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A Conceptual Framework for Production Innovation: Expanding and Creating New Production Capabilities

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Abstract

Production development has for decades concentrated on incremental improvements by exploiting existing manufacturing knowledge to improve existing production systems or adapt them for new product developments. Building up an "ambidextrous innovation" ability, and more specifically in increasing focus on explorative production innovation, is important to balance production development efforts and obtain sustainable development of production. This paper aims to provide a conceptual framework for "ambidextrous production innovation" that conceptualizes and highlights phenomenon characteristics from exploitative and explorative perspectives. The conceptual framework describes "production innovation" as the process of either increasing or developing a new production capability, enabling opportunities for new product designs. This process can be either "product-driven" or "production-driven" depending on the primary objective of the development.

Keywords

Ambidextrous innovation, Production development, Production innovation, Process innovation.

Introduction

Industrial production is facing significant challenges in terms of both sustainability and competitiveness. To address these production challenges, a climate for innovation and well-developed abilities to innovate are required to deliver incremental and radical improvements in both the short- and long-term. One of the more enduring ideas in organisation science is that an organisation's long-term success depends on its ability to exploit its current capabilities while simultaneously exploring fundamentally new competencies (March 1991; Levinthal & March, 1993). Thus, to focus solely on *incremental or exploitative innovation* (i.e. refinement or enhancement of efficiency) is not truly sustainable from a business perspective since at some point optimisation of a production system will start to deliver at best marginal improvements. In parallel, it is needed to plan and realise *radical, explorative innovations* to avoid surprise disruptions caused by competitors. *Explorative innovation* is characterised by risk-taking, experimentation, discovery, and flexibility in efforts to develop new production capabilities, which conflicts with the stability often desired in a production system, while *exploitative innovation* is characterized by refinements to improve the efficiency and operational excellence of a production system. Although both "explorative" and "exploitative" innovations are needed for a sustainable and competitive business (i.e. "ambidextrous innovation"), organisations tend to lean towards one or the other, a choice based on both calculated decisions and more intangible organisational norms and procedures (March, 1991). *Exploitative, incremental innovations* tend to be over-represented in the manufacturing industry, and many others, as short-term measures, meeting demands of existing customers, and ease of measurement are often highly prioritized.

Technology S-curves are often used to illustrate changes in technological performance as a function of time or research effort (Foster, 1985), and it has become the established descriptions of technology lifecycles and the competition between technologies (Adner & Kapoor, 2016). As a "technology" matures and

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approaches the top of its *S-curve*, further substantial improvements in performance are impossible due to technological and economic constraints, until a new technology emerges with different constraints. The "leap" from the optimisation of existing technology to embracing and beginning to optimise a new one is by definition "disruptive", as their *S-curves* are not linked and there will probably be stark differences in associated challenges (see Fig. 1).

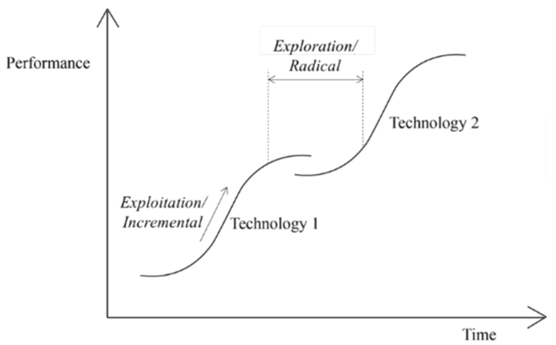

Fig. 1. Technology S-curves (adapted from Foster, 1985)

Thus, manufacturing companies need to differentiate or integrate responsibilities for running and optimising operations, and strategically develop new production capabilities to meet both needs. *Differentiation* refers to the separation of "exploitative" and "explorative" activities into distinct organisational units, whereas *integration* refers to mechanisms that enable organisations to address exploitative and explorative activities within the same organisational unit (Raisch et al., 2009). To date, the two approaches have often been positioned as mutually exclusive in practice, but scholars have pointed out the various inherent shortcomings of both. Perhaps most importantly, although most firms aim to embrace *radical innovation* because of the potential of "disrupting technologies" to increase industries' performance and enhance their value offerings, successful *radical innovation* is rare and most attempts to achieve it tend to fail (Sandberg & Aarikka-Stenroos, 2014).

For decades, practitioners engaged in *production development* have largely concentrated on "incremental improvements" by exploiting existing manufacturing knowledge to improve existing production systems or adapt them for new product developments. Therefore, *incremental innovation* is well researched in production contexts – e.g. in the continuous improvement concept of lean production (e.g. Womack et al., 1990), where many methods and tools for process control and improvement are available (i.e. lean six sigma toolkits). These are mainly focused on retaining a current state or continuously improving this state in terms of familiar performance measures such as productivity, cost, time, quality, and flexibility – 'do what we do now, but better'. Hence, they are strongly oriented towards strengthening or increasing existing production capability, rather than developing a new one.

Production innovation can be described as the process of either increasing or developing a production capability together with the manufacturing firm's organisational capabilities by implementing new production equipment and deploying new work methods in a production environment (Larsson, 2017; Romero et al., 2017). Hence, in general terms, *production innovation* is defined as "the process of change", where ideas are transformed into new processes, technologies, tools and/or work methods within a production system to create value for the organisation and its stakeholders" (Larsson, 2017; Romero et al., 2017). These descriptions or definitions incorporate different types of "innovative production developments", ranging from valuable optimisations of a production process to radically new production technologies, revolutionising industries.

Although the importance of "production innovation" for sustainable development is well-known, there is little practical or academic understanding of how to support it. In a literature review, Becheikh et al. (2006) found that only 1% of innovation studies published between 1993 and 2003 focused on "process innovation", which is the previously used concept most closely linked to 'production innovation', but not equivalent. *Process innovation*, as described in the seminal work by Utterback & Abernathy (1975), refers to the implementation of a new or significantly improved production or delivery method] (including significant changes in techniques, equipment and/or software) to acquire a new or increase a current production or service capability in a manufacturing or logistical system. *Production innovation* is however not only a "process innovation", but an innovation in a production system sub-system] (e.g. a manufacturing technology, work method, information system, management system, etc.). Becheikh et al. (2006) also concluded that product and process innovations need different approaches from an innovation management perspective.

In summary, there is a gap in the literature, where the much-needed innovative efforts in production development lack support from the research community both in terms of conceptualisation and management perspective. This paper aims to address this gap by providing a conceptual framework for "production innovation" that conceptualises and highlights the characteristics of the phenomenon and serves as a common foundation for further research on the topic.

Literature review

This section presents and discusses studies from various research fields that are relevant to the conceptualisation of *production innovation,* in five sub-sections. Firstly, a brief overview is given on how different *types of innovation* can contribute to development in society and how innovation in production is used in the existing literature. The second section presents aspects of *organisational ambidexterity* and discusses how ambidexterity is managed in production environments. The third considers the *product design space* as the link between product and production development. The last two sub-sections discuss different *innovation pathways* for different types of production engineering projects and finally present a synthesis of the considered concepts.

Innovation in society and production

Innovation has played a critical role in shaping human society, from improving our quality of life to addressing some of the world's most pressing problems. The different *types of innovation* have had a profound influence on human society. *Technological innovation* has transformed the way we work, communicate, and access information (Nascimento et al., 2021). *Social innovation* has helped address some of the world's most pressing problems, such as poverty and climate change (Schneider et al., 2021). *Business model innovation* has disrupted traditional industries and created new opportunities for entrepreneurship (Lorenzoni et al., 2021). *Service innovation* has transformed the way we receive medical care and access education (Kaplan et al., 2021). As we face new challenges, innovation will play a critical role in shaping our future.

From a production perspective, many different types of innovation may be relevant to incorporate, such as technological and process innovation. However, these types of innovation focus on optimizing a certain aspect of a production system, which may hamper more *explorative innovations* as these tend to be more systemic (Larsson & Larsson, 2018).

A search in the SCOPUS database for papers published in journals and conference proceedings between 2003 and 2023 with 'production innovation' or 'innovation in production' in the title yielded 461 papers. The initial search was restricted to titles because if a paper focuses strongly on either conceptualisation or management of "production innovation", the term should appear in its title. Subsequent screening of the retrieved papers' titles and abstracts showed that the term 'production innovation' is often mentioned, especially in studies concerning agriculture, construction, and energy industrial sectors, which tend to follow the Engineer-to-Order (ETO) production paradigm. However, the term is used to refer to "incremental improvements" more often than to "radical innovations". The limited number of publications on the topic also focus more on the benefits that cases classified as "production innovations" can provide, rather than how to accomplish and manage the phenomenon. Moreover, although the term "production innovation" is commonly used in literature, it is applied quite inconsistently, and there is still no common understanding of the concept. Possibly, at least partly, due to the paucity of conceptualisation of the phenomenon, which has received insufficient attention from innovation management scholars in the context of production systems.

Organisational ambidexterity and its management in production environments

As already mentioned, an organisation's long-term success depends on its ability to simultaneously exploit current capabilities and explore fundamentally new competencies (March, 1991; Levinthal & March 1993). In literature, this is commonly referred to as *ambidexterity*, which means in a broad sense the ability of an organisation to address multiple but conflicting objectives simultaneously and equally (Simsek, 2009; Birkinshaw & Gupta, 2013). Over time, two different, but not mutually exclusive, pathways of *ambidexterity* have emerged: "competence ambidexterity", and "innovation ambidexterity". *Competence ambidexterity* refers to the propensity, intention or capacity to simultaneously exploit and explore knowledge, i.e. refine and extend existing knowledge, skills, and processes and generate entirely new knowledge, skills, and processes (March, 1991). In this pathway, *exploration* is rooted in variance-increasing activities, learning-by-doing, and trial-and-error, while exploitation is rooted in variance-decreasing activities and disciplined problem-solving (Smith & Tushman, 2005). The other pathway, *innovation ambidexterity* refers to the simultaneous realisation of conflicting organisational outcomes, more specifically the simultaneous achievement of "incremental" and "radical" innovations (He & Wong, 2004; Raisch & Birkinshaw, 2008; Lin et al., 2013). *Incremental innovations* refer to small and gradual improvements, often in products and services, which build upon existing enabling technologies, while *radical innovations* are completely new solutions that involve big fast shifts to different technological trajectories (Wheelwright & Clark, 1992; Benner & Tushman, 2003; Atuahene-Gima, 2005).

Technological advancement is a complex endeavour, which can be approached by imitation, catch-up, overtaking or leapfrogging (Liu et al., 2019). Both *incremental* and *radical improvements* can be found in production, where lean production principles and approaches have long played a central role, providing various methods and tools for obtaining efficient and value-added productions. Key *lean production* concepts concerning development include "Kaizen" and "Kaikaku". Japanese terms refer to two kinds of focused improvement efforts. *Kaizen* is "the practice of continuous improvement, involving everyone and aiming to obtain major results from many changes accumulated over time" (Brunet & New, 2003). *Kaikaku*, in contrast, is described by Yamamoto (2013) as "a large-scale improvement that involves the fundamental re-thinking and radical design of systems and processes related to production, with the primary purpose of achieving dramatic improvements in the performance of the production system which is frequently measured in terms of cost, quality, speed, and flexibility". There are variations in descriptions of the concept of *Kaikaku*. According to some authors, it refers to an accumulation of smaller improvements (Kondou, 2003), while others regard it as the replacement of existing practices (Kondou, 2003). However, in both cases, the objective is to improve the production system's performance. New technologies for manufacturing systems are often explored outside the ongoing production operations in knowledge or technology development projects. In this context, *technology* can be viewed as a specific type of knowledge, sometimes embodied within a physical artefact (e.g. a machine, system, or product), which is applied focusing on the know-how of the organisation (Phaal et al., 2004). Hence, the development of new technology is strongly linked to "explorative innovation", where new knowledge is required and developed (March, 1991).

Achieving *innovation ambidexterity* is a significant challenge as it requires appropriate trade-offs between short- and long-term objectives and effective allocation of scarce resources between competing priorities (Birkinshaw & Gupta, 2013). This challenge is well-known and has been intensively considered in organisational science and innovation management literature, but *explorative, radical innovation* in production contexts has received much less attention in production management literature. Decisions regarding "exploration" and "exploitation" within an organisation, and how to design and structure the organisation to support opportunities of "exploitative" and "explorative" nature, are made at the strategic level (Chandrasekaran et al., 2012; Bednarek et al., 2016). However, in practice, the responsibility for *production development* tends to be delegated to the production units (i.e. middle management). The decisions on how to structure the organisation for *radical innovation* in production also need to be lifted to strategic and higher management levels, as production units lack the power to command changes in a production system's technology, resources, information, and management subsystems. For a production unit, the main objective is to run production as efficiently as possible, so the main objective of "production development" is to improve the performance of production systems for existing products or to adapt a production system for the production of future (new) products. The performance of production systems is traditionally assessed using parameters like productivity, cost, quality, time, and efficiency (Bellgran & Säfsten, 2009). From a product design perspective, flexibility and risk are also considered important when developing a production system.

In summary, to develop *ambidextrous production innovation ability*, an organisation must combine and balance an "explorative" and "exploitative" organisational mindset/culture at the strategic level, and a dual capability for "incremental" and "radical" innovations at the operational-tactical level.

Product design space: linking the product definition space and production capability space

A product does not exist until it has been produced, and the main purpose of a production system is to produce products. Hence, the two are inevitably interlinked. However, there are still differences in the nature and objectives of product and production development, which are sometimes conflicting. *Product development* tends to focus on novelty and meeting market demands, challenging the production capabilities, while *production development* focuses more on operational excellence, in terms of stability and efficiency.

In the early phases of product development, the constraints imposed by existing production capabilities on the desired *product design solution* are assessed and considered (Ulrich & Eppinger, 2012). One approach for closing the gap between product definition and production capabilities is *Design for Manufacturability (DfM)*. Wheelwright & Clark (1992) described *DfM* as a set of methodologies that "intend to minimise the cost of production and time-to-market without compromising on the quality of the product, supporting in this way industrial design engineers with various requirements related to manufacturability". In this approach, constraints of existing production capabilities are considered during product design and subsequent production design solutions.

The *product design space* with its variables and parameters in terms of desired and viable functionality and form is limited both by the "product definition space" and by the "production capability space", as illustrated in Figure 2 (Elgh & Cederfeldt, 2008; Larsson & Romero, 2017). The *product definition space* refers to the product design requirements, which consist of customer demands and wishes, and the configuration of the company's product designs. The *production capability space* refers to the company's production capabilities, as defined by the inherent production technologies and organisational, and workforce skills. The *product design space* refers to the range of feasible product definitions set by the available production capabilities, which enable and constrain possible product design solutions.

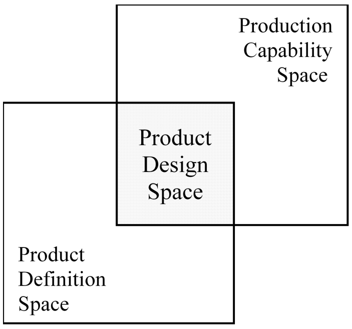

Fig. 2. Product Design Space as the area of intersection of the Product Definition Space and Production Capability Space (adapted from Elgh & Cederfeldt, 2008 in Larsson & Romero, 2017)

Different production innovation drivers for different production strategies

Olhager (2003) recognises four categories of *production strategies:* (i) Make-to-Stock, (ii) Assemble-to-Order, (iii) Make-to-Order, and (iv) Engineer-to-Order (see Fig. 3). In the *production strategies* where sales, i.e. the customer entry point, comes after product development, the 'product' itself is the value proposition. This arrangement can be found in Make-to-Stock (MTS) production regimes, in which companies plan production based on forecast demand for a set of predefined products and start producing before sales. It is also a feature of Assemble-to-Order (ATO) regimes, where customers are offered a variety of modular product choices, and Make-to-Order (MTO) regimes, where companies start producing after receiving a customer order based on a product catalogue.

The main competitive priorities of firms adopting these strategies are to deliver their products reliably at low cost and high quality. Hence, these firms tend to focus most of their innovation efforts on developing *exploitative, incremental production system innovations* based on the required production capabilities for achieving "operational excellence". In contrast, companies adopting an ETO production strategy do not offer a range of products but rather a 'production service' within the limits of their production capabilities to deliver highly customised products engineered for each unique customer order (Adrodegari et al. 2015).

Thus, for ETO companies it is more relevant to enrich their production capabilities, which are their value propositions, by adopting and/or developing new production-enabling knowledge and technologies (Larsson & Larsson, 2018).

Literature synthesis

Organisational ambidexterity is mainly a theoretical concept, and the term is not frequently used by practising managers (Birkinshaw & Gupta, 2013). Despite the new knowledge that both approaches need in the long-term, most innovations tend to be exploitative in many industries, due to the high prioritization of short-term metrics and quick fixes, to meet the demands of existing customers. Furthermore, production management tends to pursue stability, and

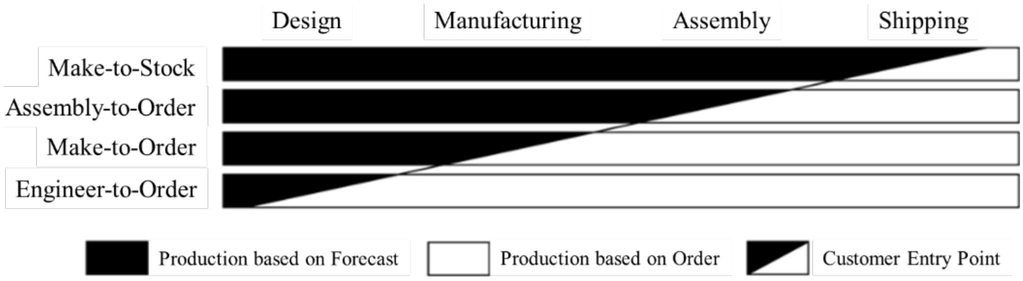

Fig. 3. The Customer Entry Point (diagonal line) (adapted from Four Recognized Production Strategies Olhager, 2003)

management generally fears risk. In addition, repetitive *exploitative innovation* or *incremental innovation* tends to reinforce itself as organisations learn from experience and an innovation pattern is built (March, 1991).

Different *production strategies* are associated with different competitive priorities, which also influence approaches to "production innovation". In MTS, MTO, and ATO regimes, the competitive priority is generally product-focused, and the most important parameters in production management tend to be productivity, cost, and quality (Olhager, 2003; Bellgran & Säfsten, 2009). Therefore, firms that apply these strategies tend to focus on *incremental* or *exploitative innovation* to obtain better results in terms of these production parameters. However, highly innovative products may also demand highly innovative production capabilities, which enable the realisation of new product designs (Larsson & Romero, 2017), an aspect which is rarely considered. In contrast, successful businesses applying an ETO strategy maintain high production capabilities to engineer and produce various products to meet volatile customer demands, all within agreed timeframes (Olhager, 2003). This requires dynamic properties, flexibility, and adaptability from a production system, correlating with the characteristics of *explorative innovation*. Nevertheless, *exploitative innovation* also tends to be over-represented in some ETO industries, such as the construction sector, since the focus on individual businesses or engineering projects performed within a limited timeframe restricts actors from exploring new production knowledge and technologies within the production phase (Larsson & Larsson, 2018). Consequently, new production knowledge and technologies often need to be developed outside of the daily business operation for their later adoption and application. In this manner, the build-up of production capabilities can support the competitiveness of ETO firms, as it opens avenues for new product design possibilities in the customer-centric engineering phase.

In synthesis, building up an *ambidextrous innovation ability*, and more specifically increasing focus on *explorative production innovation* in all production strategies, is important to balance the production development efforts and obtain a sustainable development of production.

Research method

Miles and Huberman (1994) define a *conceptual framework* as a set of key factors, constructs, or variables with presumed relationships among them. The development of the *conceptual framework* in this paper was achieved by following a step-wise process proposed by Jabareen (2009), involving mapping selected data sources, reading, and categorizing selected data, identifying, and deconstructing concepts, integrating concepts, and conducting synthesis, re-synthesis, and validation of the framework. Although this process was presented as a linear approach, the actual development of the *conceptual framework* was iterative, gradually building up to the final results presented in this paper.

Qualitative analysis can be used to support the development of *conceptual frameworks* (Jabareen, 2009). To gain in-depth knowledge of production innovation from an empirical perspective, a case study approach was chosen. Purposive sampling was used to select cases, focusing on the acquisition of in-depth data rather than representativeness and breadth (Flick, 2014). Data were collected primarily through semi-structured interviews with respondents highly involved in the innovation process (e.g. project manager, business developer, chief engineer, R&D manager, production engineer, etc.), as well as secondary sources such as public and internal documents. The interviews covered triggers for innovation, innovation process (i.e. steps, decisions etc.), and outcomes.

Results and discussion

This section presents a *conceptual framework* for two types of production innovation, "exploitative" and "explorative". The first part introduces the basic concepts for *exploitative* and *explorative production innovation* in terms of the realisation of increased or new production capabilities. The second part describes different paths for the realisation of *exploitative* and *explorative production innovation* based on the approaches to production development in the four previously outlined production strategies. Lastly, two cases of innovation in production are presented to illustrate the proposed framework.

Production innovation: expanding and creating new production capabilities

Production innovation can be described as "the process of either increasing or developing a production capability" (Larsson, 2017; Romero et al., 2017), and hence "the ability of a production system (with its inherent technologies, resources, information, and management systems) to perform its intended task", i.e. to produce a product (Romero et al., 2017). *Improvement* in the ability to perform the intended task results in an increase in production capability. Such incremental improvement is usually measured in terms of performance in common production system parameters such as cost, quality, and productivity (Bellgran & Säfsten, 2009). The resulting increase in production capability, e.g. reductions in production costs or increases in product quality, moves the constraining frames in the industrial designer's attempts to *Design for Cost or Quality.* This expansion of the product design space gives the product designer new boundaries to relate to, but still within the existing product definition space (see Fig. 4). In such cases, the changes

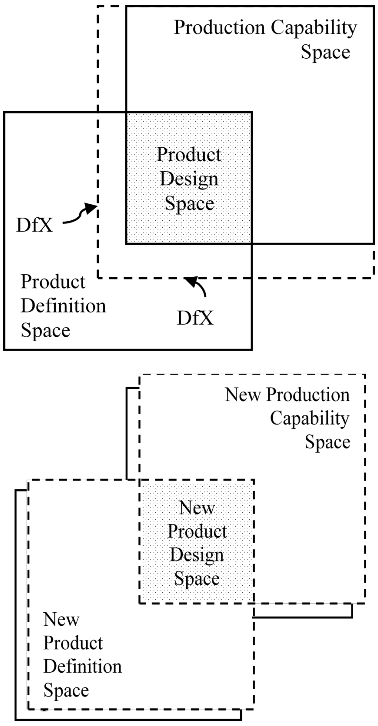

Fig. 4. Exploitative production innovation as enhancement of production capability, and explorative production innovation as the creation of a new production capability, indicated by shifts from solid to dotted lines (Authors' own conception)

in the product design and production system build on existing knowledge and optimisation of existing production technologies and ways of working. The value of this type of *exploitative* or *incremental production innovation* is relatively short-term, delivering value quite quickly, but as a technology reaches its performance limit, progress will slow down and stagnate. Sustained development over time by solely increasing production capability through the exploitation of existing knowledge and technology is hence not possible, as substantial improvements of a technology become difficult at some point (Foster, 1985), and the returns on investment to enhance it become increasingly meagre and eventually negative. Consequently, there is also a need for the development of new production capabilities – the capability to do new tasks using new knowledge and technology.

A *new production capability* created through *explorative production innovation* can make new product definitions technically feasible and financially viable, and hence generate new opportunities for the realisation of new product designs. The performance of a *new production capability* may not be directly comparable with the *previous production capability*, and it may not be possible to assess it using traditional performance parameters. This is because the main purpose and role of a new production capability are not to optimise a current production system towards higher performance, but rather to enable new product design and production opportunities. The value of a new production capability may be apparent in a longer timeframe, hence the two approaches (i.e. increasing and creating a new production capability) have complementary roles in the sustainable development of production systems. The performance of a new production capability may be difficult to assess, as relevant parameters might be unfamiliar or unknown due to its novelty, and the time horizon of tangible effects may be far away. Moreover, in terms of general assessment parameters, new production solutions may have lower performance than previous solu-

Table 1
Comparison of process innovation and production innovation

Process innovation	Production innovation
The implementation of a new or significantly improved production or delivery method (including significant changes in techniques, equipment and/or software) to acquire a new or increase a current production or service capability in a manufacturing or logistical system, which must lead to added value for the firm (company value) and its value chain (value chain value) (Utterback & Abernathy, 1975).	The process of either increasing or developing a new production (manufacturing) capability together with the manufacturing firm's organisational (workforce) capabilities by implementing new production equipment and deploying a new work method for it in a production environment (Larsson, 2017; Romero et al., 2017).

Table 2
Characteristics of exploitative and explorative production innovation

Characteristics	Exploitative/Incremental Production Innovation	Explorative/Radical Production Innovation
Approach	Increased Production Capability	New Production Capability
Objective	Optimisation, Stability	Opportunities, Flexibility
Knowledge Use	Exploitation of Existing	Exploration of New
Value Creation Horizon	Short-Term	Long-Term
Value Assessment	Known Parameters	Unknown, Uncertain

tions initially, but have scope to progress beyond previous limitations in the long run, as illustrated by production technology *S-curves* (Foster, 1985). The discussed characteristics of exploitative and explorative production innovation are summarised in Table 2.

Paths for realisation of production innovation

The realisation of "exploitative" and "explorative" production innovation can enable changes in the *product design space* in different ways. *Product-driven production innovation* is initiated by a new product design idea, for which a need for either increased or new production capability has been identified, depending on the magnitude of changes needed. The new or increased production capability is then developed later in the product development process as a response to the identified need. The development of production capability plays a central role in the possibility to realise an idea of a new product definition, i.e. to accomplish product innovation. Hence, from a product development perspective, "production development" is intended to provide viable production solutions for new product designs. In *product-driven exploitative production innovation*, increased production capability developed through improvements of existing production capability enables expansion of the product design space within the same product definition space (see Fig. 5). This could be explained as enabling new product designs within the same product fam-

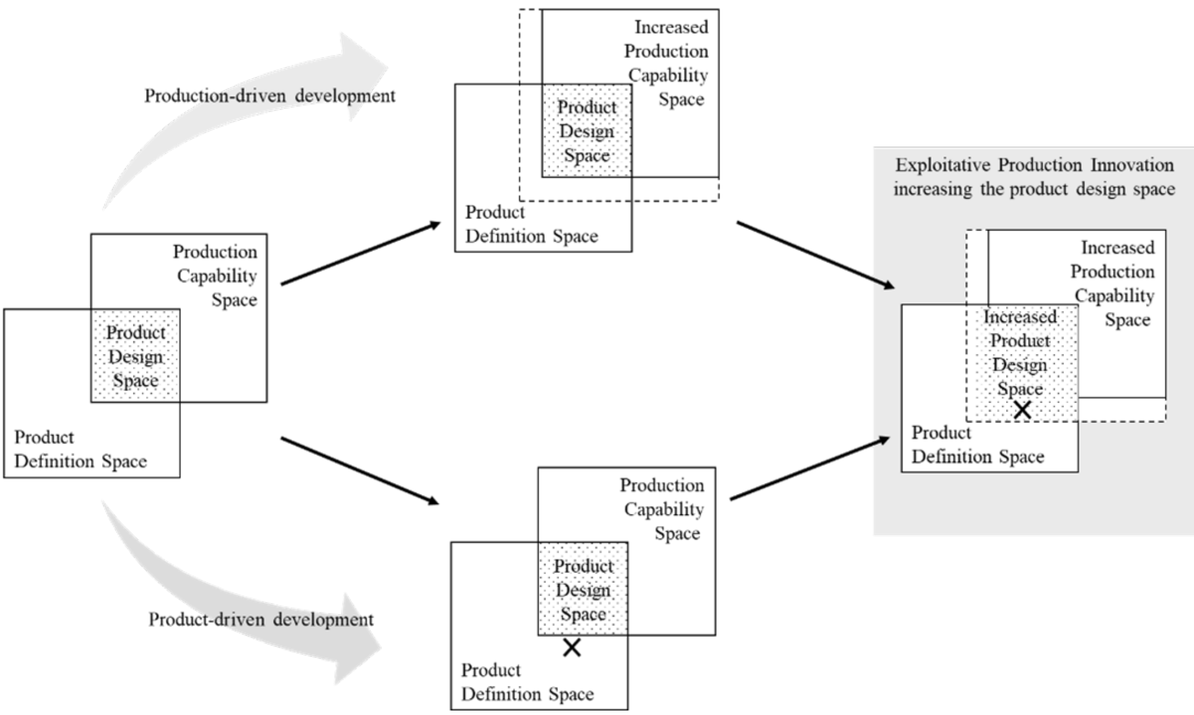

Fig. 5. Product-driven and production-driven paths for exploitative production innovation (with consequent increases in capability spaces indicated by shift (Authors' own conception)

ily. In contrast, *product-driven explorative production innovation* can support a new product family by enabling a new product design space in a new product definition space through new production capability based on new knowledge. However, new production capabilities that enable, or initiate, radical changes to both product design and the production setup are difficult to develop in product development processes. This is due to the interdependencies between "product" and "production", i.e. the early consideration of existing production capabilities, and later in the process consideration of the proposed product design(s) in the production development phase (Ulrich & Eppinger, 2012).

In other cases, the *production capability* is developed first and then applied to different product developments in *production-driven production innovation. Production-driven exploitative production innovation* is exemplified in e.g. continuous improvement in production, where the capability of the production system is increased continuously over time in efforts to raise performance. The increased production capability then creates new borders for upcoming product development, as the production parameters to adapt the design towards (e.g. using Design for Excellence (DfX) methodology) have changed (see Fig. 6).

In continuous improvement, the focus is on improving performance in the production of existing products, and the opportunities that the increased design space provides for future product designs are positive side effects rather than inherent features of the process (Larsson, 2017). This may also limit the magnitude of possible changes in the production system. New production capability generated through production-driven explorative production innovation can instead be developed outside the production system and production operations, in technology development projects (in R&D) or similar activities. In such cases, the new production capability is developed first and can then be applied in product development projects, enabling more radical changes in product design. In production strategies where the customer enters before or in the engineering phase, i.e. where sales precede product development (Salerno et al., 2015) in the innovation process, such as ETO strategies, the production-driven path for production innovation is highly relevant due to the setup of the product realisation process. The new production service (i.e. production capability packaged into an offering), can be sold and diffused into one or several engineering and product development projects (Larsson & Larsson, 2018). Their engineering and production capability

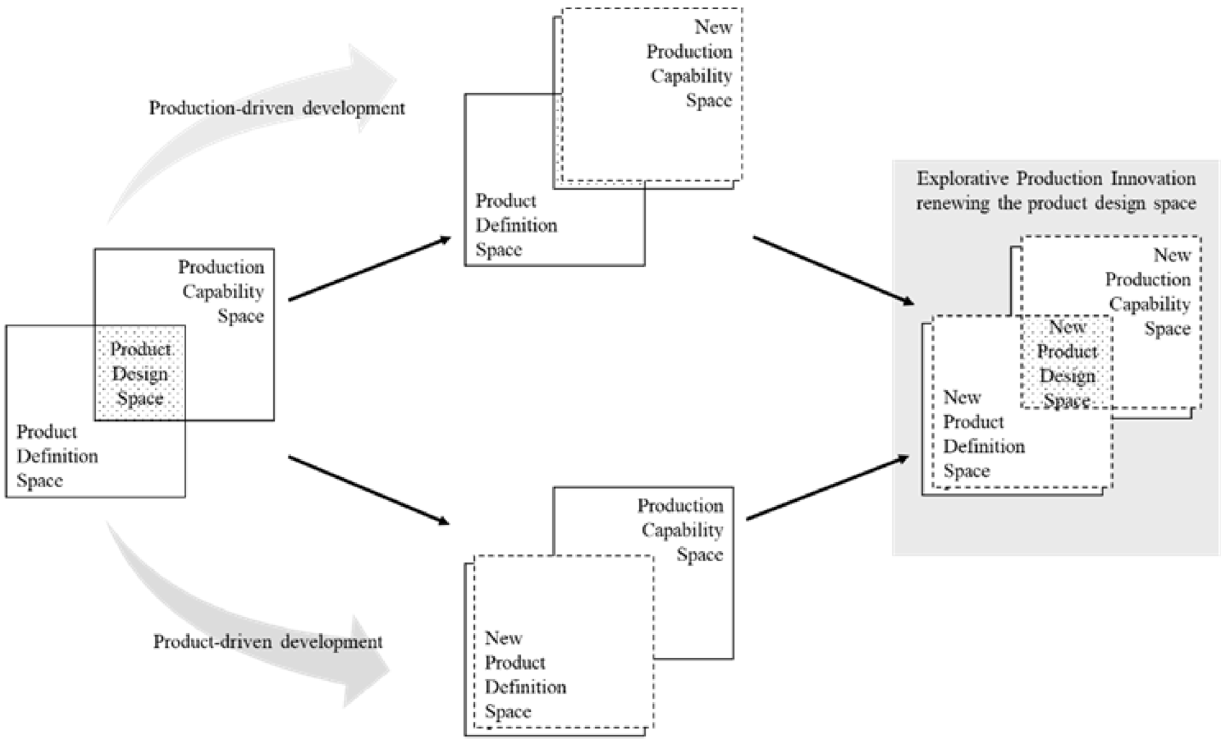

Fig. 6. Product-driven and production-driven paths for explorative production innovation with consequent increases in capability, product definition, and product design spaces indicated by shifts from solid to dotted lines (Authors' own conception)

becomes the differentiating factor that creates competitiveness for firms adopting such strategies. The transition from "production capability" development to implementation in engineering and product development projects is vital for the realisation of this type of production innovation. This path is also relevant for subcontractors that do not develop their products but rather offer a "production service". Generally, operational excellence is considered a key factor for the competitiveness of these firms, as they often compete on delivering the "production service" at a high quality but low cost. However, the range of production services subcontractors can offer, based on their production capabilities, may help them to win new contracts. Explorative Production Innovation Cases This section focuses on explorative innovation cases, which have received much less attention than exploitative innovation ones in the literature. For illuminating examples of the latter, see some recent studies by Boscari et al. (2016), Jaghbeer et al. (2017), Majava & Ojanperä (2017), and Neirotti (2018). More specifically, the section presents two cases of explorative innovation in production to illustrate the proposed framework for production innovation. Case I: Sandwich Structure for Space Rocket Nozzles – A New Production Capability Creating Opportunities in Engineering Projects The presented case involves a new production concept for space rocket nozzles, involving the creation of a sandwich structure with channels for a cooling agent by welding metal sheets together. The production method incorporates various technologies and capabilities that have been developed in subprojects over time to form the new production solution. The production of space rocket nozzles follows an Engineer-to-Order strategy, where the product is engineered within a business project in close collaboration with the customer. In this case, having suitable production capabilities are essential in the ability to form an attractive offer to the customer. The main objectives of the development were to identify potential improvements for current production and to develop better designs, which would lead to lower costs, higher reliability, better lead times, and more flexibility in both engineering projects and production. The development started with a pre-development (i.e. knowledge development) project in which possible new production technologies were explored. The project team actively sought strategic collaborations to explore new knowledge. Once the pre-development project was completed, the solution was ready for application in new product designs in engineering projects. The new product definitions enabled in Case I by the new production capability included new, previously impossible dimensions that were formerly not possible due to constraints imposed by the previous production method. The restrictions arose from the formation and welding of tubes together in a spiral pattern on a bell-shaped cast, which prohibited some product dimensions without compromising the product's functionality and quality. With the new production method, this restriction in dimensions was no longer an issue as it could be applied to products of all, or at least many more, dimensions. Thus, it provided opportunities to expand the product design space and further enhance performance. Although the industry was receptive to the technology, the transition into engineering projects proved difficult in the relatively conservative space industry where customers prefer to Management and Production Engineering Review use proven technologies to minimize risk. Thus, much effort has been expended in proving the reliability of the technology, which is now in use and has contributed to the firm's competitiveness. Case II: Spiral Coolant Holes in Drills – From a Product Idea to a New Production Capability This case concerns a new production method for making twisted coolant holes in drills through a controlled twisting of a metal block. It enables new geometries and hence much wider applications in different drills. As drills are off the shelves products, the company operates under the Make-to-Stock production strategy, and the need for new and improved types of products is a driver for new product design and the development of production capability to be able to produce these designs. The idea for the spiral coolant holes came as competitors had started making spiral cut drills but the centered coolant hole caused difficulties in the chip control as there was not enough room for the chips. The idea, from a production manager at the firm, was to move the coolant holes out into the flanges of the spiral drill to make room for better metal chip transport from the hole. For this, the coolant holes also needed to be spiral, but such holes had never been made before. The first steps in developing the production technology (for making spiral holes) were of experimental, trial-and-error nature, to see what did and did not work. Refinement of the technology and process continued to find ways of twisting in a controlled and efficient manner that could be applied in a production unit. Introduction in production (once product development was completed) proved difficult due to a lack of necessary competence, high investment costs, and perceptions of high risks. More positively, the high complexity of the solution made it difficult for competitors to copy (however, it was also patented). The establishment of the new production capability enabled drill designs with much wider applications (for smaller and deeper holes and in new materials), which opened up new markets and provided major improvements in product performance, contributing to the firm's competitive advantage. Conclusions This paper aims to provide a conceptual framework for "production innovation" that conceptualises and highlights the characteristics of the phenomenon by focusing on the value-creating aspects of the firm. Production is often seen solely as a means to produce products and most improvement efforts are aimed at reducing its negative effects, on costs and consumption of resources (Antony et al., 2017), while the products are regarded as the value-creating elements for businesses. However, production capabilities also play a central role in realising new product designs as the two are interdependent (Larsson & Romero, 2017). Increased or new production capabilities can directly or indirectly influence product design as part of the product development process to enable a "product design" already considered or by providing "new design space boundaries" for future product designs. The incorporation of both product development and production aspects in the conceptual framework aids in understanding the value-creating aspects of "production innovation". The production innovation cases illustrate a strong interrelation between product and production capability development, but also show that the pathways to their realization differ, due to differences in the triggers. The two firms in empirical Cases I and II both invest relatively heavily in R&D but focus more on technology and products, respectively, which influences the path taken. Also, incorporating "ambidexterity" in the framework supports the sustainable development of production through both incremental improvements of existing capabilities and exploration of new capabilities. Long-term competitiveness builds upon organisations' capability to build new and increase current production capabilities continuously. Therefore, it is essential to make production innovation management part of normal business, and strategically strive to consider and connect financial, organisational, and technological opportunities for both short-term and long-term horizons. This paper makes several contributions. The data and conceptual framework provide new insights into the phenomenon of "production innovation" and a distinction between production innovation and other related concepts, such as "production development" and "process innovation". This distinction may provide a foundation for more in-depth research on innovation management, e.g. innovation strategies and methods adapted for the production context. The paper describes production innovation as the application of increased or new production capability in product design. By highlighting this relation, the value-creating aspects of production innovation are put into context and enable further understanding of Management and Production Engineering Review how production innovation contributes to manufacturing firms' business. The paper also contributes to the formation of "production innovation management" as a management discipline, and the conceptual framework may provide common foundations for further research on the topic. From a managerial perspective, the conceptual framework provides an understanding that it is necessary to embrace the full spectrum of "production innovation" to evolve as a manufacturer (but also to move the industry towards more sustainable production). Although the concept of "ambidexterity" is widely used in theory, it is still challenging in practice. Many studies have highlighted the need for organisational-level management to establish and maintain ambidexterity, and general innovation management, but in production, most methods and concepts tend to be exploitative and focus on incremental improvement. The need to take a more proactive approach to production development is highlighted here, where opportunity-seeking is considered equally relevant to problem-solving as an initiating factor for production development.

In *continuous improvement*, the focus is on improving performance in the production of existing products, and the opportunities that the increased design space provides for future product designs are positive side effects rather than inherent features of the process (Larsson, 2017). This may also limit the magnitude of possible changes in the production system. *New production capability* generated through *production-driven explorative production innovation* can instead be developed outside the production system and production operations, in technology development projects (in R&D) or similar activities. In such cases, the *new production capability* is developed first and can then be applied in product development projects, enabling more radical changes in product design. In *production strategies* where the customer enters before or in the engineering phase, i.e. where sales precede product development (Salerno et al., 2015) in the innovation process, such as ETO strategies, the production-driven path for production innovation is highly relevant due to the setup of the product realisation process. The new production service (i.e. production capability packaged into an offering), can be sold and diffused into one or several engineering and product development projects (Larsson & Larsson, 2018).

Their engineering and production capability becomes the differentiating factor that creates competitiveness for firms adopting such strategies. The transition from "production capability" development to implementation in engineering and product development projects is vital for the realisation of this type of production innovation. This path is also relevant for subcontractors that do not develop their products but rather offer a "production service". Generally, operational excellence is considered a key factor for the competitiveness of these firms, as they often compete on delivering the "production service" at a high quality but low cost. However, the range of production services subcontractors can offer, based on their production capabilities, may help them to win new contracts.

Explorative production innovation cases

This section focuses on *explorative innovation cases*, which have received much less attention than *exploitative innovation ones* in the literature. For illuminating examples of the latter, see some recent studies by Boscari et al. (2016), Jaghbeer et al. (2017), Majava & Ojanperä (2017), and Neirotti (2018). More specifically, the section presents two cases of *explorative innovation in production* to illustrate the proposed framework for production innovation.

Case I: Sandwich structure for space rocket nozzles – a new production capability creating opportunities in engineering projects

The presented case involves a *new production concept* for space rocket nozzles, involving the creation of a sandwich structure with channels for a cooling agent by welding metal sheets together. The *production method* incorporates various technologies and capabilities that have been developed in sub-projects over time to form the new production solution. The production of space rocket nozzles follows an Engineer-to-Order strategy, where the product is engineered within a business project in close collaboration with the customer. In this case, having suitable production capabilities are essential in the ability to form an attractive offer to the customer.

The main objectives of the development were to identify potential improvements for current production and to develop better designs, which would lead to lower costs, higher reliability, better lead times, and more flexibility in both engineering projects and production. The development started with a pre-development (i.e. knowledge development) project in which possible new production technologies were explored. The project team actively sought strategic collaborations to explore new knowledge. Once the pre-development project was completed, the solution was ready for application in new product designs in engineering projects. The *new product definitions* enabled in Case I by the *new production capability* included new, previously impossible dimensions that were formerly not possible due to constraints imposed by the previous production method. The restrictions arose from the formation and welding of tubes together in a spiral pattern on a bell-shaped cast, which prohibited some product dimensions without compromising the product's functionality and quality. With the *new production method*, this restriction in dimensions was no longer an issue as it could be applied to products of all, or at least many more, dimensions. Thus, it provided opportunities to expand the *product design space* and further enhance performance. Although the industry was receptive to the technology, the transition into engineering projects proved difficult in the relatively conservative space industry where customers prefer to use proven technologies to minimize risk. Thus, much effort has been expended in proving the reliability of the technology, which is now in use and has contributed to the firm's competitiveness.

Case II: Spiral coolant holes in drills – from a product idea to a new production capability

This case concerns a *new production method* for making twisted coolant holes in drills through a controlled twisting of a metal block. It enables new geometries and hence much wider applications in different drills. As drills are off the shelves products, the company operates under the Make-to-Stock production strategy, and the need for new and improved types of products is a driver for *new product design* and the *development of production capability* to be able to produce these designs.

The idea for the spiral coolant holes came as competitors had started making spiral cut drills but the centred coolant hole caused difficulties in the chip control as there was not enough room for the chips. The idea, from a production manager at the firm, was to move the coolant holes out into the flanges of the spiral drill to make room for better metal chip transport from the hole. For this, the coolant holes also needed to be spiral, but such holes had never been made before. The first steps in developing the *production technology* (for making spiral holes) were of experimental, trial-and-error nature, to see what did and did not work. Refinement of the technology and process continued to find ways of twisting in a controlled and efficient manner that could be applied in a production unit. Introduction in production (once product development was completed) proved difficult due to a lack of necessary competence, high investment costs, and perceptions of high risks. More positively, the high complexity of the solution made it difficult for competitors to copy (however, it was also patented). The establishment of the *new production capability* enabled drill designs with much wider applications (for smaller and deeper holes and in new materials), which opened up new markets and provided major improvements in product performance, contributing to the firm's competitive advantage.

Conclusions

This paper aims to provide a conceptual framework for "production innovation" that conceptualises and highlights the characteristics of the phenomenon by focusing on the value-creating aspects of the firm. *Production* is often seen solely as a means to produce products and most improvement efforts are aimed at reducing its negative effects, on costs and consumption of resources (Antony et al., 2017), while the products are regarded as the value-creating elements for businesses. However, *production capabilities* also play a central role in realising new product designs as the two are interdependen (Larsson & Romero, 2017). Increased or *new production capabilities* can directly or indirectly influence *product design* as part of the product development process to enable a "product design" already considered or by providing "new design space boundaries" for future product designs. The incorporation of both product development and production aspects in the conceptual framework aids in understanding the value-creating aspects of "production innovation".

The *production innovation cases* illustrate a strong interrelation between product and production capability development, but also show that the pathways to their realization differ, due to differences in the triggers. The two firms in empirical Cases I and II both invest relatively heavily in R&D but focus more on technology and products, respectively, which influences the path taken. Also, incorporating "ambidexterity" in the framework supports the sustainable development of production through both *incremental improvements of existing capabilities* and *exploration of new capabilities*. Long-term competitiveness builds upon organisations' capability to build new and increase current *production capabilities* continuously. Therefore, it is essential to make *production innovation management* part of normal business, and strategically strive to consider and connect financial, organisational, and technological opportunities for both short-term and long-term horizons.

This paper makes several contributions. The data and conceptual framework provide new insights into the phenomenon of "production innovation" and a distinction between production innovation and other related concepts, such as "production development" and "process innovation". This distinction may provide a foundation for more in-depth research on innovation management, e.g. innovation strategies and methods adapted for the production context.

The paper describes *production innovation* as the application of increased or new production capability in product design. By highlighting this relation, the value-creating aspects of production innovation are put into context and enable further understanding of how *production innovation* contributes to manufacturing firms' business. The paper also contributes to the formation of "production innovation management" as a management discipline, and the conceptual framework may provide common foundations for further research on the topic.

From a managerial perspective, the conceptual framework provides an understanding that it is necessary to embrace the full spectrum of "production innovation" to evolve as a manufacturer (but also to move the industry towards more sustainable production). Although the concept of "ambidexterity" is widely used in theory, it is still challenging in practice. Many studies have highlighted the need for organisational-level management to establish and maintain ambidexterity, and general innovation management, but in production, most methods and concepts tend to be exploitative and focus on incremental improvement. The need to take a more proactive approach to production development is highlighted here, where opportunity-seeking is considered equally relevant to problem-solving as an initiating factor for production development.

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