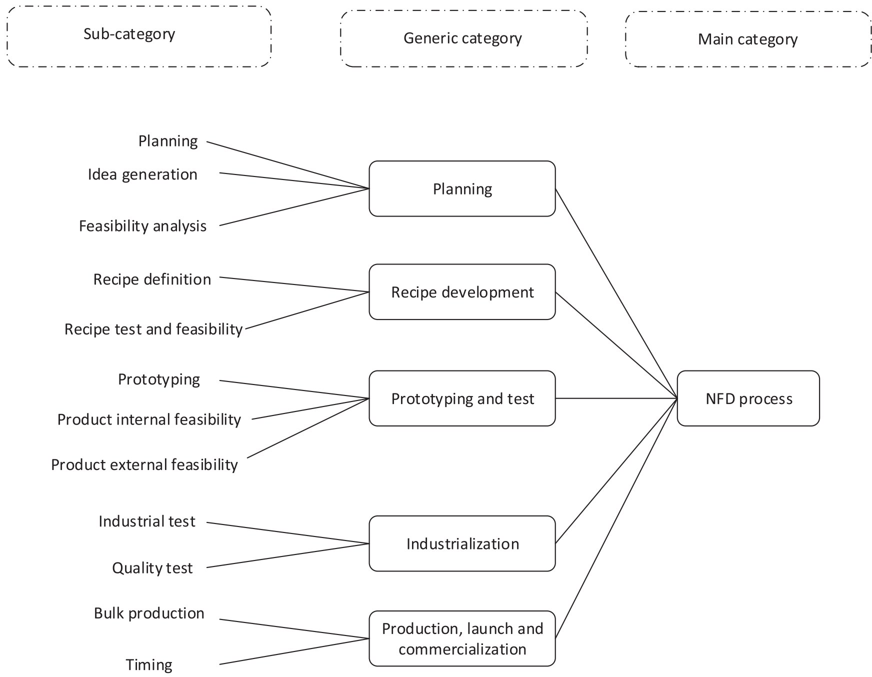

Fig. 2. NFD abstraction process.

NFD performances.

- Concerning the organization phase, this process includes open coding, creating categories and abstraction.
- Concerning the reporting phase, it starts with the open coding notes. They were written in the text while reading it. The written interviews have been read through again, and as many headings as necessary were written down in the margins to describe every aspect of the content. The headings were collected, and categories were generated at this stage. After this open coding, the lists of categories were grouped under higher order headings. The purpose of creating categories is to provide a means of describing the phenomenon, to increase understanding and to generate knowledge. In conclusion, the abstraction phase has been conducted; it means formulating a general description of the research topic through generating categories. Each category is named using content characteristic words. Subcategories with similar events and incidents are grouped together as categories and categories are grouped as main categories.

In Fig. 2, an example of abstraction for the NFD process is shown.

4. Findings

4.1. Preliminary results deriving from the analysis of the first sample

In the following section, results obtained from within and the cross-case analysis are illustrated. As previously affirmed, for (a) the definition of the NFD process, and (b) its main measures of performance, a first sample containing sixteen large food firms was considered and analysed. They can be observed below in Table 1. Their original names are not shown in order to preserve anonymity.

4.1.1. New food development process

Based on the case studies analysed, we reached the first result concerning the definition of the NFD process phases identifying the main activities for each, shown in Table 2.

4.1.2. New food development process performances

The following table shows the main NFD performance indicators that emerged from our case study research. Based on the interviews, we decided to classify them according to five main categories: Time, Innovation, Quality, Cost and Technology, as this also well aligned with prevalent classifications in literature. Table 3 shows all the performance indicators related to the NFD that the interviewed managers claimed to

Table 1
First sample of companies.

Firms	Main Products	Market segment	Interviewed Person
Firm 1	Milk products and dishes	Fresh products	R&D Manager R&D Engineer
Firm 2	Meat, poultry and game products and dishes	Fresh products	R&D Manager Marketing Manager
Firm 3	Milk products and dishes	Fresh products	R&D Manager
Firm 4	Savoury sauces and condiments	Pasta and canned food	R&D Manager R&D Engineer
Firm 5	Savoury sauces and condiments	Pasta and canned food	R&D Manager Marketing Manager
Firm 6	Meat, poultry and game products and dishes	Fresh products	R&D Manager Marketing Manager
Firm 7	Confectionery and cereal/nut/fruit/seed bars	Pasta and canned food	R&D Manager
Firm 8	Milk products and dishes	Fresh products	R&D Manager
Firm 9	Cereal based products and dishes	Pasta and canned food	R&D manager IT manager
Firm 10	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D manager IT manager
Firm 11	Cereal based products and dishes	Pasta and canned food	R&D Manager Marketing Manager
Firm 12	Cereal based products and dishes	Pasta and canned food	R&D Manager Marketing Manager
Firm 13	Milk products and dishes	Fresh products	R&D Manager
Firm 14	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D Manager
Firm 15	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D manager IT manager
Firm 16	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D manager IT manager

Table 2
NFD process phases and activities.

Phase	Activities
Planning	*Planning* *Concept/Idea generation* *Feasibility analysis*
Recipe development	*Recipe definition* *Recipe test and feasibility*
Prototyping and test	*Prototyping* *Product internal feasibility* *Product external feasibility*
Industrialization	*Industrial tests* *Quality tests*
Production, Launch and Commercialization	*Bulk production* *Timing (logistics, production, planning and commercial)*

adopt. Twenty-five NFD performances have been identified, of which nineteen have been considered relevant. We define as *relevant* those performance indicators that have been used by 50% or more of the companies. The column "# of firms implementing the performance indicator" from Table 3, shows the number of firms adopting each performance indicator. The relevant performances are bolded and italicized.

In addition to this categorization, through the interviews such performances have been classified along each stage of the NFD process (as shown in Fig. 3).

4.2. Results deriving from the analysis of the second sample

On the basis of the preliminary results obtained from the analysis of the first sample, the second stage of our research has been structured. However, we were constrained to limit our focus to a smaller number of firms, as only a sub sample matched with the requirement of having a PLM system in place. In the following, results that derived from the analysis of the second sample are presented. Firstly, we propose (a) which PLM functionalities were identified as supportive for the NFD process and then (b) the relationships existing within PLM functionalities, process management and coordination capabilities and NFD process performances, deriving from the analysis, are described. The second sample is depicted in Table 4.

4.2.1. PLM functionalities and NFD performances: process management and coordination capabilities

Before performing the interviews with companies' managers, we decided to explore which are the main PLM functionalities for the food industry. Such preliminary analysis involves three different steps: (i) a screening of the main PLM functionalities offered in form of IT solutions to the food industry, (ii) a coding and categorization phase and (iii) a validation phase with PLM experts. The first step allowed us to have an initial vision of which PLM functionalities support NFD the process existing on the market, the second step permitted us to find a common and standard name for each functionality belonging to the same meaning, while the third step allowed us to validate our analysis.

The main PLM functionalities identified can be grouped into nine categories:

(1) *Project management*: supports the project, collecting data and results along all the phases of the project in order to drive the company decisions. This functionality supports the management workflow by automating process workflows, as well as the related ability to create, archive, trace and search documents. Change management workflows direct information (which could be new or changed) to

Table 3
Main NFD process performances (relevant performances are highlighted in bold).

Classification	Performance indicators	Description	# of firms implementing the performance indicator
Time	Change and product evolution in design	Time spent to perform changes in new products	10 out of 16
Time	Compliance with the product engineering schedule	Ratio between the actual and the planned time to engineer products during a year	2 out of 16
Time	**Product development cycle time**	**Average time to develop a product (from concept to production)**	**16 out of 16**
Time	**Time to Market**	**Average time to keep a product available for sale**	**16 out of 16**
Innovation	**Compliance with Marketing Brief**	**Ratio between the average number of planned products and the average number of actual products**	**8 out of 16**
Innovation	**New product success rate**	**Annual success rate related to the introduction of new product on the market**	**14 out of 16**
Innovation	Number of carry over	Average number of carry over developed per year	3 out of 16
Innovation	**Number of new products**	**Average number of products developed per year**	**10 out of 16**
Innovation	Number of prototypes	Average number of prototypes developed per year	5 out of 16
Innovation	**Revenues from innovation**	**Revenues rate related to the new product introduction**	**14 out of 16**
Quality	**Defect rate**	**Ratio between the number of defects in production and the number of total products calculated per year**	**10 out of 16**
Quality	**External customer satisfaction**	**Success rate by external clients on selected products**	**14 out of 16**
Quality	**New product quality level**	**Average annual quality of new product**	**16 out of 16**
Quality	**Internal customer satisfaction**	**Success rate by internal clients (company employees) on selected products**	**14 out of 16**
Quality	**Number of defective prototypes per year**	**Average number of defective prototypes developed per year**	**10 out of 16**
Quality	**Product safety and health**	**Level of safety and healthy in the new product**	**14 out of 16**
Quality	**Regulatory requirements compliance**	**Rate of products that comply with current regulations in the food sector**	**13 out of 16**
Quality	**Sensory properties & shelf life**	**Level of sensory properties & shelf life of the new product proposed**	**12 out of 16**
Cost	**Effectiveness of planned cost**	**Ratio between actual cost and planned product cost**	**10 out of 16**
Cost	**New products cost**	**Average annual cost of new product**	**14 out of 16**
Cost	**Production annual cost**	**Average annual cost to produce products**	**12 out of 16**
Cost	Prototype cost/Production cost	Ratio between the average prototype cost and the average production cost	3 out of 16
Cost	Prototypes annual cost	Average annual cost to produce prototypes	6 out of 16
Cost	Total annual cost of changes in new products	Cost of changes in new products	6 out of 16
Technology	**Technological constraints in production**	**The capability to produce with a normal production cycle or the need to purchase new technology and/or machines due to the introduction of a new product**	**10 out of 16**

Process	New Food Development				
Phases	Planning	Recipe development	Prototyping and test	Industrialization	Production, Launch and Commercialization
Activities	• Planning • Idea generation • Feasibility analysis	• Recipe Definition • Recipe test and feasibility	• Prototyping • Product internal feasibility • Product external feasibility	• Industrial test • Quality test	• Bulk production • Timing (logistics, production, planning and commercial)
NFD process performances	• Number of carry over • Number of new products • Compliance with market brief	• Change and product evolution in design • Product safety and health • Sensory properties & shelf life	• Internal customer satisfaction • External customer satisfaction • Regulatory requirements compliance • Number of prototypes per year • Prototypes annual cost	• New product quality level • Compliance with the product engineering schedule • Technological constraints in production	• Product development cycle time • Time to Market • Defect rate • Effectiveness of planned cost • New products cost • Production annual cost • New product success rate

Fig. 3. NFD process phases and performances.

Table 4
Second sample of companies.

Firms	Main Products	Market segment	Interviewed Person
Firms 1	Milk products and dishes	Fresh products	R&D manager IT manager
Firm 5	Savoury sauces and condiments	Pasta and canned food	R&D Manager Marketing Manager
Firms 9	Cereal based products and dishes	Pasta and canned food	R&D manager IT manager
Firms 15	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D manager IT manager
Firms 16	Confectionery and cereal/nut/fruit/seed bars	Confectionery products	R&D manager IT manager

the right people in order to be reviewed and approved, allowing to find mistakes, ensure accuracy and consistency.

(2) *CAD for packaging design*: refers to software for packaging design, for example tools designed for packaging professionals for structural design, product development, virtual prototyping and manufacturing
(3) *Formula and recipe management*: includes software for formula or recipe calculation and validation processes for manufacturers. It allows to ensure product integrity by better managing product formulations and reformulations, with a real-time understanding of the impact on compliance, nutrition, and other product characteristics. Furthermore, this functionality includes the ability to optimize formulas, create and manage the workflows to make changes to formulations and recipes, create and configure formulation variants, manage labelling content, plan inventory for scale-up, and validate formulations to support production and regulatory needs
(4) *Label and artwork management*: refers to software that helps manufacturers develop labels and artwork for different markets that conform to market preferences and regulations. Indeed, the use of this functionality fosters companies to develop and revise product packaging and labels more effectively, improving cross-functional tasks among technical, marketing, and design teams. It manages versions and variants of labelling with artwork, as well as information about product content, for multiple products and markets.
(5) *PLM team collaboration*: supports tools to collaboration among team members, enabling the facilitation, automation, and control of the entire development process
(6) *Product portfolio and program management*: supports the continuous cultivation of product sets by prioritizing and managing product developments and retirements. This functionality allows to improve the effectiveness of the companies' innovation efforts, while also maintaining the flexibility to adapt to local requirements and regulations. This functionality assists in analysing and reporting risks versus opportunities, and it makes these analyses visible to all decision makers, including dashboards providing executive views of decision variables, such as risk, opportunity, resource allocation, investments, unit and revenue performance, and customer acceptance
(7) *Report specific to the industry*: supports tools for monitoring and developing reports for specific industry sectors
(8) *Specifications management*: captures the descriptions and quantities of ingredients, materials and other contents, including process information needed to produce, package and ship a product. It allows to maintain full traceability of accurate and complete product data through the entire product structure, from finished products down to ingredients and packaging materials. Moreover, providing a single, reliable source of technical product description, it consents to reduce the risk of quality problems due to product content errors, and to support faster new product introduction. The transparency of a corporate specifications management system reduces the risk of regulatory violations and improves the reliability that product labelling and advertising claims accurately reflect the product. This technology also streamlines production and submission of product registration documents
(9) *Regulatory compliance*: supports tools enabling companies to identify what regulations, policies and obligations are applicable to them. It allows companies to proactively ensure compliance throughout the product life cycle and fully integrate product quality and food safety into the process of developing and managing products

Furthermore, from the analysis of the interviews we identified the functionalities prevalently used by food companies to support their NFD process. These functionalities are:

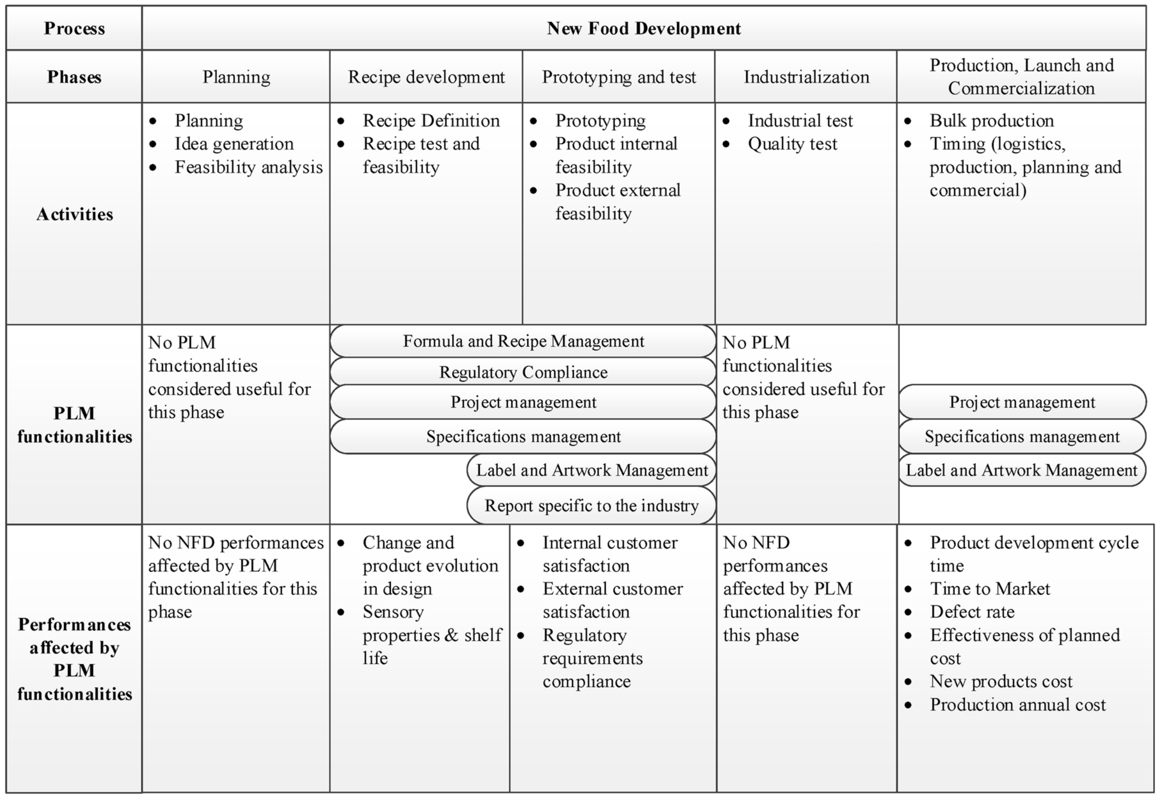

Fig. 4. NFD process phases, PLM functionalities and NFD process performances.

- Formula and recipe management (4 companies out of 5)
- Label and artwork management (3 companies out of 5)
- Specifications management (3 companies out of 5)
- Regulatory compliance (4 companies out of 5)
- Project management (4 companies out of 5)
- Report specific to the industry (3 companies out of 5)

From the case study analysis, it emerged that PLM functionalities are positively related to process management and coordination capabilities, which improve NFD process performances.

More in detail, interviewed managers emphasized several aspects. The implementation of the PLM system bring rigor to the management of product development and reduce product data inconsistencies, especially in configuration management (thus improving both process efficiency capability and process optimization capability, previously defined as the sub-concepts of the process management capability). In fact, product data from different NFD stages are more easily and accurately retrieved, thus giving employees more opportunities to take advantage of past (explicit) knowledge during NFD activities, with a significant reduction in time spent "re-inventing the wheel". The possibility to quickly search for information increases the time that employees can spend for the more technical and creative aspects of their job. Furthermore, the better document management reduced waste time devoted to work on product data that are either inconsistent or obsolete with respect to new NFD choices.

As asserted by firms' managers, the impact of the PLM technology on performances is very high in product design stages like "recipe development" and "prototyping and testing". This is due to their essential involvement in the NFD process, the high degree of non-routineness of their assigned tasks, and their greater interdependence. In these product design stages, higher information processing is needed and time spent in cross-functional coordination and problem-solving efforts is significant. Thus, in this domain, the role of PLM functionalities is greater.

Also the coordination capability resulted to be significantly and positively affected by PLM functionalities, on the basis of managers' considerations. Managers confirmed that NFD is intrinsically not predictable, require a long time, is knowledge-intensive, but (more important) it involves several teams that must cooperate across the boundary of the firm, involving various external players. The implementation of the PLM system lead product engineers to coordinate their activities with those of other NFD participants involved in the process. It emerged that, during NFD activities PLM functionalities enhance cross-functional collaboration among employees involved in the development of the new food product through the improvement of coordination and control of product engineering activities and the support provided to distributed product innovation environments. In addition, they asserted that PLM functionalities have an impact on knowledge dissemination and individual learning, which facilitate future collaborations: it emerged that in different NFD processes, when product/process knowledge was highly shared in the organization, collaborations resulted to be more effective and new informal teams appeared in the organization, which facilitated successive NFD cross-team collaborations.

Significant comments of the interviewed managers and related to the above presented arguments are reported in Appendix A.

4.2.2. PLM functionalities and NFD process performances at the single-phase level

In this analysis, only the functionalities and performances considered relevant from the food companies analysed have been taken into consideration. From the case studies emerged that no PLM functionalities are used to support both the Industrialization and the Planning phases. Indeed, these phases are very specific and different from company to company, most food firms preferred to use ad hoc software to manage them.

The results of this research, which is derived from the analysis of the different interviews, have been summarized in Fig. 4.

4.2.2.1. Planning phase. According to the previous section, the first stage of the NFD process is the *Planning* phase. Through the analysis of the different interviews emerged that no PLM functionalities are used to support the preliminary phase. This is due to the fact that the phase is very specific and customized, change from company to company. Therefore, the interviewed food companies affirmed that they prefer to develop an ad hoc solution in order to manage this phase, instead of using a standard solution that most of the time doesn't fit their needs.

4.2.2.2. Recipe development phase. The second macro-phase that characterizes the NFD process is the *Recipe development* phase. The PLM modules' supporting this phase are: *Formula and recipe management, Regulatory compliance, Project management and Specification management*. Formula and recipe management sustains the recipe development and its management. Regulatory compliance enables identification of regulations, policies and obligations applicable to the developing product. Project management supports the project, through the collection of the data and the results along all the phases of the project in order to drive the company decisions. Specification management allows food companies to capture the descriptions and quantities of ingredients, materials and other content, including process information needed to produce, package and ship a product. These functionalities support the next process phase because in case of any modification they would be mostly involved, assuring the accuracy and the availability of the data along the process. In fact, it is possible that after the prototyping, for example, the company decides to change the formula of the recipe. In this case, a check to verify the compliance with the specifications and the regulations must be conducted. For these reasons, the functionalities have to be considered as support for the following phase.

The benefits identified in this NFD stage are shown in the following table:

Following the benefits and weaknesses, we also investigated which specific NFD performances were affected by the adoption of the PLM solution. For this phase, they mainly referred to quality aspects. The quality element come up during this phase because the food product must be in compliance with the rules of the different countries where the product would be sold. Furthermore, the quality is a relevant aspect because it assures the wholesomeness for the customers as well as emphasizes the sensory properties defined during the planning phase. Specifically, the performances that emerged to be positively affected by the implementation of the PLM solution and related to this phase are: *change and product evolution in design, sensory properties and shelf life.*

4.2.2.3. Prototyping and testing phase. The following stage characterizing the NFD process is the *Prototyping and testing* phase. In addition to the features mentioned before, other functionalities used in this stage are *Label and artwork management* and *Report specific to the industry*.

Label and artwork management assists manufacturers in developing labels and artwork for different markets that are conforming to satisfy market preferences and regulations. Reporting specifically to the industry enables the facilitation, automation, and control of the entire development process.

The benefits identified in this NFD stage are shown in the following table (Table 5):

The performances that emerged to be positively affected by the implementation of the PLM solution related to this phase are*: internal customer satisfaction, external customer satisfaction* and *regulatory requirements compliance.* These performances refer again to quality aspects. In this phase, the performances of quality are those considered more relevant, because the internal and external customer satisfaction helped the company to better understand if the product is aligned both with the market expectation and with the specifications defined during the planning phase. If these expectations are not met, a change in the developing new product should be evaluated.

Table 5
Recipe development phase benefits derived from the use of the PLM solution.

Benefits derived from the implementation of the PLM solution in the *Recipe development* phase
Focus on "right the first time" results, corrections and reworks creating recipes
Cost optimization of recipes anticipating cost analysis can lower product cost and harmonize recipes
Reduction of the number of market-specific recipes vs. global recipes, variants reduction
Cost reduction for common raw materials, less materials mean more efficient purchasing and logistics
Cost reduction derived from continuous recipe optimization more frequent re-formulation, R&D productivity
Better information sharing and communication with management reducing process time and mistakes
R&D team performance improvements compared to manual processes and nonintegrated tools, improving of R&D productivity
Better decision-making with timely and accurate information reduction of the decision delays
Security and Intellectual Property Protection
Capturing the IP during NPD and past projects allow to simplify the research and the reuse of the information
Reduction on the risk of leaking of information about products to competitors
Better management of product portfolio because of timely availability of information and possibility to manage correctly more projects at the same time

4.2.2.4. Industrialization phase. Concerning the *Industrialization* phase, as mentioned previously, no PLM functionalities are used to support this phase. The reasons are the same given for the Planning phase.

4.2.2.5. Production, launch and commercialization phase. The last phase characterizing the NFD process is the *Production, Launch and Commercialization* phase. The PLM functionalities supporting this phase are: *Project management*, *Specification management* and *Label and artwork management.*

The benefits that emerged from the interviews are:

- Reduction of production timeouts due to project errors
- New product design and introduction timeframe reduction

Furthermore, from the analysis of the interview a new need has appeared: a PLM functionality for the *feasibility management*.

In addition, the identified performances to be positively affected by the implementation of the PLM solution and related to this phase are: *Product development cycle time, Time to Market* concerning the time aspects*, Defect rate* concerning the quality aspects and *Effectiveness of planned cost, New product cost, Production annual cost* concerning the cost aspects. In this phase, the time and cost aspects are considered the most important (Table 6).

5. Discussion

In the current changing business environment, firms are seeking new ways of providing maximum value to customers and gaining competitive advantage on their specific market. Therefore, a stronger focus on product design and the management of product development stages have emerged as critical areas for the success of modern firms.

Table 6
Prototyping and testing phase benefits derived from the use of the PLM solution.

Benefits derived from the implementation of the PLM solution in the *Prototyping and testing* phase
Product quality and reliability improvements
Embedding regulatory compliance into product development *speeds the process and reduce iterations*, approval requests that are required modifications
Reduce non-compliance risk
Reduce inconsistency between product recipe and labelling

This study clearly highlighted that big food companies implementing the PLM solution to support their NFD processes will be subject to a positive effect on both process management and coordination capability that lead to several performance improvements. Thus, our results seem to confirm the validity of P1 and P2.

P1 seems to be confirmed because the sub-concepts process efficiency capability and process optimization capability that form process management capability appear to be positively influenced by PLM functionalities. In this direction, our results suggest that PLM integrates all templates and best practices for product development and project management in a single solution, which could also facilitate knowledge transfer activities. Moreover, the centralization of product and project codified items in a unique database could reinforce NFD standardization. The combination of data and process transparency could reduce the propensity of project members to hold back their knowledge. Moreover, IT constrained activity with standardized processes rules and codification of templates, and on the other hand, these structuring constraints did not completely inhibit flexibility which was critical to cope with uncertainty in preliminary NPD stages. Finally, our results suggest that, despite the high costs, knowledge codification and communication network transparency (made possible by the adoption of a PLM solution) could be essential for project team communication effectiveness [54].

Also P2 seems to be confirmed, as coordination capability appears to be positively affected by PLM functionalities. The PLM system could lead NFD participants involved in the process to coordinate their activities with those of others. Object visualization should lead to a more cohesive project and product representation. Higher cohesiveness could make key objects accessible and usable by a greater diversity of participants. This could have boundary-spanning effects while enabling all NFD project members to share a common virtual representation of the future products, thus detecting potential design problems earlier. Without the support of PLM technology, this would include supplementary costs.

Finally, also P3 seems to be valid, as our results suggest that the implementation of a PLM solution has different impact on different NPD process stages and their specific performances. Firstly, it emerged that none of the food companies investigated use any PLM functionalities to support both the Planning and the Industrialization phases. Secondly, we observed that in the other NPD stages, namely Recipe development, Prototyping and test, and Production, Launch and Commercialization, the impact of PLM functionalities leads to different benefits and impact on different and specific performance.

Our results contribute to various streams of the literature.

Firstly, we add knowledge to the significant and growing scientific debate focused on the relationship between digital technologies and information systems, and innovation management [55]. From our study, it can be derived the crucial role played by PLM solutions in supporting the NFD stages and enhancing NFD performances. This finding is consistent with the arguments advanced in IT business value studies [56,57], namely the positive impact of IT systems on firm performance.

Secondly, we show that the implementation of a PLM solution could affect some NPD process stages and their specific performances and not others. These results are new for the PLM literature, as they unveil the impact of PLM systems at a deeper level of analysis. We believe that they could both reinforce scholars and managers comprehension of PLM systems and their importance in NPD environments and stimulate new research and investigations in this complex but challenging context.

Finally, we implicitly add knowledge to the literature dealing with NPD in mature industries (with specific reference paid to the food industry case) e.g. [58,59]. In fact, in our preliminary results, we have formalized a NFD framework that clearly summarized all NPD stages for the food industry.

6. Conclusions

The implementation of PLM systems to support NFD activities resulted to be an effective method for improving NFD performances that can be leveraged to develop food firms' process management and coordination capabilities. These capabilities can serve as a foundation for increasing firms' NPD performance. It is important to highlight that such improvements and benefits were clearly perceived by managers belonging to the large food firms investigated. Such awareness could lead to an improvement of the budget devoted to investments in digital solutions that aim to support or enable NFD activities.

Despite the interesting implication for both theory and practice, deriving from our study, we are conscious that the research at its current state is subject to limitations. It must be considered that our study is explorative in nature, moving the first steps toward a complete understanding of the phenomenon analysed. The methodology adopted, even if it is appropriate for the nature of our research, need further in-depth analysis to generalize results, particularly for confirming and assessing more in detail the impact of PLM solutions on NFD performances. In this direction, a quantitative approach with a higher number of large food firms adopting the PLM solution is necessary. However, we believe that our work provides strong basis for that step forward.

We investigated how PLM solution affects specific performance indicators, but we did not measure how much it would affect performances. Future research should also consider this opportunity.

In this paper, we stated that both NPD and PLM solutions are context dependent: for example, the NPD process in the food industry is very different from that in the fashion industry, and the PLM solution must be specific for each of them [8]. An interesting avenue for future research on the topic would be represented by an attempt to identify groups of industries with similar NPD processes and, consequently, similar PLM systems. By doing this, it would be possible to test and eventually extend the validity of our results to other industries. Moreover, it would be possible to investigate the same issues in other industries, group them in similar clusters, and make a comparison among them.

Finally, an additional research topic can arise as consequence of the lack of adoption that the PLM solutions play in both planning and industrialization phases identified in our study. Specifically, it would be interesting to understand why PLM solutions are not implemented in these two phases. Authors suspect (i) a lack of understanding of real benefits PLM systems applications might have on those phases (as usefulness and impact are not clearly studied yet), (ii) PLM functionalities might miss to specifically support those phases or simply (iii) implementation of software solutions in such phases are not easy to apply and be sustained on a daily work basis. Linked to this, the authors also suggest future research topic to address the challenge of understanding how structured PLM solutions might indeed enable higher performances, not only in product development process within less traditional industries (i.e. food industry) but also in more creative processes within any kind of business, such as concept development phase and the so called fuzzy-front-end process where uncertainty is extremely high and real time information availability could enhance product concept development effectiveness. Even where one could think very creative processes are highly characterized by improvisation and chaotic procedures as the means to achieve more innovative ideas, the possibility to access formal knowledge and real time information can be paramount.

Appendix A. Optimizing processes by sharing and capitalizing on knowledge

Optimizing processes by sharing and capitalizing on knowledge

"*We have managed to harmonize the development process of a new product in the same way worldwide. Having four research centres* *scattered around the world, each research centre resembled the type of product flow, and it had different streams. By using a PLM solution, which forces you to have very precise steps and stages in the same way, we have obliged people to work the same way. This also encourages collaboration because if you have different product development phases in the same company, collaboration makes a lot of effort because you cannot exchange logical information or information that is being exploited to the fullest. Imagine that two R&D centres in two different countries are studying the same product, this is something that PLM can help to avoid because it avoids duplicating. So the benefits of PLM from our point of view are to harmonize the work and to avoid work duplication in different locations in the world"* (Firm 1, R&D manager)

Enhancement of data availability

"*For companies that have so much data, it is essential to have them always available. For large companies, I do not think it is optional to have a PLM*" (Firm 9, IT manager)

Less error

"*The implementation of a PLM within the Firm 16 have influenced the processes and particularly the activities carried out within the R&D and quality services. Indeed, the construction of a single raw materials database make it easier to research and use the data during the formulation phase. Improved data quality on raw materials results in less error in formulation. Within the quality department, the implementation of a PLM tool allows to automatically generate documentation related to the product/process from the data entered in the repository/formulating"* (Firm 16, IT manager)

Economic benefits

"*The use of the PLM solution has enabled us to obtain economic benefits. In fact, the comparison of the recipe has led to improve the recipe in economic terms and this is extremely important for a company* (Firm 1, R&D Manager)"

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