In search of a product innovation work process for non-assembled products

Thomas Lager
Mälardalen University, School of Innovation, Design and Engineering
P.O Box 325, SE-63105 Eskilstuna, Sweden
Email: thomas.lager@mdh.se

Christopher Don Simms
University of Portsmouth, Faculty of Business and Law
Portland Street, Portsmouth, PO13DE, UK
Email: chris.simms@port.ac.uk

Abstract: The family of process industries embodies multiple industrial sectors and make up an important part of the entire manufacturing industries of particular importance for late-industrializing countries. In a review of the extant literature on product innovation work processes and best practice innovation of non-assembled products, an integrated conceptual framework has been developed. The novel framework is proposed to guide and invigorate company development and design of "individualized" product innovation work processes more adapted to process-industrial contextual and innovation conditions. Due to the coupling between products and the production systems in the process industries, it is concluded that development of new products must be better integrated with the development of necessary production capabilities in an end-to-end work process perspective. Research on *fuzzy front-end* of process-industrial product innovation has been amalgamated but it is demonstrated that more attention should be paid to industrialization and market launch; here denominated the *bumpy back-end*.

Keywords: process industries, manufacturing industries, product innovation, process innovation, work process, fuzzy front end, bumpy back end, industrialization, late-industrializing countries

Biographical notes:
Thomas Lager, is an affiliated Professor at Mälardalen University, School of Innovation, Design and Engineering in Sweden. He is the General Manager of blinab "boutique" management consultancy in Sweden, in the area of Management of Innovation & Technology in the Process Industries. He holds an MS degree in Mining Engineering from the Royal Institute of Technology in Sweden. He has a PhD in Mineral Processing and a PhD in Business Administration and Economics from Luleå University of Technology. He was previously a Professor and Chair in Innovation Management at University Mohammed VI Polytechnique in Morocco, and an affiliated Professor at Grenoble Ecole de Management in France. He was formerly an adjunct Professor and Director of the Centre for Management of Innovation and Technology in the Process Industry at Luleå University of Technology in Sweden. He has served 15 years in the Process Industry mainly in Sweden and Africa.

Christopher Don Simms is the Knowledge Services Lead for the Strategy Enterprise and Innovation (SEI) subject group in the Faculty of Business and Law at Portsmouth University. He is also a Reader in Innovation Management and Entrepreneurship and fellow of the Higher Education Academy. He has undertaken collaborative work with a number of organizations within the public and private sectors, working on Knowledge Transfer Partnership projects. He has a PhD in Business Administration and publish in in highly ranked journals, related to innovation management and new product development.

1 Introduction

The cluster of industries generally designated as "the process industries" consists of a number of different industrial sectors and accounts for a large part of the total manufacturing sectors (Lager, 2000); Appendix 1 defines the process industries in detail). There are a number of differences between the family of process industries and other manufacturing industries. For companies within process industries, the product's supplied to them, and often also delivered from them, are materials or ingredients rather than components (Frishammar et al., 2012), and development of new products often necessitates the corresponding integrated development of the production system.

A recent review of contextual and inherent characteristics of the "family" of process industries and other manufacturing industries concluded that the distinct characteristics of the process industries require different perspectives in innovation and production management (Lager, 2017a) Albeit the process industries consists of a number of industry sectors more or less similar in individual characteristics, the sectoral similarities within this cluster of industries (Lager et al., 2013) and their tendency for convergence, makes a conceptualization of a innovation work process for non-assembled products an interesting avenue to further explore.

Product innovation is important to success in the context of both developed and developing countries (Figueiredo and Cohen, 2019, Sutz, 2012), and the importance of a guiding formal work process for company product innovation and renovation is unquestionable (Cooper, 2014, Cooper and Sommer, 2016, Grönlund et al., 2010), and accordingly companies have widely implemented such work processes within their innovation (Cooper, 2012). It is then generally assumed that formal work processes could be deployed relatively generically within all sectors of manufacturing industry, independent of geographic location and culture.

However, the different conditions for product innovation in the process industries, call into question if not related formal product innovation work processes should follow disparate patterns? Research on the front end of product innovation in the process industries not only indicate that this phase possesses unique context-specific characteristics (Frishammar et al., 2012), but that an early integration of product and process development also is paramount for success in the process-industrial environment (Hullova et al., 2019). Yet, to date, insights into product innovation work processes within this industry context are largely limited to the front end, typically address process innovation and fail to address the issue of an end-to-end total work press design (Frishammar et al., 2013, Kurkkio et al., 2011). *This research gap informs the first major rationale for this study.*

Companies within the process industries face differing positions within value chains, differing product innovation intensities, and may produce commodities and/or products of a more functional nature (Lager and Blanco, 2010, Simms and Trott, 2014). Thus, a work process specific to this family of industries may also benefit from being further adapted to company specific contingencies (Morgan, 1986) , and their operational environment and product-market context (Hullova et al., 2016). Indeed, there is growing recognition of the weaknesses of a 'one size fits all' approach when it comes to management frameworks for new product development projects (Salerno et al., 2015). *As a consequence, and as a second rationale for this study, there* *is a need for an "integrative framework" for individualized work process development of non-assembled products.*

Focus on the improvement on the *fuzzy front-end* during the last decade may have caused product innovation in the *back end* of the work process to have been comparatively neglected. Today's product design models pay limited attention, how new or improved products could be manufactured in environmentally friendly cost-efficient production systems; the manufacturability (processability) aspect (Boothroyd et al., 1994). As a result the adaptation of existing process technologies or the requirement for new production plants in an industrialization perspective has been overlooked. Since in the process industries, the product and process are intertwined, and the production process is often inflexible and difficult to change in a short term perspective (Samuelsson et al., 2015), overlooking necessary process innovation and production system capabilities in work process design is not only unfortunate but potentially a disaster. *The third rationale for this study, therefore relates to the lack of process innovation and industrialization integration in product innovation work processes.*

"Design thinking" is not so far generally practiced in industrial product development and an opportunity less explored in company work process configurations (Beckman and Barry, 2007); an area that will be reviewed in this study. Additionally, there are two novel aspects that will be considered which are of particular concern for the process industries. The critical importance of a sustainability perspective on manufacturing products (Yu et al., 2016). This requires a holistic view on the product innovation work process, from initial selection and use of environmentally acceptable raw materials and ingredients, the use of sustainable production technologies, and ending up with recyclable products. The second aspect is the need to incorporate the digitalization of production technologies within product innovation (Horváth and Szabó, 2019).

The following research questions were thus developed:

RQ1 *In the development of an Integrated Framework guiding company initiation of a formal work process for non-assembled products in the process industries, what can be learned from previous research on work processes for assembled products in other manufacturing industries?*

RQ2 *What can especially be learned from previous research on process-industrial product and process innovation conditions, and how can this understanding be incorporated in the development of a new Integrated Framework?*

RQ3 *How can the novel influencing perspectives of "design thinking", circular economy, and digital transformation be integrated in such a Framework?*

This paper is organized as follows. First, a background on product innovation within the family of process industries is provided. Secondly, we position our study within the existing literature on product innovation. Thirdly, we highlight the changing demands resulting from design thinking, digital transformation and the growing concerns over sustainability in society. Fourth, we present a novel Integrated framework for guiding company development of an innovation work process for non-assembled products, and subsequently decompose the framework into the main activities involved. Finally, we identify the scientific contributions of our work and management implications.

2 Product innovation in the process industries – a background

Product and process innovation may be considered as two sides of the same coin, since product development in the process industries often occurs in the laboratory or pilot plants. However, in this study product innovation is defined as "development driven by a desire to improve finished products for external customers" while process innovation is defined as "development driven by internal production objectives" (Lager, 2000) Table 1 provides a summary of the contextual characteristics distinguishing process industries from other manufacturing industries which influence innovation activities.

Table 1 Contextual characteristics of process industries and other manufacturing industries; after Lager (2017ap. 202)

Contextual production system characteristics	Process-industrial characteristics	Other manufacturing industrial characteristics	References
Incoming materials	Raw materials	Components	(French and LaForge, 2006)
Process yield dependency on raw materials	Dependent	Independent	(Finch and Cox, 1988)
Influence of incoming material on finished products	High	Low	(Linton and Walsh, 2007, Samuelsson et al., 2016)
Process structural characteristics	Batch or Continuous	Job shop	(Dennis and Meredith, 2000)
Pattern of material flow	Divergent (V-type)	Convergent (A-type)	(Burbidge, 1995, King, 2009)
Material transformation characteristics	Transformational	Reconfigurational	(Dennis and Meredith, 2000, Floyd, 2010)
Type of transformational process	Indirect process	Direct process	(Dennis and Meredith, 2000, Floyd, 2010)
Time dependency for the transformation process	Dependent on time	Independent on time	(Floyd, 2010)
Outgoing products	Non-discrete	Discrete	(Lager et al., 2017)
Product life-cycle	Sometimes long	Often short	(Chronéer, 2003)
Product interrelationships	Sometimes high	Low	(Finch and Cox, 1988)
Degree of changeability of finished products	Sometimes high	Low	(Van Donk and Fransoo, 2006)

The inherent characteristics of process industries result in distinct innovation activities, presented in Table 2, since the process-industrial production system constitute a specific industrial environment. The strong coupling and interplay between raw materials, production systems and products shared by many of the process-industrial sectors are generally not experienced among other industries. These sectoral characteristics are either not recognized or of interest in other manufacturing industries (Lager, 2017a) The idiosyncrasies of the inherent innovation conditions in a process-industrial context are of substantial importance to consider for both product and process innovation. In conclusion, these contextual and inherent characteristics motivate a study and reconceptualization of the product innovation work process for non-assembled products.

Table 2 Inherent discriminating characteristics of process industries and other manufacturing industries; after Lager (2017ap. 207)

Inherent innovation characteristics	**Process-industrial characteristics**	**Other manufacturing industrial characteristics**	**References**
Sources of product functionalities	Inherent	Component-based	(Chronéer, 2003, Lager, 2010)
Pre-development environment and product design	Laboratory	Design office	(Frishammar et al., 2013, Kurkkio et al., 2011)
Ways of testing improved product functionalities	Pilot planting	Prototyping	(Lager, 2000, Pisano, 1997)
Interrelation between product and process development	High	Low	(Hullova et al., 2019, Reichstein and Salter, 2006)

3 Research approach

Weick (1989 p. 516) presents an interesting perspective on theorizing:

> *Theorists often write trivial theories because their process of theory construction is hemmed in by methodological strictures that favour validation rather than usefulness. ... and we cannot improve the theorizing process until we describe it more self-consciously, and decouple it from validation more deliberately.*

The research approach in this study adopts such a perspective, and according to Zahra and Newey (2009), theorization should be done through synthesising existing insights from prior theory, and in so doing capitalising from the connections between two or more fields. Referring to the specific process-industrial production environment for innovation (Table 1 and 2), our study merges knowledge from the disciplines of operations management and innovation management. Torraco (2005) described such theoretical integrative research as one that involves the review or synthesis of literature and its integration in order to develop a new framework or perspective. To develop our guiding “integrative framework” we thus began by reviewing the literature on product innovation work processes in general, product and process innovation work process in a process-industrial context, and subsequently new emerging perspectives on product innovation. Resting on this review, an integrative framework was developed and subsequently decomposed into a simplified Stage Gate format.

A lot of industry activities can be viewed as "work processes", and a work process must have a customer and a supplier, and feedback loops (Melan, 1992) It is also important that a process has clear boundaries, and interfaces with connecting work processes. Early in 1974, Utterback presented a three-phase model for the development process (Utterback, 1974):

- ***Generation of an idea**, involving synthesis of diverse (usually existing, as opposed to original) information, including information about market and technology.*
- ***Problem solving**, including specific technical goals and designing alternative solutions to meet them.*
- ***Implementation**, consisting of manufacturing, engineering, tooling, plant start-up, and market launch required to bring an original solution or invention to its first use or market introduction.*

This formed a sound foundation for the literature review since it incorporates the development of the production system, unfortunately often lacking in work process design.

4 A literature review and the development of a frame of reference

4.1 Revisiting the product innovation work process

Following the introduction of the Utterback model (Utterback, 1974), Booz, Allen and Hamilton (1982) presented a linear model of product development including: *idea, preliminary assessment, concept, development, testing, trial, and launch*. Early research by Cooper and Kleinschmidt (1986), identified the product development process as a number of stages separated by decision points; the Stage-Gate model was born. However, research by Cooper (1994) and other scholars (Bower and Keogh, 1996) provided a more complex picture, suggesting that work processes should be more flexible and adapted to individual project characteristics. Reengineering of the R&D work processes later turned out to be an important tool for improving R&D (Liebeskind, 1998). The Stage-Gate process by Cooper has become a "de-facto standard model" for a formal development process, which forms: *a blueprint and conceptual map to move from idea to launch* (Cooper, 2008 p. 214)

Reviewing company Stage-Gate process, Cooper emphasizes the importance of the *fuzzy front-end*, including open innovation and gathering the Voice of the Customer, and further building-in a "discovery stage" in advance of the standard model (Cooper, 2009), whilst Grönlund et al. (2010) later proposed an open Stage-Gate model. The introduction of this model reflects the growing importance of open innovation to product development (Armellini et al., 2012) In a survey of company use of this process (Cooper and Edgett, 2012), it was demonstrated that an effective Stage-Gate process drive business performance and constitute a best practice work process. Recently, the next generation Agile Stage-Gate system (Cooper and Sommer, 2016) includes: *Adaptable and flexible gates; Fast track versions of the system for low-risk and minor projects; Overlapping stages; Emphasis on the fuzzy front end*. The fuzzy front end concept, originally introduced by Smith and Reinertsen (1991), has received particular attention. Cooper and Kleinschmidt (1988) discovered that the quality of pre-development activities formed a key difference between winners and losers. These activities and decisions form the starting point of the process thus determine the direction of the new product path (Reid and Brentani, (2004).

Yet, problems are often experienced in translating customer requirements into technical specifications (Verworn et al., (2008). Within the process industry context, studies of the front end have demonstrated the importance of reducing equivocality and uncertainty (Frishammar et al., 2011). Studying the *fuzzy front end* of process innovation, Kurkkio et al. (2011), also recommended that a *preliminary process concept* should be incorporated. The need to identify the *process window* in which new product ideas are positioned has also been highlighted (Frishammar et al., 2012), as “boundary conditions” for product development projects.

4.2 Revisiting the process innovation work process

In a survey of European process industries (Lager, 2000), a new conceptual model and work process for the development of process technology was introduced and it was concluded that companies would benefit from a basic structuring model that can be developed by companies based on their specific requirements. Adapting the Quality Function Deployment (QFD) methodology for product innovation to process-industrial conditions, Lager (2005) introduced a Multiple Progression QFD system providing a structural backbone for concept development. It was further concluded that it was necessary to simultaneously develop product and process concepts. In a follow up case study (Lager et al., 2010), it was concluded that the previously presented three phase model served well as a guiding *structural work process map.* This study also identified the need for supplementary checklists for criteria to be satisfied to pass each gate. It was concluded that the *structural process map* should be supplemented by a *cross-functional process map*, identifying necessary internal and external interactions, highlighting an early integration between R&D and production.

4.3 Integrative perspectives on product and process innovation work process

Karl Marx stated very early that “the process disappears in the product” (Hannah, 1958) Ettlie (1995) further noted the importance of an interaction between product and process development, with product development often calling for process innovation (Hirsch-Kreinsen, 2008). Reichstein and Salter (2006) advocated that they should be viewed as: *brothers as opposed to distant cousins*. Boothroyd (1994) identified the importance of product manufacturability in other manufacturing industries, and within the process industries the interconnection between products and the production process further heightens the importance of processability (Lager, 2005). The requirement for integration is further pronounced for radical product development (Frishammar et al., 2012).

The significance of the interrelationship between product and process development has been further reviewed by Hullova et al. (2016) uncovering different kinds of complementarities between product and process innovation in product innovation. Follow-up research further clarified a company capability to: *identify complementarity type, deploy suitable integration mechanisms, and subsequently leverage knowledge learned and resources acquired* (Hullova et al., (2019).

4.4 Perspectives from the area of "design thinking"

"Design thinking" or "design-led innovation" is a recent research stream in product innovation (Beverland and Farrelly, 2007). Charles Owen (1997) as one of the forerunners, claim that: *From the design perspective, quality as craftsmanship is achieved through attention to issues of engineering design for manufacturing.* This must be supplanted by a greater focus on "details", and further on in better "concepts" and less focus on "how to make the product" instead of "what to make", finishing with a well-articulated "design brief". The concept of "design thinking" borrows some of the tools designers use to develop a deeper understanding of customers' needs. It is argued by Beckman and Berry (2007) that a new product concept should include a value proposition, which should describe the benefits that customers will gain from the product, and which is thus distinct from the product's features or capabilities. Design thinking puts the observation and discovery of often nuanced or tacit needs at the forefront of innovation (Gruber et al., (2015). This approach is not so far generally practiced in industrial product development and even less so in the context of company related work process design.

4.5 Sustainability in a process-industrial perspective

Sustainability is of growing importance to firms (Kaplinsky and Morris, 2018), with environmental innovations provide an opportunity to respond to concerns over the depletion of natural resources, environmental emissions, and the extent of raw materials with negative environmental impacts (Yu et al., 2016). Environmental innovations, incorporate variety of innovation types implemented to reduce harm throughout the innovation's lifecycle (De Marchi, 2012, Kemp, 2010), and innovations are significant in the process industry context. Cheng and Shiu (2012) classified innovations as product, process and organizational. Within the process industries the former two are both interconnected and provide the potential for sustainability improvements. With respect to production, approximately thirty percent of global energy usage and CO2 emissions are attributed to manufacturing industries (International Energy Agency, 2007), of which process industries constitute a considerable part. Process industries play a crucial role moving towards a 'cradle-to-cradle' approach to innovation that is founded upon the effective use of materials, sustainable processes of production, and with a reduced need for fossil fuels (e.g. (Eppinger, 2011). This underscores the necessity for an early integration of raw material properties and process technologies in innovation. Environmental activities must be incorporated within the front end, with analysis of the lifecycle impacts of products and production (Pujari et al., 2004). Current insights identify the important role that pilot and demonstration plants play in the creation of more sustainable production technologies (Hellsmark et al., 2016).

4.6 Digitalization perspectives

Industry 4.0 consists of the technologies that enable automated and digital manufacturing, and in some cases also incorporates the digitization of the company's supply chain (Oeserreich and Teuteberg, (2016). Increased use of internet and cloud technologies, sensors, and machine learning within factory environments (Sung, (2018), enables new avenues of production through communication between objects, machine learning and autonomous robots (Valenduc and Vendramin, 2016). Industry 4.0 also offers the potential for increased automation and flexibility in mass manufacturing, thus digitization is driving new process innovations (Blackburn et al., 2017, Iansiti and Lakhani, 2014). The opportunities presented create a need for innovation processes to consider the integration between individual machines, connected smart devices, dynamic software systems, smart logistics systems and suppliers (Horváth and Szabó, 2019). Smart Manufacturing, which forms a key component of Industry 4.0, consists of integrated and collaborative manufacturing systems that are able to respond and meet the demands of the plant itself, supply networks, and customer needs in real time (Kusiak, (2018) The opportunities provided by customisation, increased productivity and improvements in environmental sustainability necessitate integration of digital technologies in a work processes.

5 An integrated framework for company development of an innovation work process for non-assembled products

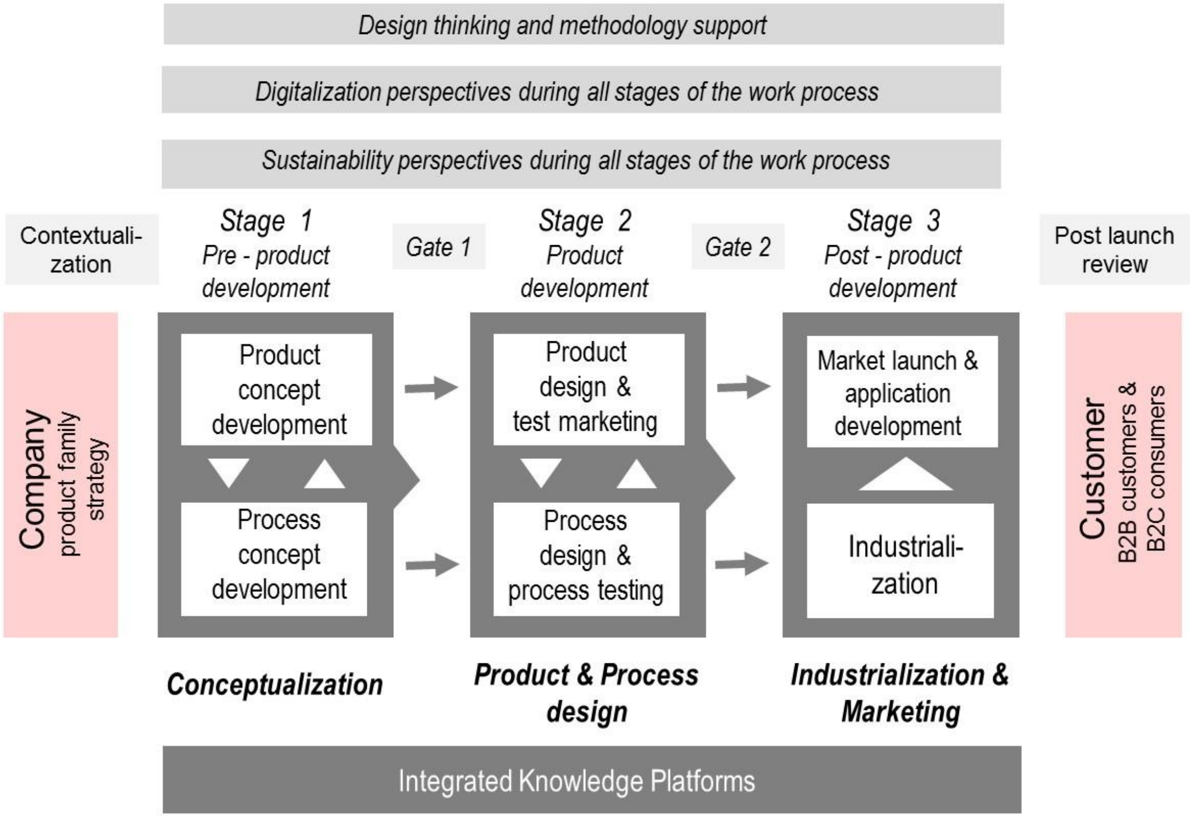
The integrative framework, in correspondence and reference to the Utterback model (1975), the Stage-Gate system (Cooper, 1994) and Lager et al. (2010), has been compartmentalized into three separate stages separated by two gates – the product innovation work process *structural map*; see Figure 1. In front of the work process a *contextualization* of product ideas is suggested, and after Stage 3 a *post launch review*. Referring to Lager et al. (2010), the *structural map* should be supplemented with a *cross-functional map* in order to secure cross-functional project organization (Perez-Luno et al., 2019), and complementary check-lists for passing each gate:

Gate 1*: Concept development is finished, and a decision to initiate the product development Stage II.*

Gate 2*: Product and process design is completed, and a decision to initiate industrialization and marketing activities.*

In order to simplify the framework, the focus is on the three separate Stages, whilst the associated gates are left to company development of *individualized* company-specific Stage-Gate processes. Moreover, and referring to the previously presented need for flexible Gates, those gates and their necessary list of deliverables should be tailored to project complexity and project newness.

Figure 1 An Integrated Framework for company development of a formal product innovation work process for non-assembled products.



While the product innovation work processes are structuring WHAT to do – methodologies and supporting tools are focusing more on HOW to do it. A number of such potentially supporting methodologies have thus been reviewed, listed, and presented in Appendix 2. Their applicability during each Stage has been indicated in the headings of each section.

5.1 In front of the fuzzy front end

5.1.1 Contextualization – alignment to company product family strategy (methodologies: A;E)

Contextualization is the activity of putting ideation into a company framework. Backman et al. (2007) thus advocate that concepts also necessitates a "contextualization" where the concept is: *dressed in a way to fit a NPD process*; an activity also denominated "alignment" of a concept to the organisation and its "legitimization" across key actors (Floren and Frishammar, 2012). A contextualization of a new product idea is framed under the following headings:

A "market brief"

In this introductory part of product innovation it could initially be advisable to review if the company existing business model is applicable (Grönlund et al., 2010). Furthermore, it is required to understand how well a new product idea conforms to company overall product strategies and product portfolio context.

A "production brief"

A review of production capabilities forms an integral part of product innovation in the process industries, due to the complementarity between product and process innovation (Hullova et al., 2016). Need for new production equipment may constrain the viability of potential projects, and proactively reviewing capabilities may reveal potential opportunities (Hullova et al., 2019).

A "raw material brief"

Incoming materials frequently exhibit strong influence on output product characteristics and production system design (Linton and Walsh, 2007, Samuelsson et al., 2016). Thus the consideration of existing material platforms and potential new raw materials forms a central foundation for forthcoming idea generation. This is further pronounced as a result of the growing need to consider the potential to use materials that have been recycled, are able to be recycled, or that provide other potential environmental benefits.

5.1.2 Replacing a "discovery stage" with Integrated Knowledge Platforms

The often vast "unspoken" knowledge base from company previous development projects and previous market research is in reality the disparate platform of knowledge from where all projects begin. Current product development work processes generally start with a phase often denominated the *fuzzy front end*. During the last decade, and rightly, there has been a strong focus on the improvement of this difficult part of the work process (Floren and Frishammar, 2012). However: *companies cannot start from a "clean slate" if they want to develop products in both a timely and cost efficient manner* (Lager, 2019). To reduce the fuzziness of the *fuzzy front end*, and to shorten product innovation cycle time, it is necessary to begin from a supporting knowledge base. This creates a need to begin with previously accumulated company platforms of knowledge; see Figure 1 (Frishammar et al., 2012).

5.2 Stage 1 Pre-product development – Conceptualization in the "fuzzy front end"

In an overview of innovation management of the front end of product development, Florén and Frishammar (2012), concluded that: "*projects do not necessarily lend themselves to high degrees of formalization. Instead, firms need to manage the front end in a way that takes into account its idiosyncratic character, especially in radical development"* (p. 23). Backman et al. (2007) highlight the distinctions between various types of concepts and their subsequent inherent obstacles for being included in the process. Transition between the early and the late phases within the front end, which Backman et al. (2007) denominate *conceptualization*, are an important activity that makes concepts suitable to be evaluated in a formal process.

On the concept construct and definition in innovation

As a result of the intimate connections between the product and production process it is not sufficient to move from the *fuzzy front end* into product development based only on a *product concept*. In order to develop products that also are designed for processability (Boothroyd et al., 1994), the *product concept* is in need of a complementary *process concept*. Such a process concept is then defining what production capabilities are needed for manufacturing of a defined product concept. *Product concepts* are usually restricted to a description of the new product idea and its main features and customer benefits. Bacon et al. (1994) suggested early that a robust *product definition* should include: *target market segments; product price, functionality and features; resources to complete product development*; an idea supported by Frishammar et al. (2012). In a similar vein it is here suggested that a process concept could not only be defined, but it is suggested that a *process definition* also should be articulated and delineated.

5.2.1 Product concept development - setting target figures for product attributes (Methodologies: A; C; D; E; F)

The importance of the development of product concepts in product innovation was early identified by Stuart Pugh (1981), proposing a process for minimizing conceptual vulnerability. Burchill and Fine (1997) argued that concept development should rest on the use of the *House of Quality* in the QFD methodology, transferring the “requirement space” into a “idea or solution space”, and using Pugh selection process (p. 3). In a review of alternative concept developing methods, King and Sivaloganathan (1999) corroborated that the QFD methodology combined with the Pugh selection system was superior. In a study of “concept shifting” in radical product innovation (Seidel, 2007), it was concluded that later changes are likely to be important, and recommending to maintain dual concepts. Reviewing the important recommendations to product developers by Beckman and Berry (2007) presented in Section 4.4, the use of the *Voice of the Customer* in the Quality Function Deployment methodology is fully congruent.

5.2.2 Process concept development – setting target figures for process capabilities

The development of process concepts is a road less travelled, but in this study a process concept is about setting target figures for a selected production process in the technology/engineering dimension (Kurkkio et al., 2011). The development of a process concept is however contingent on the product and process interrelationships (Hullova et al., 2016). Production processes in process industries are highly automated and can be characterized as “fixed” production, with minimal interruptions and long changeover times, resulting in a desire to reduce the number of new products and difficulties in changing portfolios due to existing production structures (Floyd, 2010). Product innovation must consider both the production process for the product being developed, and change over requirements when this product will be produced alongside other products; a necessity for early production planning.

Defining “boundary conditions” for product manufacturing

Preliminary laboratory testing will establish if and how a new product can be manufactured. This activity is a preliminary assessment of company existing production capabilities – defining the *process window* for incremental product development, and identification of new *boundary conditions* for radical product innovation (Frishammar et al., 2013, Kurkkio et al., 2011). This assessment should consider the potential to stretch the capabilities of the existing process through an identification of ‘bolt on’ equipment (Aylen, 2013). It is critical to early identify if there is a need to move outside a process window, as it holds the potential for systemic production line change and collaboration with equipment manufacturers (Lager and Frishammar, 2010). For B2B products, it could also involve a defining the customers *process windows* for new or improved products (Frishammar et al., 2012). The interrelationships between product and process innovation also necessitate examination of the complementarity and the selection of suitable integration mechanisms (Hullova et al., 2019).

5.3 Stage II Product development – Product and process design

Ease of manufacturing of new products is nothing new in other manufacturing industries, and for decades the mantra of designing products for manufacturability has been acknowledged (Boothroyd et al., 1994). The need for cost-efficient product manufacturing processes is generally recognized in the process industries, but the importance of a very early integration of new or improved products together with the development of related production process technology is generally not observed (Lager, 2017b).

5.3.1 Product design and test marketing (methodologies: A,D, E,F)

In search of a "product dominant performance"

In other manufacturing industries the concept of dominant design (Utterback, 1994) is often used to communicate that successful product innovations may become a sort of de facto standard as a result of the standing they hold with customers. Since products in the process industries often are more or less homogenous products the *dominant design* concept is not applicable. It is here suggested to introduce the concept of *dominant performance*, when product specifications and functionalities surpass all products on the market; e.g. the "Goretex" product from DOW Chemicals, or the "Losec" product from AstraZeneca.

Platform-based product design

Today, companies often need to create multiple product varieties tailored to the requirements of different customers. Product innovation in other manufacturing industries has during the last decades undergone a dramatic change when *platform-based design* philosophies has been introduced and practiced in product innovation (Robertson and Ulrich, 1998). In the process industries this concept is still in its infancy (Lager, 2017b), but how to develop new or improved products using captive or supplied raw materials to produce *product families* supplying different market segments is however today an important concern (Jianxin et al., 2007, Samuelsson and Lager, 2019).

Integrated packaging development

Packaging development nowadays forms a key consideration across a range of process-industrial sectors. Packaging is of particular importance within the Food & Drinks Industries, and the Pharmaceuticals Industries, where it has a strong influence on the product's characteristics, performance, safety and potentially its sales (Agariya et al., 2012). Yet, it is sometimes overlooked as a product innovation opportunity, since decision-making is highly influenced by considerations of production investment (Trott and Simms, 2017). Companies need to consider more the production and containment of the product, alongside environmental concerns (Silayoi and Speece, 2007, Simms and Trott, 2014). In conclusion, an integrated design of the core product and packaging is an area that should be better recognized in the design of an innovation work process.

5.3.2 From laboratory testing to demonstration plants

Laboratory testing is often the starting point for product innovation in the process industries, but the use of simulation already has replaced test work in some applications (Lager, 2000). Increasingly, many tests are conducted in the production environment, resulting in fast feedback. Finding a correct balance between fast process development in plant tests and minimum production disturbance remains an important issue (Trott and Simms, 2017). Production plant trials may be undertaken to test new equipment, new process conditions, new process configurations. Problems often occur at the point of scaling up (Linton and Walsh, 2008), thus, moving from the laboratory stage to production testing or pilot planting is an important step to improve the understanding of a production process. Demonstration plant trials are often very costly and generally carried out in projects involving a more innovative production process (Hellsmark et al., 2016).

Product design for processability

Within this process and design phase equipment suppliers play an integral role (Lager and Frishammar, 2010, Lager et al., 2015). Different situations also exist according to whether the new process is to be integrated into an existing production structure or operated as a stand-alone process in a completely new production plant (Leonard-Barton, 1992). The consideration of processability in early product design can help avoid later delays as a result of challenges to process plant operation. Likewise, considering process constraints may lead to product designs that require less adaptation to existing equipment, reducing the investments and change required (Aylen, 2013).

Process design - detailing the operational conditions for product manufacturing

At this stage, whether the company erects a new plant or adapts an existing production line, analysis should be undertaken to establish the capabilities of production. Building on the work of Frishammar et al. (2012) and Kurkkio et al. (2011), the *boundary conditions* of the existing plant, or its *process window*, will critically influence the potential product opportunities available. Hence, proactively analyzing this may provide insights into further development opportunities or in itself influence choices on process design to increase production flexibility. Indeed, considering the V-type flow pattern (Chakravorty, 2000) of production, new process conditions may provide opportunities for multiple new products (Samuelsson and Lager, 2019).

5.4 Stage III Post-product development – Industrialization and Marketing in the "bumpy back-end"

The final step is the transfer of the results from the Product development stage into the Post-development stage. At this point, efforts shift from the R&D organization to the production and marketing functions. Introducing existing, improved or radically new process technology in the process industries is not complete until it is operating well (Lager, 2012). This final stage will generally involve modifications of existing equipment, new process installations or even the erection of a complete new production plant. One can argue that this phase is not just a simple matter of ensuring the factory correctly functions and handing it over to production (Bagsarian, 2001). Post-product development thus represents the part of the total development process that can make the difference between project success and failure. It thus argued that particular attention should be paid to this stage, including industrialization, start up, market launch and application development. While uncertainty and unequivocally are the fundamental problem during the *fuzzy front end* of product innovation (Frishammar et al., 2011), the problem of complexity and costliness during the Post-product development stage has induced us in this study to name this final part of the work process the *bumpy back end*.

5.4.1 Industrialization (methodologies: A)

Introduction of process technology in existing plants or erection of a new production plant

Innovation is dependent on high quality raw material supplies and cost-efficient production systems in order to achieve good product price/performance relations; a process industry dominant logic (Lager and Blanco, 2010). However, it is not sure that the necessary equipment/technology can be acquired directly “off the supplier’s shelves” without customisation (Lager et al., 2015). Strong commitment may be required to find competitive production solutions in collaboration with equipment suppliers, thus activities that should be started early in the work process (Lager and Frishammar, 2010).

Since process companies usually are very asset-intensive, their ability to respond to change is often limited (Lager et al., 2017). Hill (1994) noted this inconsistency between changing customer requirements and manufacturing’s inability to support the specification of its products. However, a window of opportunity for equipment supplier collaboration is often the building of a new plant, particularly in the concept and design phases (Trott and Cordey-Hayes, 1996). However, in later phases of product life cycles when products need to be further improved or new ones added, it is more difficult to adapt existing production systems to new customer-market conditions (Samuelsson et al., 2015). Thus the design of the production system should be stronger integrated with strategic product development, in order to avoid a poor match between the market and the machine.

Production system start-up and hand-over to production

Bringing new plants, major production processes, minor unit operations or even single equipment on stream is not only a production risk, but an activity that is always also a safety-critical endeavor (Bagsarian, 2001). Installation and startup must not be overlooked, since even minor process equipment integrated in big plants has the potential for major production disturbance (Lager, 2012). Problems during start up may strongly influence both the internal and external production environments, and substantially delay market launch. Front end planning and scheduling can thus lead to more expedient commissioning and startup activities during the industrialization stage (Sheridan, 2015); consequently reducing innovation lead-times.

5.4.2 Market launch and application development (methodologies: A)

Market launch

Effective product launch management forms a key problem, when the non-assembly nature of new products may result in slower launch speed (see e.g. Vickery et al., 2015). Whilst initially benefit from differentiation new products are frequently emulated by competitors, and quickly become ‘downgraded’ into a commodity position (Lager, 2000); capturing early returns is therefore crucial. A study by McKinsey (2012) on materials commercialization within the Chemical Industries, revealed a significant lag between the launch of new products and the point at which they achieved meaningful revenues. This identified a need to better understand target markets for new materials, thus effective messages must be designed to improve understanding of product benefits and thus increase diffusion, providing clear information on the product's use, technical facts, and financial details (Talke and O´Connor, 2011).

Application development with B2B customers and end-users

Within the process industries, application development forms a key activity in the business to business context. This involves assisting customers in the use of products, with development activities emphasising the optimisation and improvement of the products and/or production process of the customer (Lager and Storm, 2013). It involves the identification of new application development opportunities for existing and newly developed products (Lager and Storm, 2013). This activity is thus located at the interface between incremental product development, technical services, and new business development. This undertaking is often neglected but critical for a process-industrial product innovation work process, since lead-times not seldom are influenced by delayed customers' adaption of their process system to new raw materials.

5.5 Post launch review (methodologies: G)

Final product adjustments and fine-tuning of the production system

At this stage further review of potential innovation opportunities occurs. Critically, within the process industries, the installation of new equipment and process capabilities necessitates an analysis of further opportunities (Hullova et al., 2019). Significant improvements can be achieved in the periods following the introduction of new products and associated process equipment. Availability of time for 'learning by doing' and 'learning by using' within production schedules can provide additional productivity gains.

6 Discussion and research outlook

The purpose of this article is to provide theoretical insight and practical guidance how companies can develop and implement an improved product innovation work process tailor-made to process-industrial conditions. In the development of the Integrative Framework, a simplified three phase model was initially selected for the literature review (Utterback, 1974), and was consequently selected for the Stage-Gate structure, eliminating the complaint of too complex work processes. The first Gate is positioned after completion of the *fuzzy front-end*; before entering the resource demanding product and process development Stage. The second Gate is positioned after completion of the product and process design Stage; before entering the post-development *bumpy back-end* Stage.

6.1 Theoretical contribution

Resting on the assumption that a work process design for product innovation of non-assembled products needs to be well-adapted to specific process-industrial conditions, an Integrated Framework for company development of individualized work processes has been developed.

To the best of the authors' knowledge, such a holistic perspective has not so far been presented, and in reference to Corley and Gioia (2011) the scientific utility of the research findings thus provides a new development within the literature that improves conceptual rigor and increases the potential for this area to be operationalized and tested. Figure 1 captures the two integrated activity flows: product innovation from ideation to marketing and process innovation from ideation to industrialization; a novel end-to-end cross-disciplinary approach for this work process. In the pre-development Stage, the importance of *well-integrated* product and process concepts has been recognized, together with packaging, logistics and raw material concepts. In the perspective of company search for shorter lead times in product innovation, the significant importance of the post-development Stage has been identified, as an area that ought to be given more attention in work process design. The use of product innovation methodologies in relation to work process design is generally overlooked in previous research, and it is argued that some well-proven methodologies like QFD seems to have been lost in transition, and need to be revitalized.

6.2 Managerial implications

In consideration of the idiosyncrasies between the development of non-assembled products and assembled products, it is concluded that companies in the process industries should not copy-and-paste work process design from other manufacturing industries. The Integrated Framework is thus intended to give an incentive and guidance for product innovation managers in different sectors of the process industries to take a fundamental out-of-the-box review of their existing work processes. The Integrative Framework illustrates the importance of product and process integration in a total "end-to-end" work process perspective, whilst highlighting the integrating aspects of supportive methodologies, circular economy, and digitalization from ideation to product launch. The proposed, simplified, Integrated Framework structural configuration is thus an effort to move from efficiency to effectiveness, making formal work process design somewhat more user-friendly, focusing on the "Der schwerpunkt" within each Stage.

The mantra "from customer understanding to design for processability" introduced in the article title, is purposefully deployed to underscore the importance of development of cost-efficient production systems throughout product innovation. Since the industrialization and marketing Stage often delays product introduction, it is advocated that this part of the work process requires more attention in process design. Figure 1 gives an overview of the Integrated Framework, but the associated text for the individual Stages are to be deployed as guiding memos for design of companies' individualized work processes.

6.3 Policy implications

Companies in many sectors of the process industries like the Food Industries (Gamal, 2015, Lager and Kjell, 2007)(ref), Forest Industries (Figueiredo and Cohen, 2019) and Mining and Metal Industries (Figueiredo and Piana, 2016, Lager et al., 2010) generally strive to reposition in the supply/value chain, from suppliers of commodity products to suppliers of more functional products; the commodity battle (Lager and Blanco, 2010) Excellence in product innovation is thus an important strategic capability in all manufacturing industries, and of particular importance for raw material producing companies in late-industrializing countries. One way to improve company product innovation capabilities within the family of process industries is the implementation of an improved company's product innovation work process more adapted to the process-industrial context. The new Integrated Framework is intended as a guiding instrument for company design of such an improved work process. If successfully implemented, a more efficient work process thus has the potential to give a company a stronger innovation capability and an improved competitive position in today's global and dynamic product innovation arena (Teece, 2007) Not only is there a need for further empirical research in order to further develop, detail, and industrialize such a framework, but there is furthermore a need to establish and support the academy-industrial transfer mechanisms for such a concept. National innovation programs and policies facilitating company innovation strategic development, are thus recommended to further consider supportive funding of *improved process-industrial infrastructural capabilities for improved product innovation performance.*

6.4 Research limitations and a way forward

The presented theoretical Integrative Framework is to be regarded as a bundle of propositions to be tested in further empirical research. In our on-going research, the findings will be integrated in a questionnaire in a Delphi study with a number of companies from different sectors of the process industries, when the industrial usability of the Integrated Framework will be tested and further improved. In the process industries, often with a divergent V-type of material flow pattern, a large number of product varieties are usually manufactured. Since it is recognized that the product variety aspect is important in work process design it is concluded that this aspect should be further researched.

7 Conclusions

It is initially advocated that the product innovation work processes should be more adapted to the industrial environment where they are to be used, and that scholars should stop searching for the *Holy Grail* of a generic all-purpose product innovation work process. *In reference to research question No 1*, it is first concluded that the well-proven Stage-Gate model (Cooper, 2012), is a fundamentally useful "decision model" to enhance company product innovation also for non-assembled products. A company product family contextualization of new product ideas has been included in advance of Stage 1, and a post-launch review of project outcomes after the completion of Stage 3. Cooper (2009) has earlier suggested a supplementary discovery stage in front-end, but it is here suggested an extension into an *Integrated Knowledge Platform* supporting the total end-to-end work process with available general information. Later versions of Stage-Gate recommend the use of overlapping gates (Cooper, 2014), and in reference to Figure 1 this advice has been further expanded into a possible end-to-end work process overlapping optional mode. In response to the need for faster work processes that also offer flexibility (Cooper and Sommer, 2016), it is proposed that the two Gates in Figure 1, should be contingent on alternative lists adapted to project complexity and product and process complementarities. Finally, whilst the extant literature emphasizes the importance of the *fuzzy front-end*, it is here recommended to pay even more attention to the *bumpy back-end* in process-industrial work process design.

In reference to research question No 2, the product focused Stage-Gate decision process typically neglects the importance of a simultaneous development of manufacturing capabilities. The importance of a well-integrated product and process innovation process for the development of non-assembled products is at the core of the Framework. Whilst the product development models often capture the importance of *product concepts,* the need for the development of *process concepts* is something that can be learned from research in process industries (Kurkkio et al., 2011). However, the need for a process concept development in the product development work process and their simultaneous development and strong integration of those concepts are findings of importance for work process design. Moreover, the deployment of target setting facilities in the use of the House of Quality is a further improvement of product concept development approach and for concept screening of non-assembled products.

Previous suggestions on the use of supplementary product definitions is acknowledged and it is suggested that this could as well apply for process concepts. The importance of identifying “process windows” is recognized including the identification of B2B customer “process windows” (Frishammar et al., 2012). The importance of helping B2B customers to introduce supplied new product (raw materials) in their production systems, in this study denominated *application development*, is highlighted when the concept of a the customer’s process ‘window’ fits in well (Frishammar et al., 2012). The use of the Process Matrix in the Multiple Progression QFD (mpQFD) system is proposed as a suitable methodology support for such an endeavor.

In reference to research question No 3, the importance of *sustainability* is of particular importance in the context of the process industries, which provide important material inputs for other industries, and are in many cases significant producers of pollutants. Their position also presents significant opportunities for positive impacts through increased use of recycled materials, more energy efficient production processes, and producing products that have a lower environmental impact (Johnsson, 2011). Thus future work process design should in an “end-to-end” perspective integrally incorporate ‘circular’ thinking in order to lower these impacts. *In a digitalization perspective* the growing importance of IoT and Smart factories is increasingly recognised (Oesterreich and Teuteberg, 2016, Sung, 2018). However, such factory considerations are rarely linked to product development and are not captured in generic models. Yet, within the process industries the interlinkages between raw materials, production processes and the final product necessitates the integral consideration of digitization. The need for listening to the Voice of the Customer and translating customer requirements into product attributes has been previously recognized by Cooper (2009), which is also an area articulated in *design thinking*. However the use of the House of Quality in Quality Function Deployment as a supportive methodological tool is unfortunately generally overlooked, including the use of the mpQFD system (Lager, 2005) and the related process and raw material matrices. The area of supporting methodologies for the product innovation work process presents new perspective on process-industrial product innovation and an area in need of further research.

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Appendix 1: The process industries

An intentional definition of the process industries is as follows (Lager, 2017a):

> *"The process industries are a part of all manufacturing industries, using raw-materials (ingredients) to manufacture non-assembled products in an indirect transformational production process often dependent on time. The material flow in production plants is often of a divergent v-type, and the unit processes are connected in a more or less continuous flow pattern."*

A number of process-industrial sectors have been selected from the manufacturing industries using the statistical classification of economic activities in the European community (NACE, 2006). The following industrial sectors are thus suggested to be included in the family of process industries; their associated NACE codes are presented in parenthesis:

- *Mining & metal industries (05; 06; 07; 24)*
- *Mineral & material industries (minerals, cement, glass, ceramics) (08; 23)*
- *Steel industries (24.1; 24.2; 24.3)*
- *Forest industries (pulp & paper) (17)*
- *Food & beverage industries (10; 11)*
- *Chemical & petrochemical industries (chemicals, rubber, coatings, ind. gases) (20; 22)*
- *Pharmaceutical industries (incl. biotech industries and generic pharmaceuticals) (21)*
- *Utilities (electricity & gas, water, sewerage, waste collection & recycling) (35; 36; 37; 38)*

Appendix 2: Supporting product innovation methodologies

Potential supporting methodologies for a product innovation work process	Targeted Stages and Phases
Quality Function Deployment (Lager, 2005, Lager, 2019) A cross-functional approach in product innovation and renovation, and an investment in improved understanding and knowledge creation about customers and competitors. ***Voice of the Customer*** A work process in which stakeholders' requirements for a product are initially collected, refined and structured. ***House of Quality*** Requirements are related in a matrix to measurable properties of the product. Stakeholders' importance ratings are then translated into this new technical dimension. ***Process & Raw material matrices*** Measurable product properties and their importance ratings and target figures are then further progressed as requirements on the production system.	**A**
Kano model (Afshan and Sindhuja, 2013) In customer interviews, the customers usually only articulate the requirements termed *Performance Quality Requirements* but not their *Basic Quality Requirements* and certainly not their *Excitement Quality Requirements*, sometimes called "WOWs". The Kano model is using the two dimensions Customer satisfaction and Degree of requirement satisfaction in the analysis.	**B**
Conjoint analysis (Green et al., 2001) Conjoint analysis is a survey-based statistical technique in market research that determine how people value different product attributes that make up an individual product.	**C**
Concept generation and selection methodologies (Pugh, 1981, Seidel, 2007) Pugh selection process is still the preferred methodology in combination with the use of the House of Quality transferring the "requirement space" into the "idea or solution space". Concept "shifting" and multiple concept development is recommended.	**D**
Target costing and functional cost analysis (Cooper and Slagmulder, 1997, Monden, 2000) By setting target costs based on market-driven selling prices, target costing transmits the cost pressure that is placed on the firm by the marketplace to everyone involved in the design process.	**E**
Design for manufacturability/processability (Boothroyd et al., 1994, Lager, 2005) Product developers usually do not recognize the importance of a very early integration between the development of new or improved products and the development of related improved production process technology.	**F**
GEMBA and Lean methodologies (Floyd, 2010, King, 2009) It is advantageous to study customers' behavior in their use of a product in its natural environment—an ethnographic product innovation approach sometimes described as "walking in the customer's shoes" – GEMBA.	**G**

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