JÖNKÖPING UNIVERSITY
School of Engineering

Licentiate Thesis

Supporting Long-Term Production Development

Towards Production Platforms

Simon Boldt

Jönköping University
School of Engineering
Dissertation Series No. 077 • 2023

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Licentiate Thesis in Production Systems

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Abstract

With shrinking product life cycles and increasing competitive pressure, the traditional way of developing production systems is becoming obsolete. A longer-term perspective that considers the stream of product realisation projects to be implemented in the production system over its lifetime is required. Because of the success of different platform strategies in the product domain, platforms in the production domain are deemed a viable avenue for exploration to reach longevity in production capabilities. Therefore, the purpose of this thesis is to support a long-term view of production development through production platforms. This aim is addressed through two research questions (RQs). RQ1 is '*What challenges and enablers exist for long-term production development?*' and should identify hindrances and good practices towards reaching long-term production development. RQ2 is '*How can a platform approach support long-term production development?*' and describes how a platform approach for long-term production development could be. Four studies were conducted and reported in the four appended papers. The research is based on an interactive research approach with three empirically-based studies and one systematic literature review. The findings indicate that production development is conducted from a short-term perspective. Several challenges were identified regarding long-term production development, as well as the fact that the use of production platforms is not applied in industry. Further, the production platform literature is found to be still rather limited but it has been concluded that production platforms are an approach to describe the production system and its assets to facilitate reuse. Support for achieving long-term production development is presented, including production capability mapping (PCM) support. PCM support enables platform descriptions to be generated and used as a foundation in long-term production development to create a production system that possesses a higher ability to absorb changes.

Keywords: production development, production platforms, long-term, perspective, changeability, integrated product and production development, manufacturing

Sammanfattning

Med krympande produktlivscykler och ökande konkurrens är det traditionella tillvägagångssättet att utveckla produktionssystem föråldrat. Det behövs ett långsiktigt perspektiv som tar hänsyn till strömmen av produktrealiserings-projekt som ska implementeras i produktionssystemet under dess livstid. För att nå långsiktighet i produktionsförmåga anses framgången av olika plattformsstrategier inom produktdomänen vara en indikator på att plattformar inom produktionsdomänen kan vara en livskraftig väg att utforska. Syftet med denna forksning är att stödja långsiktighet i produktionsutveckling genom produktionsplattformar. Syftet adresseras genom två forskningsfrågor. Den första forskningsfrågan är ”*vilka utmaningar och möjliggörare finns för långsiktig produktionsutveckling?*” och syftar till att identifiera hinder och bra tillvägagångsätt för långsiktig produktionsutveckling. Den andra forskningsfrågan är ”*hur kan ett plattformstillvägagångssätt stödja långsiktig produktionsutveckling?*” och beskriver hur andvändingen av plattformar för långsiktig produktionsutveckling kan se ut. Fyra studier genomfördes och rapporterades i de fyra bifogade publikationerna. Forskningen är baserad på en interaktivt forskningsmetod med tre empiriskt baserade studier och en litteraturstudie. Resultaten indikerar att produktionsutveckling genomförs med ett kortsiktigt perspektiv. Flera utmaningar identifieras mot långsiktig produktionsutveckling. Produktionsplattformar är inte en implementderad metod för långsiktig produktionsutveckling och litteraturen kring produktionsplattformar är fragmenterad. Däremot dras slutsatsen att produktionsplattformar kan vara ett tillvägagångssätt för att beskriva produktionssystem och dess tillgångar för att främja återanvändning. Ett stöd för att kartlägga produktionsförmåga (PCM- stöd) presenteras i denna avhandling som stöd för att nå långsiktig produktionsutveckling. PCM- stödet möjligör att plattformsbeskrivningar kan genereras och agerar som basen i långsiktig produktionsutveckling för att skapa produktionssystem som besitter en hög förmåga att absorbera förändring.

Nyckelord: produktionsutveckling, produktionsplattformar, långsiktigt perspektiv, förändringsbarhet, integrerad produkt och produktionsutveckling, tillverkning.

Acknowledges

As a PhD student, I have met countless people who have supported me, challenged me and guided me in my journey towards this licentiate thesis. Thus, I would like to take this opportunity to show my gratitude.

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Simon Boldt
Jönköping, March 2023

List of appended papers

Paper I

Boldt, S., Rösiö, C., & Linnéusson, G. (2021). Challenges Towards Long-Term Production Development: An Industry Perspective. In A.-L. Andersen, R. Andersen, T. D. Brunoe, M. S. S. Larsen, K. Nielsen, A. Napoleone, & S. Kjeldgaard (Eds.), *Towards Sustainable Customization: Bridging Smart Products and Manufacturing Systems: Vol. CARV MCPC 2021.* Lecture notes in mechanical engineering (pp. 113–121). Springer International Publishing. https://doi.org/10.1007/978-3-030-90700-6. Proceedings of the CARV MCPC Conference 2021, Aalborg, Denmark. Springer

Work contribution: Boldt, Rösiö, and Linnéusson contributed to the ideation of the paper and the planning of the paper. All authors participated in the collection of the data and contributed to the data analysis. Boldt wrote the majority of the paper with editorial support and constructive comments from the co-authors. Boldt presented the paper at the CARV 2021 Conference in Aalborg, Denmark.

Paper II

Linnéusson, G., Boldt, S., & Rösiö, C. (2022). Exploring conflicting dynamics in product and production development within industrialized house building. In *Advances in transdisciplinary engineering* (Vol. 21, pp. 807–818). Proceedings of the SPS Conference, Skövde, Sweden.

Work contribution: Linnéusson and Boldt initiated the ideation, planned the paper, collected data and analysed the data. The presented findings and the final CLD were modelled by Linnéusson and Boldt, including analyses and insights. Linnéusson had the lead in the paper writing, supported by Boldt, who also wrote the section regarding product and production platforms and parts of the presented findings and conclusions. Rösiö provided editorial support and constructive comments throughout the process, as well as in the paper writing. Linnéusson presented the paper at SPS 2022 in Skövde, Sweden.

Paper III

Boldt, S., Linnéusson, G., & Rösiö, C. (2021). Exploring the concept of production platforms - A literature review. *Procedia CIRP*, *104*, 158–163. Proceedings of the CIRP-CMS Conference, Athens, Greece.

Work contribution: Boldt, Linnéusson, and Rösiö conducted the ideation and planning of the paper. Linnéusson conducted the literature search, and all the authors participated in the paper screening. Boldt conducted the detailed paper review and content analysis. Boldt wrote the introduction, search results, findings and conclusion chapters with editorial support and constructive comments from the co-authors. Linnéusson and Boldt wrote the methodology chapter. Rösiö contributed editorial support and constructive comments throughout the writing process. Boldt presented the conference paper digitally at the CIRP CMS 2021.

Paper IV

Boldt, S., Rösiö, C., & Linnéusson, G. (2023). Mapping production capabilities: Proposing support towards changeable production. Accepted for publication in CARV MCPC 2023.

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Additional publications

Augustsson, K., Boldt, S., & Tiedemann, F. (2017). Leveransledtidsreduktionens påverkan på räntabilitet (in Swedish) [The effect of leadtime reduction on profitability] . *PLANs Forsknings- Och Tillämpningskonferens [PLAN's research and application conference]*. Proceedings of the PLAN Conference, Gothenburg, Sweden.

Boldt, S., & Rösiö, C. (2020). Evaluation of reconfigurability in brownfield manufacturing development. In K. Säfsten & F. Elgh (Eds.), *SPS2020: Proceedings of the Swedish Production Symposium*, *13*, 513–524. Proceedings of the SPS Conference, Jönköping, Sweden. IOS Press.

Napoleone, A., Andersen, A., Brunoe, T. D., Nielsen, K., Boldt, S., Rösiö, C., Hansen, D. G., & Andersen, R. (2020). Towards an industry-applicable design methodology for developing reconfigurable manufacturing. In B. Lalic, V. Majstorovic, U. Marjanovic, G. von Cieminski, & D. Romero (Eds.), *Advances in production management systems. The path to digital transformation and innovation of production management systems*, *591*, November, 449–456. Proceedings of the APMS Conference, Novi Sad, Serbia. Springer International Publishing.

Boldt, S., Rösiö, C., Bergström, A., & Jödicke, L. (2021). Assessment of reconfigurability level within existing manufacturing. *Procedia CIRP*, *104*, 1458–1463. Proceedings of the CIRP-CMS Conference, Athens, Greece.

Rösiö, C., Karltun, A., Trolle, J., Coelho, D., Boldt, S., & Fagerström, B. (2021). Agil och rekonfigurerbar produktion – Projektmetod och utformning av produktions-system (in Swedish) [Agil and reconfigurable production – Project management and development of production system].

Andersen, A.-L., Andersen, R., Napoleone, A., Brunoe, T. D., Kjeldgaard, S., Nielsen, K., Sorensen, D. G. H., Raza, M., Bilberg, A., Rösiö, C., Boldt, S., & Skärin, F. (2022). *Nye veje til omstillingsparat og rekonfigurerbar produktion: Grundprincipper, fremgangsmåde & eksempler (in Danish) [New way to adaptable and reconfigurable production: Basic principles, approaches and examples]*. REKON Press.

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1 Introduction

This chapter presents the background of the research and formulates the research motivations, purpose and research questions. Lastly, the delimitations and thesis outline are presented.

1.1 Background

For manufacturing industries to succeed, they must excel in designing, developing and producing competitive products. A traditional approach has been to focus on developing one product and its means of production at the same time (Koren, 2010). This way was viable since the life cycles of the products were long, which allowed for long ramp-up periods and long periods of returns of the capital investments made in the development of products and the production system (Koren, 2010). However, as the manufacturing industry is experiencing increased pressure from global competitors, shorter product life cycles, higher innovation pace and an increasing number of customised products (Corrêa, 1992; Koren, 2010; ManuFUTURE, 2018; Produktion2030, 2016), the traditional ways of developing products and production systems are becoming obsolete.

To be able to produce the desired products, it is necessary to have a production system with desired production capabilities, extrapolating from the definition of capabilities (Oxford Learner's Dictionaries, 2022) is production capability defined as *"abilities or qualities necessary to produce products"*. The development of the required production capabilities to produce a product is often carried out sequentially after the product's development within the product realisation process as it is part of the company's stage-gate model (Bellgran & Säfsten, 2010; Cooper, 2008; Pahl & Beitz, 1996; Ulrich & Eppinger, 2012). This has the effect that the product realisation project merely focuses on the new product in isolation, thus, only requiring the development of the production capabilities for that new product. The subsequent development of production capabilities to enable producing the new product is conducted by investing in new equipment or tools, changing process plans or remaking parts of or the entire production system (ElMaraghy, 2009). This production development approach can be considered a reactive production development strategy, i.e. developing production means for one product generation at a time, even though the lifetime of the production system is longer than the initial product (Järvenpää, 2012).

As early as 2001, issues with deploying a reactive development strategy to product realisation projects were described by Repenning (2001). Repenning concluded that it does not come naturally to effectively manage the stream of product realisation projects and that it will lead to sub-optimisations focusing on short-term gains. This can be described as the production capabilities being developed to respond to the identified immediate product requirements. A focus on the immediate product requirements can impose the risk that the production solutions will only be valid for those identified requirements, resulting in the creation of dedicated optimal production solutions. When additional new product requirements are to be met, the implemented production solutions could already be obsolete (Järvenpää, 2012). This means that the product to be produced will change, and when the product is continuously changed, changes in production capabilities are also required (Bellgran & Säfsten, 2010). Hence, the reactive approach increasingly introduces costly and reoccurring repurposing of the production solutions as new product introductions increase (ElMaraghy, 2009; Koren, 2010). This results in waste, such as underutilised equipment, scrapped production solutions and a shortened window of recuperation of investments (Järvenpää, 2012). To remain competitive, the reactive approach to developing and producing one successful product at a time is not enough. Instead, it is crucial to continuously develop, produce and deliver successful products.

Furthermore, there are often multiple product realisation projects simultaneously in the development process, which makes the reactive production development strategy even less beneficial. Consequently, a long-term perspective on the development of production capabilities is required to enable the management of the continuous stream of new products under development. It is important not only to consider the product requirements of today but also to consider the requirements of tomorrow in a structured manner (Bruch & Bellgran, 2014b; Järvenpää, 2012).

1.2 Problem statement

Production development needs to have a longer time perspective when considering what capabilities the production system should possess, how to reach these capabilities and how to manage the increasing changes in requirements. In short, the production system needs to be able to manage change based on different change drivers (Rösiö, 2012). Change divers for production systems are either product-related, volume-related, technology-related or strategy-related (ElMaraghy & Wiendahl, 2009; Park & Choi, 2008; Wiendahl et al., 2007). This is the case when not knowing exactly which requirements or which sales volumes are to be expected, since they are uncertain. Thus, the production system must be able to absorb these uncertainties over time.

One established way of working with long-term development in the product domain is through product platforms (Baldwin & Clark, 1999; Jiao et al., 2007; Meyer & Lehnerd, 1997; Robertson & Ulrich, 1998; L. L. Zhang, 2015). Product platforms are built on modularity, and through modularity, these can enable the building of complex systems from smaller sub-systems (Baldwin & Clark, 1999). By having smaller systems that can be integrated through standard interfaces, it is possible to develop the sub-systems separately, as well as upgrade the sub-systems later to update the functionality for future needs (Baldwin & Clark, 1999; Meyer & Lehnerd, 1997; Robertson & Ulrich, 1998). Product platforms allow for reusing these sub-systems, i.e. modules, over product generations and across product variants, reducing the development effort of new products, while simultaneously increasing flexibility and responsiveness in product development as well as reducing system complexity and production cost (Luo et al., 2010; Meyer & Lehnerd, 1997; Ulrich, 1995; Ulrich & Eppinger, 2012). In summary, product platforms allow for exchanging modules of the product and sharing them between product generations and variants, which allows for upgradeable products as well as reduced costs for their realisation.

A platform could be a physical platform consisting of a set of components or an abstract structure formed by sub-systems and their interactions (Jiao et al., 2007). A physical platform focuses on modular sub-systems that could later be used to derive a stream of products that could be developed and produced

(Meyer & Lehnerd, 1997). The other definitions of platforms are expanding what the concept can include by looking at what a company has to offer, i.e. its assets, and striving towards maximising the reuse of them (Sawhney, 1998). Robertson and Ulrich (1998) argued that a platform could be the assets that are shared by a set of products. This view has opened the opportunity to use the platform strategy in products that do not have physical sub-systems to be reused, e.g. engineer-to-order products, according to André et al. (2017). André et al. developed a design platform that focused on common assets between products, such as the working process, computer-aided design (CAD) models and calculations. The design platform aims at utilising the platform strategy within the wider application of the product development processes exceeding physical assets, yet without placing any further focus on the subsequent processes of production development.

Because of the success of different platform strategies in the product domain, platforms in the production domain are a viable avenue for exploration to reach longevity in production capabilities. Johannesson (2014) argued that products and production systems are co-equal systems, and thus it would be possible to enable significant similarities in how platforms in the production domain could be defined and used (Bossen et al., 2015). At its core, a platform exploits the commonality of multiple products (Meyer & Lehnerd, 1997) to reach the commonality of the production system, e.g. reusing production solutions. By being able to change production capabilities by adding, removing, exchanging and upgrading modules in the production system, it is possible to have the right capability at the right time (Koren, 2010). This would allow the production system to exchange modules to compensate for the new requirements instead of having to repurpose larger parts of dedicated production systems. Thus, a new approach to the product and production development issue is required. Production platform literature has shown examples of modular concepts in production, e.g. modular fixture platforms (Bejlegaard et al., 2018), or extensive classification of the production solutions for matching with future production needs when introducing new products (Sorensen et al., 2020). However, the production platform literature lacks mature and comprehensive methods of production development (Bossen et al., 2015). How production platforms could be utilised in production development to support the longevity of the production system has been less investigated. As a result, there exists a need to support production development engineers in the development of production systems based on a long-term perspective.

1.3 Purpose and research questions

This thesis aims to increase knowledge of how long-term production development could be supported. To facilitate increased longevity in production development, production platforms could be a viable avenue to explore as platforms inherently consider a long-term perspective. Thus, the purpose of this licentiate thesis is to:

> *Support a long-term view in production development through production platforms.*

To achieve this purpose, it is necessary to understand what hinders companies from practising long-term production development. Thereby, the challenges and enablers that companies are experiencing are of interest, which leads to the first research question (RQ):

> *RQ1. What challenges and enablers exist for long-term production development?*

By understanding which challenges and enablers exist for long-term production development, it is possible to investigate how production platforms could be used to support these challenges. This leads to the second research question:

> *RQ2. How can a platform approach support long-term production development?*

When the two research questions have been answered, the purpose of the research will be achieved. Where challenges and enablers would be identified as well as how platforms in production can support long-term production would be described.

1.4 Scope and delimitation

Research in production development can be conducted on many hierarchical levels, from a network of factories down to stations in a production system. In this research, the focus will be on production development carried out within a factory. The focus of this research will be on production development that occurs in relation to product development and the introduction of new products.

1.5 Thesis outline

This licentiate thesis consists of five chapters and includes four appended papers. Each of the chapters is briefly described below to present an overview of the content.

Chapter 1: Introduction provides a brief background to the need for long-term production development as well as introducing production platforms. The purpose of the licentiate thesis and the two research questions are also presented.

Chapter 2: Theory presents the research areas which are used to support the findings of this research. The three main areas are production development, changeability in production systems and production platforms.

Chapter 3: Research methodology describes the methodology employed. Each of the different studies is elaborated regarding their design, data collection and data analysis. Finally, research quality and ethical considerations are discussed.

Chapter 4: Summary of papers explains the linkage of the four appended papers with the research questions. Thereafter, the results of the four appended papers are individually presented.

Chapter 5: Results and discussions addresses the answers to the research questions, utilising the results of the four appended papers. This is followed by a discussion of the selected research methodology and the scientific and industrial contributions, and finally, the conclusions are presented.

2 Theory

In this chapter, the theoretical background of the research is presented. Different perspectives on production development are provided, followed by a description of changeability in production systems. The chapter ends by introducing production platforms and their different definitions.

2.1 Production development

A production system in respect to this thesis is considered as a part of the larger manufacturing system, where a production system consists of all activities and facilities required to transform raw material into finished products (CIRP, 2020). Machining systems, assembly systems and parts production systems are seen as sub-parts of a production system. Production development has been described in different ways, either as a separate development process or as an integrated part of the product realisation process. Even though production development is required for a successful product launch, it is often regarded as an obstacle to rather than an enabler of competition (Bruch, 2012). This is due to the high investment costs of new production equipment (Hayes et al., 2005) and the fact that changes in requirements result in changes in the production system (ElMaraghy, 2009), which also adds to the investment costs.

Production development as an integrated part of the product realisation process has been examined by several authors. Säfsten and Johansson (2005) described production development as part of the product realisation process within the product life cycle. Henriksson and Detterfelt (2018) reviewed seven commonly used product development approaches in engineering education and found that product development is finalised or nearly finalised before production development is initiated. Ulrich and Eppinger (2012) described the product development process in six steps: (1) planning, (2) concept development, (3) system-level design, (4) detail design, (5) testing and refinement and (6) production ramp-up. Production development occurs continuously during the process but as certain deliverables, following the same process as described: (1) identify production constraints, (2) estimate production cost and assess production feasibility, (3) perform make or buy decision and define final assembly scheme, (4) define piece-part production process, design tooling, and define quality assurance process, (5) refine fabrication and assembly processes, train workforce, refine quality assurance process, and finally (6) begin full operation of the production system (Ulrich & Eppinger, 2012). Ferguson et al. (2014), who conducted a literature review of mass customisation and condensed several scholars' work into a new product development process, outlined a phased process with five stages: (1) product planning, (2) requirement specification, (3) conceptual design, (4) embodiment and detailed design and (5) manufacturing, sales and distribution design (as one development stage). The process puts its emphasis on product development and includes integration into production development through three interaction points in the process: two interactions through 'design for X' and one to 'develop the production approach'. In other words, first, develop the product for mass customisation, and then develop the production system without any substantial support.

Production development as a separate process from the product development process has also been described by several authors. Wu (1994) presented an approach with three phases: (1) analysis and goal setting, (2) conceptual modelling and (3) detail design, which finally results in a solution. The approach considers the existing production system while setting objectives through the initial analysis and allows for iterations in each stage in the development approach. Chryssolouris (2006) argued that the production development process should be viewed as a continuous cyclical activity, involving (1) the definition of the system's objectives, (2) the development of requirements and constraints and (3) the implementation of the design as the requirement changes for the production system. Bellgran and Säfsten (2010) developed a structured way of working for production development with five phases: (1) management and control, (2) preparatory design, (3) design specification, (4) realisation and planning and (5) start-up.

To summarise, production development is a development process that has the task of mapping product features and requirements into production solutions and capabilities to enable production of the products. This is often carried out in a phased process with the stages of analysis and goal setting, conceptual design, detailed design, implementation and ramp-up, and finally handing the production system over to operations (see Figure 2-1).

Figure 2-1. Generic production development process.

This generic development process implies that production development is one-off process, i.e. that after the production is developed and handed over to operations, the project is closed. If new requirements arise, then new development projects might be launched, as there is a need for expansion of the production capabilities. This creates a pattern in which the production development effort over time is not structured according to an overarching structure as a production portfolio that employs generational planning of how the production should be developed over time (Bruch & Bellgran, 2014). Even though integration between product and production development has been debated for close to 30 years (Adler, 1995), the development effort is nevertheless carried out in separate pathways to be aligned with project milestones and sometimes supported by 'design for X' guidelines (Vielhaber & Stoffels, 2014). Thus, to complement the picture illustrated by the two perspectives, production development is a process where production capabilities are developed by converting the intended product features and requirements into production solutions. This occurs as the development process is parallel and synchronised with the product development process, where the product concept and production concept mature over time to realise a production system that is capable of producing the intended products. The two systems that are developed are interconnected and affect each other's designs. The two systems differ as the expected lifetime of a production system is often many times longer than the lifetime of the products that are produced in the production system (Järvenpää, 2012; Wiendahl et al., 2007). The two parallel development processes, the life cycles of products and production systems and their interactions are illustrated in Figure 2-2.

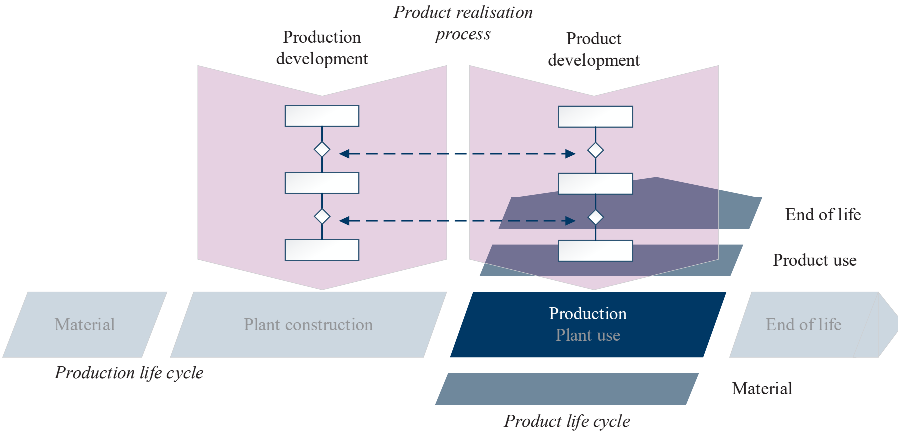

Figure 2-2. Product/production development and life cycles. Adapted from Vielhaber and Stoffels (2014).

2.2 Changeability in production systems

Changeability is an umbrella term that regards different research streams all dedicated to managing change within the production domain (Wiendahl et al., 2007). Changeable production research regards the development, implementation and utilisation of production systems that employ modularity to possess the ability to change their production capabilities to meet new customer demands (ElMaraghy, 2009). The production systems should be designed for product families but should also be ready to be changed for new product variants or families (Mehrabi et al., 2000). The different elements of the production system should be able to be easily reconfigured, i.e. exchanged, upgraded or removed to reach the desired production capability (Rösiö, 2012). The reconfigurations are achieved efficiently through the following six core characteristics: customisation, convertibility, scalability, diagnosability, integrability and modularity (Koren, 2010). These characteristics would allow production systems, production lines, and machines to become changeable in terms of capabilities, i.e. their functionality and capacity (Koren, 2010; G. Zhang et al., 2006). Modularity is considered the foundation needed to reach a production system that can be reconfigured (Maganha et al., 2021; Napoleone et al., 2018). The changeability of production means can be viewed from six different hierarchical structuring levels (Wiendahl et al., 2007):

- Network: The highest structuring level, which comprises the network of sites in which the manufacturing company is embedded.
- Factory: The level of the plant, including the building and its infrastructure.
- Segment: The level above the system, which contains all activities involved in manufacturing and making ship-ready products.
- System: The level containing interlinked cells used for manufacturing variants of a part or a product family.
- Cell: The level covering a subsystem of the system, containing groups of workstations and material handling that perform most activities to finish a part.
- Workstation: The lowest structuring level, containing single workstations and machines that add a feature to a workpiece.

These structuring levels can be broken down into one or more instances on the lower level, such as a network made of multiple factories, which are made of multiple segments and which are made of multiple systems. The different structuring levels have been related to different concepts of changeable production, which relates to all aspects of manufacturing organisations that enable fast and efficient change to meet new market conditions (ElMaraghy & Wiendahl, 2009).

Changeability within system, cell and workstation levels is here considered as representing reconfigurability, flexibility and changeover ability (Andersen et al., 2015). These changeability classes have been described by Benkamoun (2016) as four different changeability strategies for managing change in a production system. These strategies are divided into whether they can absorb the change within the current capability (i.e. flexibility) or if it is necessary to implement change by rearranging, adding or removing production system solutions (i.e. reconfigurability) (Koren et al., 1999). The flexibility strategies can, in turn, be divided into two different flexibility strategies: (1) strategies that have built-in dedicated flexibility and (2) strategies that can adapt to change through a change-over phase. The reconfigurability strategies are also divided into two categories: (1) extensibility, which relates to the ability to extend or reduce the capacity, and (2) convertibility, which relates to the ability to change the function of a production system. These four different changeability strategies can further be differentiated according to their uncertainty and time for achieving the change. Flexibility is for planned changes where the need for change is immediate with no or short lead time, while reconfigurability is for a hypothetical future need for change. These changeability strategies depend on the level of uncertainty, the time scale of future needs and internal strategic decisions. The different change strategies are illustrated in Figure 2-3.

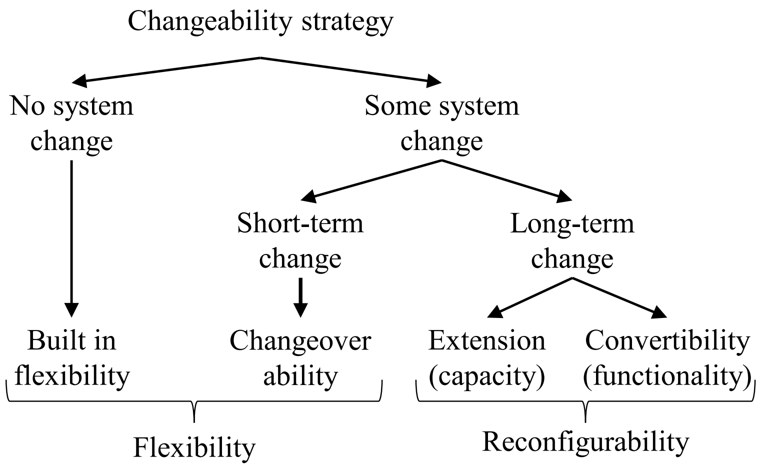

Figure 2-3. Changeability strategies.
Adapted from Benkamoun (2016).

The development procedures for changeable production systems have an extended process compared with the traditional development processes as presented in Figure 2-1. These processes are, in general, similar to the generic production development model; however, these models are not of the same one-off character as they are supposed to enable reconfigurations after the production system is handed over to operations to adopt the production capabilities to meet new product requirements. Several methods and models have been presented to develop changeable and reconfigurable production systems (Andersen et al., 2017). Sequential design approaches, including steps of initiation, conceptual design, detailed design, implementation and finally reconfiguration, have been proposed by, for example, Shuh et al. (2009), Rösiö (2012), Deif and ElMaragy (2006), Andersen et al. (2017), and Napoleone et al. (2020). Generally, the structure of the development process is emphasised, rather than how each step should be conducted (Andersen et al., 2017). In other words, production engineers lack concrete models to support how to manage the steady stream of product introduction when developing production solutions.

2.3 Production platforms

Production platform research is a relatively new area that stems from product platforms (Sorensen, Bossen, et al., 2018). Platforms in product development have been used for several years to reuse or create commonality of parts and sub-systems across product variants and generations (Baldwin & Clark, 1999; Baldwin & Woodard, 2009; Meyer & Lehnerd, 1997). Some researchers have extended the concept to include other assets, such as processes, knowledge and people and relationships (e.g. André et al., 2017; Robertson & Ulrich, 1998). According to Sawhney (1998), using platforms includes the process of identifying and exploiting the shared logic and structure in a firm's activities and offerings to achieve leveraged growth and variety. Thus, it is imperative to understand what the core is and what the derivative values are (Sawhney, 1998).

Within the production domain, several authors have conducted research on production platforms. Michaelis and Johannesson (2011) used function-means modelling of platforms in both the product and production domains to create a modular and configurable robotic welding cell. Sorensen (2019) developed a classification coding system of production solutions to identify which aspects could remain stable and which could vary over time. L. L. Zhang et al. (2005) developed a production configurator using generic structures, generic planning and variety planning to coordinate how product variants should progress through the production system. However, the terminology and definitions used in production platforms are widespread today, as the field has yet to reach a mature state (Bossen et al., 2015; Sorensen, Brunoe, et al., 2018). Due to this, several similar terms are used. For example, the terminologies used are production platform (Bejlegaard et al., 2016; Nielsen, 2010; Sorensen, Brunoe, et al., 2018), production platform philosophy (Lager, 2017), process platform (Halman et al., 2003; Jiao et al., 2005; L. L. Zhang et al., 2005), process parameter platform (Williams et al., 2007), manufacturing platform (Joergensen, 2013; Michaelis & Johannesson, 2011), manufacturing system platform (ElMaraghy & Abbas, 2015) and fixture platform (Andersen et al., 2018). The ways in which the different authors have described platforms in the production domain are shown in Table 2-1.

Table 2-1. Platform definitions in the production domain

Term	Author	Definition
Production platform	(Bejlegaard et al., 2016, p. 35)	*'...[production platforms] are physical process solutions that constitute the production system'.*
	(Nielsen, 2010, p. 81)	*'A production platform is a platform, which is about sharing of production components or architectures for a product family'.*
	(Sorensen, Brunoe, et al., 2018, p. 1)	*'The standardisation, consistency and reusability of platforms, which has proven successful in managing product variety (Simpson, 2004), is a seemingly attractive choice for managing production variety (Bossen et al., 2015). Platforms incorporating these aspects in production, and manufacturing systems are called production platforms and can be utilised to achieve appropriate levels of changeability'.*
Production platform philosophy	(Lager, 2017, p. 31)	*'A production platform philosophy for non-assembled products in the process industries involves the identification and exploitation of the shared logics and commonalities of a firm's products, production technologies and raw materials, in order to achieve leveraged product variety and other customer offerings, while maintaining economies of scale and scope of its production capabilities'.*
Manufacturing platform	(Michaelis & Johannesson, 2011, p. 5)	*'Based on this analysis and inspired by the Factory-in-a-Box concept, a new, strictly modular manufacturing cell concept is devised, including a larger bandwidth and certain restrictions (in other words, a manufacturing platform)'.*
	(Joergensen, 2013, p. 28)	*'Manufacturing platforms are interpreted as a structural description of a subset of a manufacturing architecture including only the reusable/widely-used standard designs. This interpretation includes both existing and future standard designs, this due to the low volume of specific manufacturing systems and hereby the related use as a design platform for future manufacturing systems'.*

Table 2-1. (continued)

Term	Author	Definition
Process platform	(Halman et al., 2003, p. 151)	*'Process platform refers to the specific set-up of the production system to produce easily the desired variety of products'.*
	(Jiao et al., 2005, p. 615)	*'A platform module is employed to support product and process platforms, i.e. predefined product and process configuration structures. They can be either imported from the legacy systems or constructed from scratch'.*
	(L. L. Zhang et al., 2005, p. 2)	*'A process platform involves de facto three aspects: (1) a common process structure shared by all process variants; (2) derivation of specific process variants from the common structure; and (3) correspondence between product and process variety, which resembles the correlation between the generic product and routing structures'.*
	(Lager, 2017, p. 22)	*'Similar to a product family, a process family comprises a set of similar production processes that share a common process structure, referred to as a process platform'.*
Manufacturing system platform	(ElMaraghy & Abbas, 2015, p. 407)	*'Manufacturing system ''platform'' represents the core machines capable of performing all the processes required to fabricate the core product features. The term machines are used to represent all processes and tools that allow it to perform many operations and processes to produce certain product features'.*
Fixture platform	(Andersen et al., 2018, p. 20)	*'The modular fixture concept has customized flexibility, where commonality across part types has been identified, resulting in a common fixture platform'.*
Process parameter platform	(Williams et al., 2007, p. 206)	*'A process parameter platform is defined as a set of common process parameters from which a stream of derivative process parameters can generate a customized machining process efficiently despite changes in required capacity'.*

As can be seen in Table 2-1, the platforms in the production domain are varied with a lack of consensus on definitions or terminology. By considering only the terminologies, it is hard to distinguish its fundamental distinctions. To gain more structure, it is possible to use Michaelis and Johannesson's (2011) two distinction perspectives for platform concepts, i.e. level of abstraction and level of specificity. The level of abstraction can be less abstract, where the physical embodiment of the production system is used to identify commonality, as in the case of Bejlegaard (2017) who developed(2017) a modular fixture platform to lower the required amount of fixtures while reducing the investment cost for fixtures. It can also be more abstract, where assets used in the production system are used to find commonality, as with Lager (2017), who developed a platform philosophy extension for non-discrete products that encompassed different platforms from customer platform, raw material platform, production platform, and process platform. Within production systems, the level of specificity could reflect hierarchy levels (Wiendahl et al., 2007). It is possible to define several system-specific platforms or one all-embracing platform. A platform with a low hierarchy level could be a fixture platform (Bejlegaard, 2017) in contrast to a platform on a higher hierarchy level which could be a process platform (Jiao et al., 2005).

As shown in Table 2-1, there have been different focuses among the different researchers, reflecting the different contexts and intentions resulting in different definitions of production platforms. However, in all the definitions, the platform provides a way to explicitly describe the production system and its assets. Different aspects are reflected in the different definitions, including the architecture of the system, the process structure, the production equipment etc. Fundamentally, a production platform can thus increase the reuse of the production system assets through increased awareness of where change is acceptable and where standardisation and stability are required (Sorensen, Bossen, et al., 2018). The specific definitions have different focuses ranging from lower to higher abstraction as well as lower to higher specificity, thus focusing on different aspects, such as identifying core machines (ElMaraghy & Abbas, 2015), identifying generic process structures (Jiao et al., 2005) or designing modular production systems (Joergensen et al., 2012). The proper fit depends on the context in which the production platform is be used and which objective it is used for.

3 Research methodology

In this chapter, the research methodology is described. An outline of the conducted research is given, followed by the research design and case selection. The individual studies are then presented along with the purpose, data collection and analysis. Finally, the research quality and ethical considerations are given.

3.1 Research outline

The research was conducted from September 2020 to February 2023. The different studies and papers are laid out on a timeline to visualise the research process (see Figure 3-1).

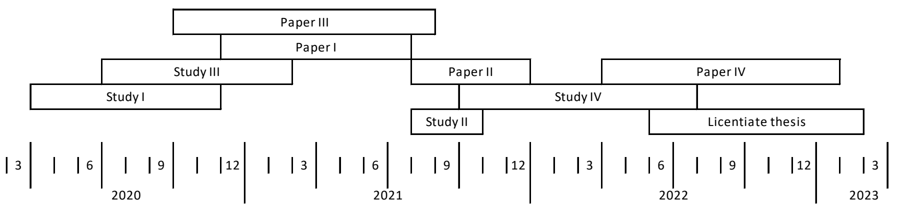

Figure 3-1. Timeline of the research process.

This research was focused on understanding how a long-term view of production development could be supported by production platforms. Two research questions have been established within the scope of this thesis, addressed by four studies and four papers (see Figure 3-2). The dotted lines in Figure 3-2 represent an indirect connection, and the full lines represent a direct connection between studies and papers. In principle, each paper was based on one study; however, Papers II and IV built upon the knowledge gained from previous studies, i.e. indirect connection.

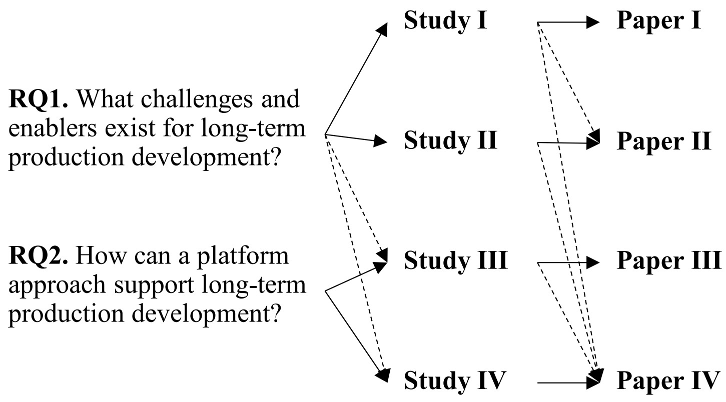

Figure 3-2. Connection between purpose, RQs, studies and papers.

All four studies were carried out to increase understanding of the long-term view of production development and to build knowledge about how production platforms could assist in production development.

3.2 Research design

In this research, an interactive approach was adopted. The interactive approach allows for working together with the industrial partners, as they have an important role in the analytical work by providing industry knowledge as well as identifying practical problems from their perspectives (Ellström, 2007). Interactive research enables researchers to approach industrial concerns as well as contribute to scientific relevance (Svensson et al., 2002). This approach, as depicted in Figure 3-3, includes joint learning processes where the researchers and practitioners interact to generate academic and industry knowledge.

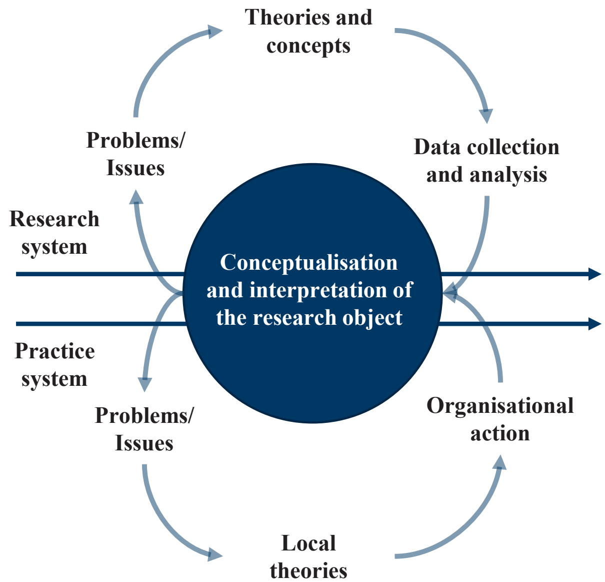

Figure 3-3. Research and practice systems in interactive research. Adapted from Ellström (2007).

The interactive research approach supports joint learning based on a continuous dialogue between researchers and industrial partners whose roles are commonly separated. This implies that the responsibility to select a suitable alternative and to take the required development steps at the companies is not the primary task of the researcher (Nielsen & Svensson, 2006). The four studies in this thesis were created from several loops through the interactive approach to create a deepened understanding of the initial research aim and to provide knowledge for both academia and industry. Studies I and III sought to provide insight into state-of-practice and state-of-the-art, respectively. Studies I and III were considered as the starting points to answer RQ1 and RQ2, respectively. Studies II and IV were initiated partners as a result of joint learning to increase the understanding of long-term production development and how production platforms could be used. Through using the interactive approach, closeness to the studied phenomena was achieved, and spin-off ideas and inquiries were possible to set up as per the relationship with the industrial partners.

Within the interactive research approach, case study design was used in Studies I, II and IV. The case study methodology is suitable when there is an exploratory component to the research or if the research questions are exploratory (Voss et al., 2002; Yin, 2018). The case study design enabled the investigation of the phenomenon in its natural environment (Yin, 2018). A case study design is appropriate to answer research questions that are of a *how* and *why* character (Eisenhardt, 1989) but can also be appropriate for explorative *what* questions (Yin, 2018), which relates to the two RQs of the thesis. Using a multiple case study design also allowed for cross-case comparisons and for seeing similarities and differences between the cases in Study I. Case studies are deemed to be powerful in the development of a new theory (Eisenhardt, 1989); they also allow for new and creative insights and have high validity among practitioners (Voss et al., 2002). This was suitable for this research, which explores long-term production development and the use of production platforms.

3.3 Case selection

The selected industrial partners were part of the synergy research project IDEAL. IDEAL had an overarching research goal of investigating *how integrated product and production platforms could support agile and demand-driven product realisation*. Within the research project, there were six industrial partners. Based on this pool of industrial partners, a selection was conducted for each study through a set of criteria: (1) the company should have in-house production and production development, (2) the company should have an interest in improving its production development and becoming longer term and (3) the company should have an interest in the studied phenomena in each study. For the purposes of three of the studies, five industrial partners were selected as participants. A short description of the five companies' types of products and the number of employees is outlined in Table 3-1.

Table 3-1. Company description (Employee data from November 2022)

Company	Type of product	Number of employees
Alpha	Engine-powered forest and gardening products for professionals and consumers	14,000
Beta	Outdoors and automotive accessories for consumers	3,300
Gamma	Industrialised house building for consumers	900
Delta	Lighting solutions for professional customers	1,000
Epsilon	Industrialised house building for professional and public customers	180

Within the different studies, there was a selection of the companies presented in Table 3-1. In each of these companies, a specific unit of analysis was selected, which represented the studied phenomenon. The details are presented in each study's specific section in the following section.

3.4 Research studies

Four studies were conducted within the scope of this research: one literature review, two multiple case studies, and one single case study. In the following section, each of the four studies is presented, including the case company, case study design, data collection technique, data analysis and main outcome.

3.4.1 Study I

This study investigated the state of practice for long-term production development at five industrial companies. This was conducted through a multiple-case study. The multiple case study consisted of five cases; the cases were from companies Alpha to Epsilon. The unit of analysis was the production development in the product realisation process, as represented in Figure 3-4. The purpose of the study was to present industrial practices in production development and identify challenges to applying long-term production development.

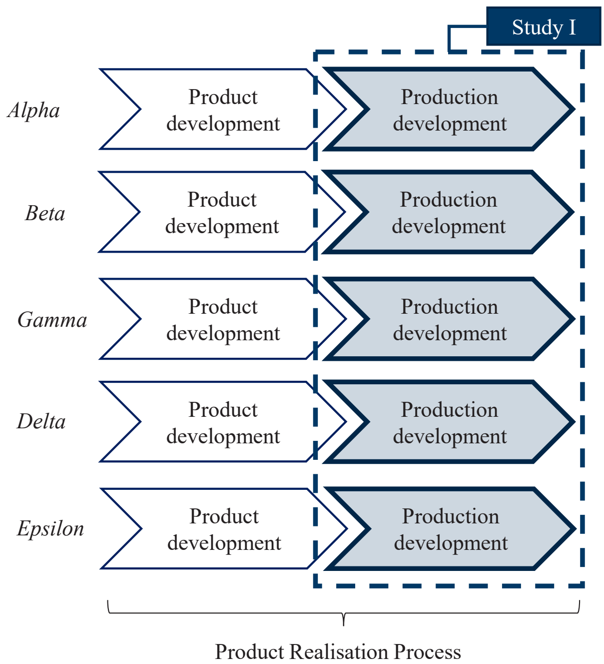

Figure 3-4. Unit of analysis in Study I.

3.4.1.1 Data collection

The data were collected through semi-structured interviews and document studies. Semi-structured interviews enable the interviewer to follow up on leads that arise during the interview and allow respondents to elaborate and explain something if necessary (Williamson, 2002).

An interview guide was developed by the project team to cover the product realisation process (see Appendix 1). Reported in this study were the aspects related to production development in the context of the product realisation process of the cases, i.e. the sections *product realisation and related challenges, production platforms* and *common platform issues*. Within each case, a broad range of interview respondents was chosen in collaboration with the company. The respondents were working in multiple roles in the product realisation process from the project management, product and production domains. A total of 51 interviews were conducted with 9–11 interviews per case and the interviews lasted for 63–107 min with two outliers of 29 and 34 min, respectively. Each interview was conducted by two researchers, and all the interviews were recorded and transcribed. The studied documents included formal descriptions of the companies' product realisation processes. See Table 3-2 for a detailed view of the roles, number of interviews, and the time spent for each case.

Table 3-2. Study I, interview respondents.

Company	Respondents	Interviews [#]	Time [min]
Alpha	**Project**: Industrialisation manager, Project manager **Product**: Group manager, product lab, Engineering manager, Lead engineer **Production**: Quality process manager, Sourcing manager, Production engineer, Production manager	9	75–105
Beta	**Project**: Project manager **Product**: Lead engineer, Method and process developer, Polymer construction specialist, Simulation manager, Material and process specialist, Engineering design manager **Production**: Production technology manager, Tooling manager, Production engineer, Production manager	11	68–95
Gamma	**Project**: Product platform/industrialisation manager, Project manager (construction site) **Product**: Product manager, Structural engineer, Technology manager, CAD engineer, Process owner, business area manager **Production**: Production preparation engineer, Production manager/production engineer	11	65–107
Delta	**Project**: Industrialisation manager, Project manager **Product**: New product development manager, Product engineer, Product engineer, Product account manager **Production**: Production engineer, Production engineer, Production manager, Production line manager	10	63–90
Epsilon	**Project**: Project manager (construction site), Project manager **Product**: Technology manager, Operational purchaser, CAD and process development engineer, Product platform engineer, Product engineer **Production**: Production engineer, Production preparation engineer, Production manager	10	48–86 (29) (34)

3.4.1.2 Data analysis

The data analysis followed Miles et al.'s (2020) three steps: (1) data condensation, (2) data display and (3) drawing and verifying conclusions. To condense the data, each transcribed interview was analysed, and content was coded based on its relation to production development. The content ranged from future challenges for the production system that must be managed to specific questions on production platforms to long-term plans to cooperate with these challenges. Data not directly linked to this scope were omitted. Each case's data were first separately, condensed and analysed, and the results were reported in workshops to validate the findings within the case. Subsequently, further data condensation resulted in the themes presented in the paper, i.e. production development, long-term objective, long-term plan, standardisation, reuse of solutions and concepts, the method for reusing knowledge, lessons learned, implemented production platforms and view on production platforms.

3.4.2 Study II

The second study aimed to explore the prominent conflicting dynamics persistent in the complex business of co-managing product and production development within industrialised house building, generalised to any context including the conflicting objectives of mass customisation combined with pressures of increased production performance. A single case study (Yin, 2018) was conducted within the Gamma company. Study II's unit of analysis was the cooperation between product and production development, here represented as two departments (Figure 3-5).

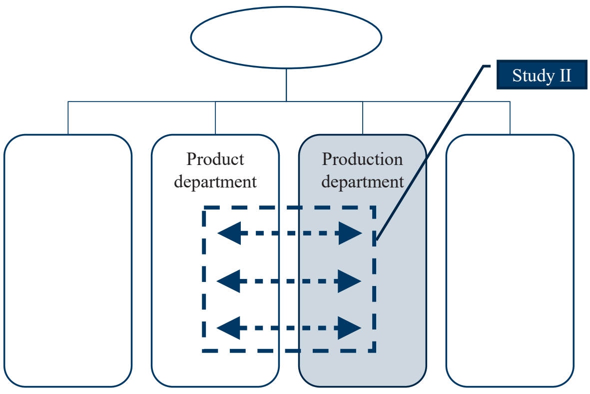

Figure 3-5. Unit of analysis in Study II.

Secondary data from Study I was used for knowledge and understanding of the context of company delta. The study was designed to enable system dynamic modelling using causal loop diagrams (CLDs). CLDs use the notation of causal links between variables, and their interrelations are connected into networks of feedback loops to explain phenomena (Sterman, 2000).

3.4.2.1 Data collection

Data were collected through semi-structured interviews to study cooperation and different perspectives on product and production development. Two semi-structured interviews were conducted with the two respondents who had managing positions within product development and production development, respectively. The same interview guide was used for both interviews (Appendix 2). The questions were intended to reveal time-dependent parameters and causal feedback relations and allow for an increased understanding of the conditions leading to the current state of business or the reasons behind the intentions to achieve expected future developments. The interviews were conducted by two interviewees via teams, lasted for 1.5–2 hours and were recorded and transcribed.

3.4.2.2 Data analysis

The interview transcriptions were processed into a synthesis of each perspective through thematic analysis (Miles et al., 2020). Initial CLDs were modelled to capture the perspectives of the respondents. Thereafter, each synthesis was reviewed together with initial CLD models in a first meeting with the respective respondent, lasting for 2 hours each to enable individual face validation to correct potential errors (Sargent, 2013). After this, further modelling was carried out, resulting in two main models that were presented in a 1.5-hour meeting to examine how the resulting models resonated with the interviewees and to obtain their reflections on each other's presented models and perspectives. This also allowed for verifying the relevance and usefulness of the model scope and correcting errors in the interpretation of the empirical findings (Sterman, 2000). Thereafter, the resulting CLD presented in Paper II was composed to exhibit the overall main interactions in one model to support the walkthrough of the conflicting and cooperating system dynamics identified from the empirical findings.

3.4.3 Study III

The third study sought to develop an initial understanding of how production platforms have been used in the existing literature; thus, a systematic literature review was designed (Tranfield et al., 2003a). After initial searches on production platforms, only four hits were found. Therefore, the studied population of papers was adjusted to investigate product platform literature and its consideration of production development aspects. The review explored and classified the product platform literature based on how production development aspects, such as design, development, justification, planning and operations, were discussed and utilised. The focus of the study is illustrated in Figure 3-6.

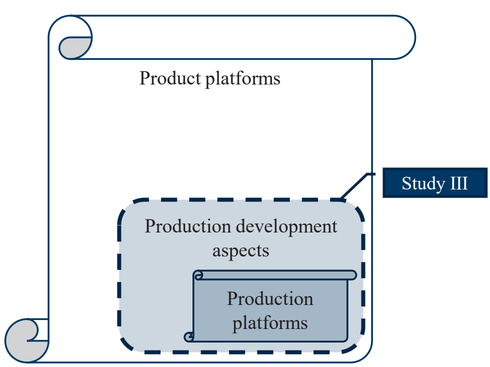

Figure 3-6. Unit of analysis in Study III.

3.4.3.1 Literature search

The review followed Tranfield et al.'s (2003) three stages: planning the review, conducting the review and disseminating the review. First, a plan of how to conduct the study was designed using a set of criteria to classify the product platform literature. Second, the review was conducted. Finally, a summarised descriptive analysis of the explored field was developed. The 1,155 identified papers were filtered through four steps, and 126 were selected for classification in two different dimensions, including the product platform and the production development. Another inclusion criterion was that the paper had to focus on the dimension rather than only mentioning it. To qualify for the 'focus' category, the paper had to discuss the topic; otherwise, it was classified as a 'mention' paper, which typically contained weak statements, such as 'production is relevant to consider', without further discussion. The final number of selected papers was 27. The overall exclusion process is shown in Table 3-3.

Table 3-3. Literature exclusion process

Steps	Description	Papers [#]
Search for 'product platfor*'	In Scopus	1,155
Filtering 1, keywords, and exclusion criteria	Keywords: 'product platfor*' AND 'develo*' AND 'manufacturing' OR 'production' Exclusion criteria: e.g. 'petroleum', SUBJAREA, 'PHYS'	261
Filtering 2	Review of abstracts	240
Accessibility	Ability to access the papers	206
Relevance	Should at least mention product platforms and production development aspects	126

3.4.3.2 Data analysis

The journal papers that focused on production development aspects were selected for content analysis (Seuring & Gold, 2012a). The papers were first read in their entirety, and then the papers were assigned keywords based on the terminology used in each paper to reflect what each paper presented. These keywords were later normalised into standard keywords that reflected the entire population of papers. Based on these keywords, the central topics were determined, and the papers were then classified in terms of these topics, based on the production development aspects included and discussed in the papers. Finally, each paper was presented.

3.4.4 Study IV

The fourth study aimed to increase knowledge of long-term production development and provide support for production engineers in mapping production capabilities and showing how new products might impact the production system. The study used an interactive research design with two cases within the Alpha and Beta companies. The development of one production line was studied at each of the companies. The multiple case study approach enabled the investigation of the phenomenon in its natural environment (Yin, 2018). The interactive research approach supported joint learning, in which the industrial partners and the researchers had separate tasks (Ellström, 2007). The industrial partners continued their development project as usual, while the researchers provided theoretical knowledge, structured the development phases and synthesised empirical data into the proposed support. The unit of analysis was the production development project within their respective product realisation process (see Figure 3-7). The production engineers in the two projects strived to adapt their production capabilities to match the new product requirements. The two cases were studied over a period of 13 months.

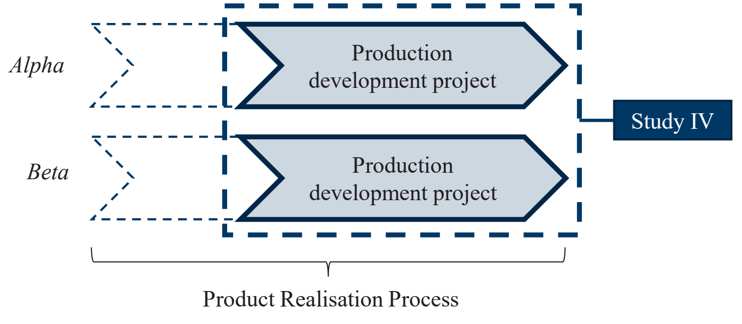

Figure 3-7. Unit of analysis in Study IV.

3.4.4.1 Data collection

Data were collected through interviews, observations, workshops and document studies, and the progress of how the production capabilities were mapped was studied. To ensure a mutual understanding of the state-of-practice in production development processes, group interviews were initially carried out. The group interview was also designed to work as a self-evaluation of the current production capabilities and included questions regarding, for example, product variation, production volumes, reuse, equipment suppliers and ways of working. The questions were sent out to the respondents in advance to give them an opportunity to prepare the answers. The group interviews were, thereafter, carried out within each case and lasted for 1.5 hours.

In total, 18 workshops were carried out, seven at Alpha and nine at Beta; five of these were conducted together with both companies. A workshop as a technique for data collection is beneficial to apply within interactive research in forward-looking processes such as organisational change or design (Ørngreen & Levinsen, 2017). During the workshops, annotations were taken. Workshops were used to follow the production development project and generate theoretical knowledge. The participants in the group interviews and the workshops had different roles. At Alpha company, a production engineering manager and production engineers were represented, while in the case of Beta, a production engineering manager and a project manager from production engineering were represented. The existing production line was observed twice at Alpha to gain a deeper understanding of its capabilities, while at Beta, a line similar to the conceptual line being studied was observed once. Documents, including blueprints, process charts and production system documentation, were studied to increase this understanding. The interviews, observations and workshops are summarised in Table 3-4.

Table 3-4. Study IV: interviews, observations and workshops

Phase	**Company**	**Type**	**Number**	**Time [h]**
Factory visit	Alpha	Observation	2	3.75
	Beta	Observation	1	3
Self-evaluation	Joint	Group interview	2	4
Production capability mapping	Alpha	Workshop	4	3.25
	Beta	Workshop	5	6.5
	Joint	Workshop	1	2,75
Product requirement mapping	Alpha	Workshop	2	2
	Beta	Workshop	2	2.5
Capability and requirement comparison	Alpha	Workshop	1	1
	Beta	Workshop	1	2
	Joint	Workshop	1	3
Face validation	Joint	Workshop	1	3

3.4.4.2 Data analysis

The project was structured according to four phases: (1) the current way of working, (2) current capabilities and requirements to manage change, (3) requirement specification and (4) evaluation. Each of these phases represents one loop in the interactive research approach (see Figure 3-3). At the end of each loop was a joint workshop held with the two companies to close the phase and start the next. The participants from Alpha and Beta conducted the production development work with their project, while the researchers provided theoretical knowledge in the form of changeability classes (Benkamoun, 2016) and production hierarchy levels (Wiendahl et al., 2007). The theoretical knowledge provided the opportunity to apply the theories to the production development process and to allow for new perspectives by the participants. After the four phases were conducted, the PCM support synthesised the empirical data into the proposed PCM support. The final PCM support had five phases, as the second phase's current *capabilities and requirements to manage change* were split into two phases to better match the way Alpha and Beta worked. After the PCM support was synthesised, a face validation (Sterman, 2000) workshop was held, which allowed for verifying the relevance and usefulness of the support as well as adding future expansions of the support.

3.4.5 Summary of studies

To summarise, four studies were conducted to answer the research questions. The four studies used different research methods, data collection techniques and data analysis methods to study long-term development from different angles. All four studies resulted in one of the appended papers in this thesis. An overview of the studies is given in Table 3-5, where an account of the research method, industrial partners, unit of analysis, data collection techniques, data analysis and the main outcome is given.

Table 3-5. Methodology overview of the thesis' studies

	Study I	Study II	Study II	Study IV
Research method	Multiple case study	Single case study	Literature review	Multiple case study
Industrial partners	*Alpha, Beta, Gamma, Delta, Epsilon*	*Gamma*	N/A	*Alpha, Beta*
Unit of analysis	The production development process in the product realisation process	Product and production development process	Production development aspects within product platform literature	Production development project
Data collection techniques	Semi-structured interviews Document studies	Secondary data from Study I Semi-structured interviews Workshops	N/A	Group interviews Observations Workshops Document studies
Data analysis	Thematic analysis	Thematic analysis Causal loop diagram modelling	Content analysis	Synthesis
Main outcome	Paper I	Paper II	Paper III	Paper IV

3.5 Research quality and ethical considerations

This section presents the methodology considerations regarding the research quality as well as the ethical consideration of the research.

3.5.1 Research quality

The studies were designed to meet the quality criteria of *construct validity, internal validity, external validity* and *reliability* (Yin, 2018).

Construct validity refers to the fact that what is studied is the thing that was intended to be studied (Saunders et al., 2015). The research questions were clearly defined, and the study design was chosen to achieve the research intent (Miles et al., 2020). The design of each study and the selection of the unit of analysis were made to address the purpose of this thesis, that is, to support a long-term view of production development through production platforms. This meant that production development, the use of a long-term view and production platforms were encased in the study designs. The construct validity was further strengthened by using multiple sources, and triangulation

(Williamson, 2002) was applied to both sources (e.g. interview respondents) and methods (e.g. type of data collection techniques). To further ensure that interviews were interpreted accurately by the researcher, the respondents throughout the studies were allowed to review the analysed data (Yin, 2018) by member checking (Carlson, 2010) or face validation (Sargent, 2013).

Internal validity refers to the extent to which it is possible to form causal links in a study. Internal validity is relevant to consider in the design of Study II since it is only applicable in explanatory or causal studies, not descriptive or exploratory (Yin, 2018). In a CLD, the causal loops are described and logically tested (Sterman, 2000), both with the other researchers and with the respondents who know the context they are in.

External validity refers to the extent to which the findings are possible to generalise and to what extent the findings are of relevance to other cases. In case study research, external validity is difficult to achieve in other than the studied context (Voss et al., 2002). The specific results and conclusions for the case studies are only valid within the specific case, but might provide valid insights in other contexts. To make it possible for the reader to evaluate if results and conclusions are valid in their context, the theories and the empirical data should be presented (Guba & Lincoln, 1989). In the multiple case studies, replication logic was applied to strengthen external validity, while the theory was applied in the single case studies (Yin, 2018). Detailed descriptions are provided about the types of data, types of respondents, case context etc. to allow a further understanding of the context in which the conclusions were made. By describing the cases, the context and the methods used, it becomes possible for others to determine if the results and findings would be valid in their context even though their context is different from that of the case study (Guba & Lincoln, 1989). Moreover, this thesis provides insights into how the cases could be tested further to gain additional possibilities for generalisation (Miles et al., 2020).

Reliability refers to whether the result of the conducted research is possible to replicate. Reliability for case study research is hard to achieve since it depends on the context, and the context is continuously changing (Saunders et al., 2015). Thus, it is important to describe the methodological decisions and conclusions that were made. For others to determine the reliability of the study, case protocols were established, interviews were recorded, transcribed and stored, and the methodological decision was given a detailed account in the thesis and the appended papers (Yin, 2018).

3.5.2 Ethical considerations

Concerning ethical considerations, adherence to the principle of not doing any harm to the participants was imperative (Bryman & Bell, 2011). Within the research, informed consent and anonymity of the participants were considered. This was relevant for Studies I, II and IV, where the participants were informed regarding the research and assured that their involvement in the study was entirely voluntary. Informed consent was evident throughout all interactions and was continuously emphasised during interviews and workshops. The participants were notified that the information they shared would be confidential and this policy was maintained throughout the studies (Williamson, 2002). Sensitive information was normalised during the writing process of the papers.

Further ethical considerations included the authorship of research papers. The gold standard for assigning authorship of research material in Sweden and at the School of Engineering at Jönköping University is the Vancouver recommendations for co-authorship (Vetenskapsrådet, 2017). Thus, the authorship of the research on which this thesis is based applied the Vancouver recommendations.

4 Summary of papers

In this chapter, the summaries of the appended papers. The papers' contributions and alignment to the research question are given. Thereafter, the key findings from each paper are presented and summarised.

4.1 Paper contributions and research questions

The purpose of this research was to *support a long-term view of production development through production platforms*. To achieve this, two RQs were articulated: RQ1: *What challenges and enablers exist for long-term production development?* and RQ2: *How could platforms in production support long-term production development*? The linkage between RQs, studies and appended papers is shown in Figure 4-1.

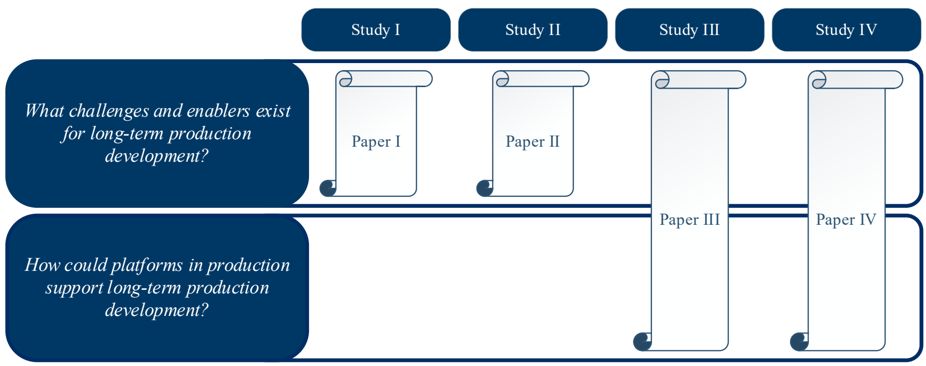

Figure 4-1. Linkage of research questions, studies and appended papers.

Paper I contributed to RQ1 by providing insights into the state of practice of how production development in general and long-term production development in specific were conducted. Several challenges towards long-term production development were identified and reported on.

Paper II contributed to RQ1 by highlighting the interplay and dynamics between product and production development. In this dynamic, several insights have contributed to challenges and enablers for long-term production development.

Paper III contributed to RQ1 by identifying the limited support for production platforms in product platform literature. Paper III also contributed to RQ2 in reviewing the production platform literature. Insights regarding how to develop platform strategies and how to design production platforms were found.

Paper IV contributed to both RQ1 and RQ2. The contribution to RQ1 was through deepening the understanding of long-term production development and further identifying new challenges and enablers in the production development practice. For RQ2, the presented support was a proposition to the approach of how platforms can act as a support in production development and how the platform could be described and communicated within and to the production development department.

4.2 Paper I – Challenges towards long-term production development

Paper I had the purpose of *presenting the industrial practices in production development and identifying challenges to applying long-term production development*. A multiple case study was conducted analysing production development within five companies: three manufacturing companies and two industrialised house builders.

In case 1 (Alpha company), production development was conducted as part of the company's product realisation projects. Investments were also made into increased capacity, and decreased environmental impact of the production system was also carried out in addition to the product realisation projects. The production development process was incorporated within the product realisation process, which was a company-adapted stage-gate model. The company employed a 5-year vision for the production plant with increased levels of digitalisation and automation. However, this vision was not concretely planned or connected to the upcoming product realisation projects and, thus, the production development. The company employed standards such as working procedures in operations, requirement specifications and type of production equipment. Reusing knowledge and learning between development projects was reported to be difficult, since they were reported in lessons learned but seldom reused later. Within the production development, there was neither a production platform concept established nor implemented. Production platform was not a well-known term and was considered to be the same as 'the production system' or 'plug-and-play concepts'. However, the company strived to reuse production solutions between production lines and projects, and although no formalised way of achieving this was established, it was highly person-dependent.

In case 2 (Beta company), the company had an adapted version of a stage-gate model for its product realisation process in which production development was conducted. The company had a definitely stated long-term objective of increasing the automation level within the production plant. However, there was no concrete plan for how this long-term objective was supposed to be achieved. The company had developed standard automatic cells for assemblies together with their machine supplier, which were now used in the production operation. The process of developing standard production solutions was not formalised; it was heavily person-dependent. The company strived to have a homogenous machine park and used standard requirement specifications in the acquisition phase to achieve this. Successful production solutions were reused for other projects from time to time, mainly dependent on who was working within the project, i.e. person-based reuse. The production platform concept was neither implemented nor established at the company, but the respondents had several perspectives on what it could be, for example, standard assembly modules, description of production capabilities or limits of the production system in which the new products need to be contained.

In case 3 (Gamma company), the production development was mainly conducted per their stage-gate process. The process involved an extra phase in which adaptions to local demands for their building sites and houses were conducted. They had a five-year vision of becoming a leading actor within industrialised housebuilders, where increasing the automation level was identified as a key success factor. However, current practices had a high degree of reactiveness in preparing the production for future products, and how long-term production development was supposed to be conducted was deemed a pressing issue. In addition, how the acquisition of production equipment was carried out was identified as an obstacle to reaching the long-term vision. There were standard work procedures in production. The concept of production platforms was not established, and the respondents had no idea of what it was. Knowledge from previous projects was collected, but it was hard to find since no standardised way of classifying the learnings existed. Also, the knowledge was mainly person-based and hard to share. However, there was a strong problem-solving culture present across disciplines, which helped in extracting tacit knowledge from each other.

In case 4 (Delta company), a stage-gate model for product realisation was adapted to their company, and the production development was determined in a yearly plan. No other long-term strategy for production development was employed. Unformalised standards existed for the type of production equipment. Lessons learned were documented after each project; however, they were mostly focused on product development in the product realisation. Mistakes in production development were often repeated and knowledge from previous projects was restricted to the people who participated in the project and who kept the tacit knowledge to themselves. The production platform concept was not established nor implemented but was expressed as ‘it constitutes of some kind of common base, and something modularised which can be reused, a foundation to stand on’.

In case 5 (Epsilon company), production development had been a low-prioritised activity, and they had recently hired their first staff within production development. The production engineer employed a trial-and-error approach to production development within their stage-gate model for product realisation; the process had an extra phase in which adaption to local demands for their building sites and houses was conducted. Recently, productivity and quality key performance indicators had been introduced. No formal ways of collecting lessons learned between projects were employed. The reuse of knowledge was person-dependent, and standard working procedures existed but were mainly used by new employees. Production platforms were not established, but the concept was understood as ‘how one works in production’ or the ‘[company name] production system’.

The case study reports on five companies and their state of practice regarding production development. The results of the paper are summarised in Table 4-1.

Table 4-1. Paper I, summarised results.

	Case 1	Case 2	Case 3	Case 4	Case 5
Long-term objective	Automation and digitalisation	Automation	Automation	No formal objective	No formal objective
Long-term plan	5-year plan, not connected to product development	No concrete plan	No concrete plan	1-year plan	No plan
Standardisation	Work procedures, specifications, types of production equipment, automation	Types of production equipment, automatic assembly modules	Work procedures	Partly types of production equipment	Work procedures (only new employees)
Reuse of solutions and concepts	Lacking formalised work processes	Lacking formalised work processes	Lacking formalised work processes	Lacking formalised work processes	Lacking formalised work processes
Method for reusing knowledge	Person-based	Person-based	Person-based	Person-based	Person-based
Lessons learned	Yes, hard to extract knowledge	Yes	Yes, hard to extract knowledge	Yes, focus on product development	No
Implemented production platforms	Not implemented	Not implemented	Not implemented	Not implemented	Not implemented
View on production platforms	'Same as the production system' and 'Plug-and-play concepts'	'Standard assembly modules', 'the described capabilities of the processes', and 'limits of the production system, in which new products must be constrained'	N/A	'It constitutes some kind of common base and something modularized which can be reused, a foundation to stand on'	'How one works in production'and '[Company name] production system'

The production development practices were more mature in the manufacturing industry than within the industrialised house building industry. Automation and digitalisation were seen as important objectives related to production development. The use of synchronised plans between product development and production development was not present in any of the cases. The issue of reusing production solutions was managed in informal ways, mainly through people who had solved similar problems before and, thus, were able to reuse their tacit knowledge to create suitable solutions for a new project. The methodology of reusing production solutions was highly person-dependent and not systematically structured. Even though lessons from the projects were collected, they were considered difficult to access and apply in new situations. Neither was a portfolio mindset in the production present, nor was there any general structure for mapping how future product requirements could require change in production solutions. Instead, each currently known product requirement demanding an adaption of the production solutions was treated as they appeared. The production platform concept was not established.

4.3 Paper II – Exploring conflicting dynamics in product and production development within industrialized house building

Paper II aimed to explore the *prominent conflicting dynamics persistent in the complex business of co-managing product and production development within industrialized house building.* The study used causal loop modelling and analysed the resulting CLDs, which generated insights into challenges towards long-term production development.

The paper reports on the issue of integration between product development and production development. Through using CLD, it was possible to investigate if and how product development and production development were both being used to improve performance. However, neither their plans nor their efforts were aligned. Seemingly, they had different objectives, and there were varying perspectives in the company as to which challenges were most pressing. It became evident that there might be conflicting efforts to achieve the objectives, which created contra-productive dynamics between the two departments. The product portfolio manager focused on streamlining the product range offered to the customers, while the production development manager focused on ensuring long-term factory productivity performance and increasing capacity. At first, these two objectives appeared to be aligned; however, the streamlined standard range for the customers was not connected to the current capabilities of the production nor the future production development plans. From the production perspective, it was considered obvious that too many products that lay outside the current production capabilities generated issues, since this was considered to take too many production resources in the form of cycle time and preparation work, as well as the risk of creating a product that had a higher likelihood of generating unplanned halts in production. Both the standard range and the special products (i.e. products that were outside the standard range) impacted the production system, as the standard and special labels regarded the customers' perspective and not the production perspective.

Within the product development department, there was a belief that it was necessary to allow high variation to attract customers. One insight was that the product variation created to attract customers could potentially be decoupled from the variation the production system experienced by modularisation and alignment between product modules and production capabilities, here called external and internal variations. One way of approaching this issue could be by using platform strategies (Jiao et al., 2007; Robertson & Ulrich, 1998) of reusing standard solutions or modules to create more product variation while minimising the impact on the production system. Another identified insight pertained to the requirement to know the production capabilities and what types of product features lay outside of the production capabilities. It was identified as a two-fold problem that the product development should know the limits of the production and how new products impact it and that the production development should be able to convey the production capabilities more efficiently. Another insight was that the need for increasing production capacity through automation would generate more constraints compared with a manual assembly. It was thought that this could become a real challenge if not properly managed. Increasing the production capacity through automation would potentially reduce the variation allowed for new product introduction, which could result in longer and more complex development efforts. It was determined that it would be important to be able to identify whether a new product could be produced within the current production capabilities or if an expansion would be required. The identified insights from Paper II are summarised in Table 4-2.

Table 4-2. Paper II, a summary of insights.

Insights	Summary of topic
Long-term objective	The long-term product development efforts were not guided by the current production capabilities nor the future development plans for the production system.
Alignment of external and internal variation	The product development manager was working on reducing variation generated by the customers, i.e. external variation, and the production development manager was working on reducing the variation within the production system, i.e. internal variation.
	The work with reducing internal and external variation was not aligned, i.e. if a product was part of the standard range, it could still induce higher production variation.
Realising product requirements	An identified need was to know the current production capabilities and which product features lay outside limits.
Understanding production capability	The production system would have more constraints to consider as more and more automation is implemented to increase the production capacity.
	It would be important to determine if a product can be produced within the current capabilities or if an expansion is required.

4.4 Paper III – Exploring the concept of production platforms - A literature review

Paper III had the purpose *to review the current product and production platform literature to insights into the production platform co-development research.* The study conducted a systematic literature review and presented papers that focused on production development within the product platform literature.

The paper provides insights into the fact that production development research is lacking within product platform research. The initial search for production platforms yielded four hits and was, thus, abandoned in favour of the idea that research that also highlights production platforms, production development or modularity in production systems could be found in the product platform literature, which was flawed. The product platform research mainly reports on the product perspective. However, a few papers had an expanded view and focused on production and production development aspects, which became the highlight of the review. The review considered 126 papers that at least mentioned production development aspects. Among these, 27 journal papers were fully reviewed and described within the paper.

In total, there were seven central topics identified from the reviewed papers: co-development, reuse of manufacturing knowledge, modularity, evaluation methods, costs, production preparation, industrialisation, and other. A summary of the content of each of the central topics is presented in Table 4-3.

Table 4-3. Paper III, central topics.

Central topic	**Summary of topic**
Co-development	Insights into how product and production development could be conducted with each other in mind.
Reuse of manufacturing knowledge	Insights into how production knowledge could be reused between development projects.
Modularity	Insights into how modularity could impact operation and production development.
Evaluation methods	Insights into how different evaluation methods for product platforms, where operation and production development aspects are taken into consideration.
Costs	Insights into how cost savings could be done with product platforms.
Production preparation and industrialisation	Methods and tools for production preparations and industrialisation within product platforms.
Other	Provided platform learnings and insights into production architectures.

From the review, it was evident that production platforms are not extensively used; it was explicitly mentioned in only five of the reviewed papers. There was limited support for production platforms found in the product platform literature. In addition, production development was viewed as a separate topic and something that would usually be managed separately from product development and product platform development.

A few scholars had, however, deeper insights into platforms based on different perspectives. Sorensen et al. (2018) reported on a production platform development project in which key insights from the case company included a lack of consistency in vocabulary and the production development process. Watanabe and Ane (2004) investigated the role of product platform modularity in improving manufacturing agility. They found that product modularity enables assembly on the same production line but also that product modularity enables the company to increase its manufacturing agility. Thuesen and Hvam (2011) reported on learnings on platform work from a German house builder. They found that product platform strategy is a long-term strategy and should be developed over time, using small steps to increase performance (i.e. incremental development).

4.5 Paper IV – Mapping production capabilities: Proposing support towards changeable production

Paper IV proposed to investigate the *support for evaluating production capabilities and mapping how product introductions may impact the production system.* The study was conducted with an interactive research approach in a multiple case study, including industry cases.

The paper reports on two cases in which production development projects were studied. In the projects, automatic assembly lines were developed by applying a traditional development approach. Historically, the design of production solutions had only considered immediate product requirements. Neglecting any potential future product requirements led to extensive repurposing of the automatic assembly lines when a new product was to be introduced. The two production development projects were structured according to the four phases of a generic method for changeable production development (Boldt et al., 2023). Through studying the four phases in the two cases, a production capability mapping (PCM) support for production engineers was synthesised.

The PCM support is a process distributed over five phases (Figure 4-2). The five phases are (1) self-evaluation, (2) production system decomposition, (3) production capability mapping, (4) product requirement mapping and (5) capability and requirement mapping. The phases allow for progressively adding information in a structured manner. The process is designed to structure the way of working for the production engineers.

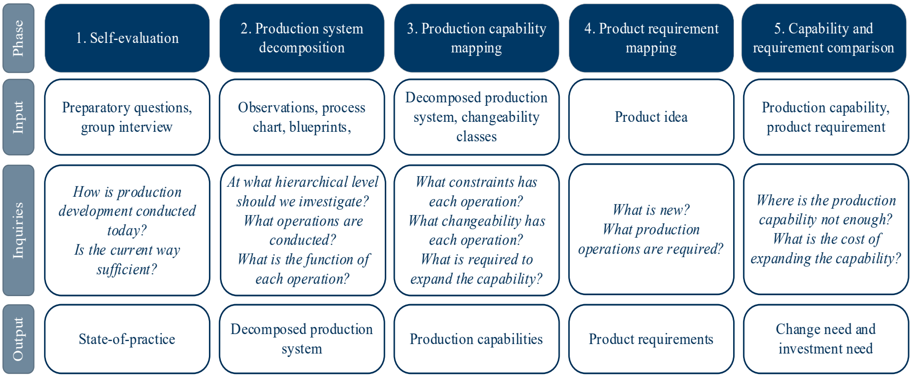

Figure 4-2. Overview of the proposed PCM support.
Source: Boldt et al. (2023).

The first phase includes a brief review of the current way of working through a self-evaluation regarding product variation, production volumes, reuse, investment structures, equipment and system suppliers and the standard way of working. Self-evaluation allows for reflection and visualisation of the current state of practice in production development. It enables the creation of a common ground of current struggles and shortcomings in the production development practice for the production development team.

The second phase includes activities to decompose the selected production system or line. This determines at what hierarchical level the functionality of the production line is created; this is conducted by stepping through the production line and describing the equipment and tools that are used to fulfil the requirements in each operation. This includes creating a decomposed view of the production system and an operational sequence and detailing what tools and equipment are used.

The third phase includes further describing the capabilities of the production line by using the decomposed view of the production system and analysing the changeability of the production line using changeability classes (Benkamoun, 2016), by elaborating on the constraints of the equipment and tools through describing what is possible to accommodate and by detailing capability expansions of each operation that could be required to be repurposed when new product requirements are to be introduced. Each operation is also given a severity index rating based on how the capability expansion would impact the development lead time, process capability, layout possibility and investment cost.

In the fourth phase, the new product requirements posed to the production line are identified by reviewing the early product design, identifying potential carry-over components and sub-systems, identifying what is new and reviewing potential assembly sequences.

In the fifth and final phase, production capability and product requirements are brought together to identify where repurposing, upgrades, expansions or other actions are required in the production system or line. This is accompanied by cost estimates for typical costs, such as reprogramming an industry robot, adding a new fixture or even adding a new type of screw. The cost estimates allow for a quick overview of the investment costs required for introducing the new product requirements.

After traversing the five phases, two main sections were created. The first section systematically describes the current production capabilities and their constraints, as well as how these limits could be improved through capability expansion. The second section described how the new product will impact the assembly line, what is required to accommodate the required functionality in the production solution and how it should be expanded, ending with an estimate of what the cost of the expansion would be.

The proposed support aims to give production engineers systematic ways of developing production systems that allow less repurposing when new products are introduced. PCM support provides ways of revising the production development approach to cater for an approach that considers the future product requirements, without them being known during the development. This is achieved through considering that the products tend to change in certain areas and a large portion of know-how is used when developing new products, making them more predictable than it might seem at first.

5 Result and discussion

In this chapter, the research results and limitations are discussed. The four appended papers' challenges and enablers for long-term production development are presented to answer RQ1. To address and answer RQ2, long-term production development is discussed, together with a discussion on the applicability of PCM support and production platforms to support long-term production development. The chapter ends with a discussion of the limitations of the research methodology.

5.1 RQ1

The answer to RQ1, *What challenges and enablers exist for long-term production development?*, is based on the challenges and enablers presented in the four appended papers. These challenges and enablers were clustered into eight categories: *platforms*, *long-term planning, production development scope, standard production solutions, knowledge management, product requirements, collaboration and alignment, and automation*. All the challenges and enablers are summarised in Table 5-1. Each challenge (–) or enabler (+) is described as well as connected to the paper in which it is presented. In the following section, the categories are presented.

Table 5-1. Challenges and enablers towards long-term production development

Category	#	Challenge/enabler	+/–	Paper
Platforms	1	Limited support for production development using production platforms.	–	III
	2	Limited support for how to structure, document and use production platforms.	–	III
	3	Platform strategies are required to be developed over a long time, i.e. incremental development.	–	III
Long-term planning	4	Lacking long-term production development objectives.	–	I
	5	Lacking a production development plan.	–	I
	6	Lacking a long-term production development plan.	–	I
	7	Lacking connection to future requirements and demands, i.e. production development/portfolio planning/product platforms.	–	I
	8	Product streamlining is not connected to the current production capabilities or the future production development plans.	–	II
Production development scope	9	The production development scope is limited to considering the immediate product requirements.	–	IV
	10	Production development is viewed as the subsequent process step within the product realisation process.	–	III, IV
	11	The forecasts of production volumes in product realisation projects determine which type of production solutions are possible to develop.	+	IV
	12	Strategic projects allow for disregarding the traditional production development scope which would allow for larger considerations.	–	IV
Standard production solutions	13	Modularisation of the production would allow for higher degree of reusability.	+	I
	14	Joint development with machine suppliers to create standard automatic assembly modules.	–	I
	15	No formal process for developing standard solutions.	+	I
	16	Production equipment acquisition process is not structured and established in the organisation.	+	IV

Table 5-1. (continued.)

Category	#	Challenge/enabler	+/–	Paper
Knowledge management	17	No process for reusing manufacturing knowledge.	–	I
	18	No formal way of collecting lessons learned.	–	I
	19	Learning from previous development efforts saved as lessons learned are hard to access and use in new projects.	–	I
Product requirements	20	The product development team does not know the current production capabilities' constraints, so the products are developed while not connected to the production capabilities.	–	II
	21	Product realisation projects are limited to the immediate product requirements, thus only developing production solutions for today's requirements.	–	IV
	22	Customer variation is coupled with production variation, could be decoupled through product modularity.	–	II, III
Collaboration and alignment	23	Contradicting objectives between product development and production development.	–	II
	24	Misaligned processes and objectives between product development and production development.	–	II
	25	Lack of understanding of other department's realities.	–	II, III
	26	Difficult in communicating what and why certain production solutions are difficult or expensive to repurpose for a new product.	–	IV
	27	The current production capabilities are not explicitly described; they are merely known by the engineers loosely with the production line.	–	IV
Automation	28	A high automation level is necessary to be able to keep production in Sweden.	–	IV
	29	Automatic assembly will have more constraints to consider compared with manual assembly.	–	II

First, within the domain of *platforms*, which was considered an enabler, it was indicated that there existed several challenges. It was found that organisations need a long-term perspective, since platform development requires incremental development over time. Only limited support for production development was found.

Second, a group of identified challenges indicated that there has been less focus on *long-term production planning*. The indicated lack of a long-term view reflects the general description and argumentation stated in the introduction of this thesis. It can be deduced that there is a general lack of planning for the next development steps that should be taken to increase production capabilities. The current procedures do not employ a structured way of working that connects the future requirements added to the production system with the production capabilities developed within a production development project. This creates long-term production capability objectives that are vague and not connected to current capabilities or future requirements.

Third, there were some challenges and enablers indicated within the *production development scope*. The scope of production development was that it was merely a step within a step within the product realisation process, entailing that the production development reacted to the new products that should be introduced in the production system. This traditional scope limits the considerations taken by the production development team, as their scope is limited to the specific product realisation project and its immediate requirements. It was found that the traditional scope of only considering the immediate product requirements was prominent, but was exempted through using strategic projects, which did not adhere to the regular requirements. On these occasions, the production development team could include considerations of future product requirements in its scope. The forecasts of sales volume for the products within the product realisation projects were found to have a large impact on what type of production solutions were developed, as higher volumes allowed for higher investment in the production system.

Fourth, there were challenges which indicated that developing and reusing production solutions, i.e. *standard production solutions*, across production system generations and between production lines were hard to achieve. Modularisation was seen as a way forward, as it decreased the potential propagations in the production system when it had to be changed for new product requirements. Collaboration with machine suppliers to develop modular automatic assembly modules was one success story. However, there was no formal process for developing these modular production solutions.

Fifth, there were identified challenges within *knowledge management*. There were challenges with utilising learning from past projects and reusing production knowledge. Learning from projects had historically focused on product development; however, accessing and using past lessons were deemed difficult.

Sixth, it was indicated that the product realisation projects were limited to the immediate *product requirements*, thus only requiring the development of production solutions for today's products. It was also found that the product development team did not currently know the capabilities of the production system and thus designed products that lay outside the capabilities. The scope of the production development project did not consider more than the immediate new product.

Seventh, several challenges indicated that there were issues in the *collaboration and alignment* between the two domains of product development and production development. It was found that the two domains had different objectives and processes that were not aligned with each other. Even though they in general strive towards the common goal of their company, there might be several contradictions in what they are doing. These two domains have different contexts and are not always aware of each other's contexts. It was shown that the capabilities of the production system were not explicitly described, but rather existed as tacit knowledge of the engineers working closest with the different production solutions. Regarding the production system and its solutions, it was indicated that there were issues in effectively being able to convey why it was challenging to accommodate certain product requirements or why it might have more significant consequences than first thought.

Eighth, and finally, *automation* was also found to be an important factor in production to remain a competitive alternative as a factory. At the same time, automation within an assembly created more constraints that must be taken into consideration when developing production systems and introducing new products.

To conclude, 29 challenges and enablers towards long-term production development were identified within the four appended papers and contribute to answering RQ1.

5.2 RQ2

To answer RQ2, *How could a platform approach support long-term production development?*, it was required to propose an expanded view on long-term production development, present the contribution of Paper IV and combine and relate the results of Paper IV and long-term production development to production platforms. This resulted in presenting how a platform approach could support long-term production development.

Regarding long-term production development, Bruch and Bellgran (2014) brought forward the idea of introducing a portfolio planning perspective, including both product portfolios and production systems, allowing for an integrated portfolio perspective between product development and production development. The integrated portfolio perspective introduces a long-term view that enables an improved connection between future product requirements and expected production capabilities within the production system. Elucidating the opportunity for long-term planning in production development is essential, even though it is not always known what the future product requirements are, or if new unforeseen products will be introduced.

Vielhaber and Stoffels' (2014) illustration in Figure 2-2 highlights the connection between products and production systems in their two different life cycles. During the product realisation process, these two systems are affected in different parts of their life cycles. The product is produced in the use phase of the production system, while the product requirements and product design affect the upstream phase of plant construction, which needs to be completed before there is a production system that can produce the product. Thus, the illustration is helpful as it underlines the time dependencies of the integration of product and production development considering the different life cycles and shows that during the product realisation process, the life cycles are impacted in different phases.

To answer RQ2, it was proposed to combine the long-term view, illustrated by Bruch and Bellgran (2014), with the life cycle perspective, illustrated by Vielhaber and Stoffels (2014), to complement our understanding of how a production system is affected by multiple products across its life cycle. This was achieved, as shown in Figure 5-1, by introducing several life cycles of products to the initial illustration. Introducing several product life cycles and placing them into the production system's life cycle at different points in time is considered even more helpful to underline the time dependencies of the integration of product and production development with a long-term view.

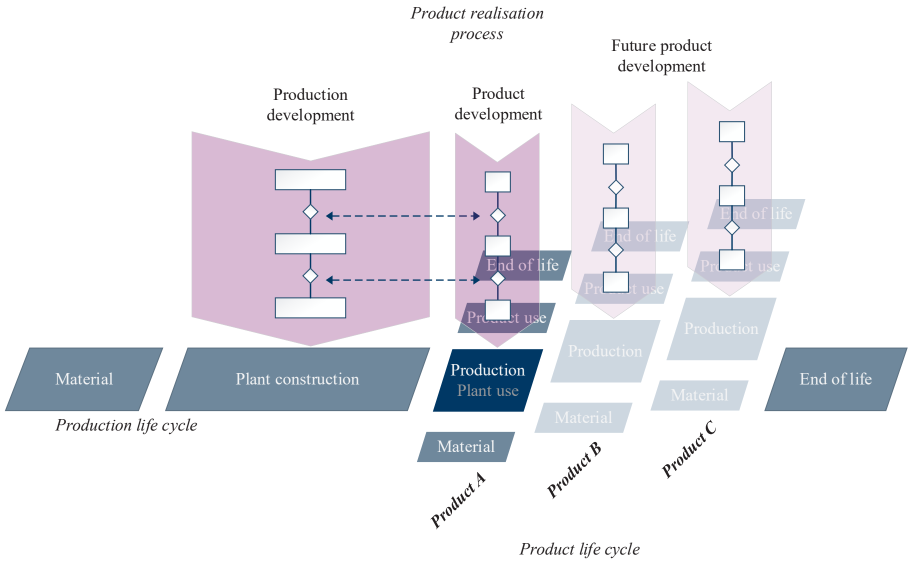

Figure 5-1. Long-term production development.
Further developed from Vielhaber and Stoffels (2014).

Consequently, the increased long-term view, illustrated by Figure 5-1, makes it possible to acknowledge how the production system is going to be exposed to future changes. Highlighting the flow of changes in requirements is supposed to help in managing new product realisation projects during the production systems lifetime. These future product requirements will eventually also need to be implemented in the plant construction phase to enable a functional future plant use phase in the future production system generation. These above-mentioned aspects are included in the concept of *long-term production development*. The proposed PCM support discussed in Paper IV specifically provides one approach to support such long-term production development.

The purpose of the PCM support is to map the production capabilities within the dark blue production plant use phase, illustrated in Figure 5-1. In the process of using the PCM support, the production solutions' changeability classes are determined to describe the ease of changing these production solutions. During this process, it is also identified and described how a change in product requirements would require changes in the plant construction phase if it would occur. Consequently, the future product requirements are considered and collected from the future product realisation projects, in this case, related *Product A, Product B* and *Product C* in Figure 5-1 Furthermore, this implies that PCM support can be iterated in a continuous process to provide support in long-term production development.

When the concept of long-term production development and the contribution of Paper IV have been presented, it is required to introduce how production platforms are utilised in the answering of RQ2. Based on the theory regarding production platforms and their definitions (Table 2-1), it was concluded that *production platforms provide a way of explicitly describing the production system and its assets* to facilitate reuse. Thus, a production platform approach should provide the means to explicitly describe the production system and its assets as well as describing the future product requirements. The result of using PCM support is having the descriptions of production solutions and their capabilities. For these to support long-term production development, they need to consider the stream of product realisation projects and that the production system is expected to experience changes across its lifetime. By emphasising both the assets of the production system as well as the future product requirements, it is possible to identify where changes are likely to occur. The cyclical work structure of the PCM thus supports gradually increasing the awareness of where change is acceptable and where standardisation and stability are required, that is, fundamentally, what a production platform is tasked with (Sorensen, Bossen, et al., 2018). The cyclical approach of PCM support aligns with the knowledge of platform development, which should be incremental and built over time, as argued by Thuesen and Hvam (2011). Thus, the refinement of production platforms results in accumulated and improved descriptions of the production system's capabilities and assets as well as how these may be designed to accommodate not only the current but also the future stream of product realisation projects.

Consequently, employing a production platform approach in product realisation projects would continuously produce updated descriptions of the production capabilities. Eventually, all sub-systems of the production system would have to be detailed. By including the focus on future product requirements and how these are accommodated, these production platform descriptions would also allow for employing a mindset of using changeability and modularity in production solutions, which allows for absorbing more of the changes without major interventions. Thus, in turn, the effect for the production system is a continuous development consisting of production solutions already adapted to future product requirements, minimising the required changes in production capabilities in the long-term. Moreover, on the production solution level, by implementing such a platform approach, it is possible to decouple the impact of future product requirements as they are limited to certain production solution modules, and these modules could be changed with minimal impact on the rest of the system. In all, the platform approach, as proposed above, is creating a movement away from the traditional way of developing production systems that only considers the immediate product requirements and, instead, takes steps towards a longer-term view in production development.

To conclude, the proposed illustration, Figure 5-1, of long-term production development elucidates the need for working continuously with reducing, not only the immediate but also the future required changes in production capabilities to accommodate new products. PCM support provides one approach for how platform descriptions are generated and used as a foundation in long-term production development to create a production system that possesses a higher ability to absorb changes. In other words, it shows how a production platform approach could be used to support long-term production development.

5.3 Discussion of research methodology

This research is based on an interactive research approach comprising case studies and a literature review. Three empirical-based studies were conducted, i.e. Studies I, II and IV. These studies explored how production development and long-term production development are conducted and influenced. Thus, the units of analysis varied among these three studies. At the centre were production development and long-term production development, and various other aspects that arose through the interactive research approach were explored. These studies have, thus, provided three perspectives: Study I provided the foundation, while Studies II and IV provided deeper explorations into the issue of long-term production development. Therefore, triangulation of methods and perspectives was achieved. These different perspectives allowed for gaining significant insights into the issues concerning long-term production development. The individual studies were somewhat difficult to generalise, as there were limited cases in Studies II and IV. However, the lower number of cases meant that it was possible to conduct a much more comprehensive investigation of each case rather than less thorough examination of a large number of cases.

The studies are separated and individually sound, but they were conducted within the same companies with the same individuals across three years. This led to deep understanding of the context in which the cases were situated. These positive aspects aside, there was an increased risk of influencing the respondents as the project evolved and understanding of the context increased. There is always the risk that the researcher will form conclusions too rapidly as they become more and more immersed in the context, cases and the data thus possibly conclude that the respondents *probably meant X instead of Y,* while they did not. The use of recordings and face validation were essential to reduce the risk of such researcher bias.

The discussion of the methodology choices made for this research has, up to this point, concerned empirical Studies I, II and IV, but there are important comments to make regarding the literature review of Study III. Study III's literature review can be considered a systematic literature review, which is often criticised for a lack of thoroughness (Seuring & Gold, 2012). To ensure the appropriate literature review process, Tranfield et al.'s (2003) methodology for systematic literature reviews was followed. However, the literature review was limited in its exploration and description of the selected papers. Based on continued exploration after Paper III, associated concepts such as process platforms, manufacturing system platforms, fixture platforms and manufacturing platforms were found through backward and forward citing. There are other potential concepts in this newly emerging field that could have provided further insights.

6 Concluding remarks

This chapter presents the concluding remarks of this thesis. First, the conclusions of the research conducted as part of this thesis are presented. Thereafter, the scientific and industrial contributions are highlighted, and, finally, future research avenues are presented as an extension of the research conducted.

6.1 Conclusion

The purpose of the thesis was to *support a long-term view in production development through production platforms*. The thesis indicates that PCM support provides one way to generate a production platform that considers a long-term view of production development. In other words, it is possible to employ production platforms to support long-term production development.

To arrive at this conclusion, several challenges and enablers were identified. It is clear that production development at the studied companies was conducted with a short-term perspective, utilised informal structures for reusing production solutions and relied on tacit knowledge of the workforce. It is evident that the product and production domains were not aligned in their long-term plans for increasing competitiveness. This suggests that it would be beneficial to describe the current production capabilities to comprehend how new product requirements would impact them and to guide production development efforts to align with long-term product development plans.

In addition, the concept of long-term production development was absent, nor were production platforms used; thus, was an expanded perspective for long-term production development presented in the thesis. The expanded perspective (see Figure 5-1) illustrates that the stream of product realisation projects flows into the production system life cycle. Based on the diversity of production platform definitions (see Table 2-1) and the expanded long-term perspective, could production platforms be defined as *proving a way of explicitly describing the production system and its assets to facilitate reuse*.

This thesis illustrates how PCM support can systematically describe production capabilities and map the impact of new product requirements on these capabilities. PCM support provides one approach for how platform descriptions can be generated and used as a foundation in long-term production development to create a production system that possesses a higher ability to absorb changes.

6.2 Scientific and industrial contributions

The thesis contributes to industry as to describe the practices of how production development is conducted today, as well as current issues with long-term perspectives. It has been highlighted that long-term work is limited and difficult to perform as there are no formal ways of conducting it. The research presents insights from the conflicting dynamics of integrated product and production development, where objectives and plans are not aligned with each other. However, once PCM support has been developed, it presents an approach for production engineers to describe the production capabilities of today as well as express the next logical capability expansion step while putting into the context new product introductions. The PCM support allow production engineers to work with the production solutions to facilitate increased commonality and reusing solutions over time. This could then be the initial steps towards implemented production platforms which considered a long-term perspective on production development.

Concerning the scientific contribution were there a multitude of challenges that production development encounters in industry identified. These are summarised in the answer to RQ1 (see, Table 5-1). Also, were the definitions for production platforms complied (see Table 2-1), which underlined that production platform literature is scattered and that the different definitions are similar in certain terms. It was concluded that production platforms provide a way to explicitly describe the production system and its assets for facilitating reuse. However, this research presents a novel perspective on long-term production development. This perspective builds on the research in this thesis, the different research areas of changeability (Andersen et al., 2017; ElMaraghy, 2009), integrated product and production development (Vielhaber & Stoffels, 2014) and portfolio planning (Bruch & Bellgran, 2014), which were then synthesised to address RQ2. The long-term view of production development is expanded in Figure 5-1 and highlights the flow of new product realisation projects that production systems are supposed to manage during their lifetime. This realisation emphasizes the necessity of developing production capabilities which considers a long-term view which is what production platform approach enables.

6.3 Future research

Several potential research avenues arise from this work. To start, one avenue could be to explore other contexts to investigate if the identified challenges and enablers for long-term production development exist there. Further investigation into how PCM support could be improved for detailing and describing the current production capabilities. There would be significant value in exploring how more perspectives could be used in the platform approach, for example, further integrating technology and product development. Furthermore, it would be valuable to test the PCM support in more contexts and to determine under which contexts PCM support provides valid and worthwhile resource investments. Also, it would be valuable to explore how the long-term production development perspective could be motivated from an economic and sustainable perspective and when it would be beneficial to apply the production platform approach.

References

Adler, P. S. (1995). Interdepartmental interdependence and coordination: The case of the design/manufacturing interface. *Organization Science*, *6*(2), 147–167. https://doi.org/10.1287/orsc.6.2.147

Andersen, A.-L., Brunoe, T. D., & Nielsen, K. (2015). Reconfigurable manufacturing on multiple levels: Literature review and research directions. *IFIP International Conference on Advances in Production Management Systems*, 266–273.

Andersen, A.-L., Brunoe, T. D., Nielsen, K., & Bejlegaard, M. (2018). Evaluating the investment feasibility and industrial implementation of changeable and reconfigurable manufacturing concepts. *Journal of Manufacturing Technology Management*, *29*(3), 449–477. https://doi.org/10.1108/JMTM-03-2017-0039

Andersen, A.-L., Brunoe, T. D., Nielsen, K., & Rösiö, C. (2017). Towards a generic design method for reconfigurable manufacturing systems. *Journal of Manufacturing Systems*, *42*, 179–195. https://doi.org/10.1016/j.jmsy.2016.11.006

André, S., Elgh, F., Johansson, J., & Stolt, R. (2017). The design platform–A coherent platform description of heterogeneous design assets for suppliers of highly customised systems. *Journal of Engineering Design*, *28*(10–12), 599–626. https://doi.org/10.1080/09544828.2017.1376244

Baldwin, C. Y., & Clark, K. B. (1999). *Design rules: The power of modularity*. MIT Press.

Baldwin, C. Y., & Woodard, C. J. (2009). The architecture of platforms: A unified view. *Platforms, Markets and Innovation*, *32*, 19–44. https://ink.library.smu.edu.sg/sis_research

Bejlegaard, M. (2017). *Design of reconfigurable manufacturing system architectures methodology for low volume industry*. Aalborg University.

Bejlegaard, M., Brunoe, T. D., Bossen, J., Andersen, A.-L., & Nielsen, K. (2016). Reconfigurable manufacturing potential in small and medium enterprises with low volume and high variety: Pre-design evaluation of RMS. *Procedia CIRP*, 32–37. https://doi.org/10.1016/j.procir.2016.05.055

Bejlegaard, M., ElMaraghy, W., Brunoe, T. D., Andersen, A.-L., & Nielsen, K. (2018). Methodology for reconfigurable fixture architecture design. *CIRP Journal of Manufacturing Science and Technology*, *23*, 172–186. https://doi.org/10.1016/j.cirpj.2018.05.001

Bellgran, M., & Säfsten, K. (2010). *Production development: Design and operation of production systems* (pp. 1–36). Springer. https://doi.org/10.1007/978-1-84882-495-9

Benkamoun, N. (2016). *Systemic design methodology for changeable manufacturing systems*. https://tel.archives-ouvertes.fr/tel-01420120

Boldt, S., Rösiö, C., & Linnéusson, G. (2023). Mapping production capabilities: Proposing support towards changeable production. Accepted for publication in CARV MCPC 2023.

Bossen, J., Brunoe, T. D., & Nielsen, K. (2015). Platform-based production development towards platform-based co-development and co-evolution of product and production system. *IFIP Advances in Information and Communication Technology*, *459*, 53–61. https://doi.org/10.1007/978-3-319-22756-6_7

Bruch, J. (2012). *Management of design information in the production system design process.* [Doctoral dissertation, Mälardalen University, Västerås, Sweden]. http://www.divaportal.org/smash/record.jsf?pid=diva2:592090

Bruch, J., & Bellgran, M. (2014). Integrated portfolio planning of products and production systems. *Journal of Manufacturing Technology Management*, *25*(2), 155–174. https://doi.org/10.1108/JMTM-09-2013-0126

Bryman, A., & Bell, E. (2011). *Business research methods*. Oxford University Press. https://doi.org/10.1017/CBO9781107415324.004

Carlson, J. A. (2010). Avoiding traps in member checking. *Qualitative Report*, *15*(5), 1102–1113. https://doi.org/10.46743/2160-3715/2010.1332

Chryssolouris, G. (2006). *Manufacturing systems: Theory and practice* (2nd ed.). Springer. https://books.google.se/books?id=663VBwAAQBAJ

CIRP. (2020). *Grundlegende Begriffe der Produktion/Termini fondamentali della produzione* [Fundamental terms of manufacturing]. Wörterbuch *der Fertigungstechnik III – Produktionssysteme Dizionario di Ingegneria della Produzione III – Sistemi di produzione* [Dictionary of production engineering III - Manufacturing systems]. (Trilingual edition). Springer. https://doi.org/10.1007/978-3-662-53334-5_1

Cooper, R. G. (2008). Perspective: The stage-gates® idea-to-launch process - Update, what's new, and NexGen systems. *Journal of Product Innovation Management*, *25*(3), 213–232. https://doi.org/10.1111/j.1540-5885.2008.00296.x

Corrêa, H. L. (1992). *The links between uncertainty, variability of outputs and flexibility in manufacturing systems*. http://ethos.bl.uk/OrderDetails.do?uin=uk.bl.ethos.541228

Deif, A. M., & ElMaraghy, W. H. (2006). A systematic design approach for reconfigurable manufacturing systems. In H. A. ElMaraghy & W. H. ElMaraghy (Eds.), *Advances in design* (pp. 219–228). Springer. https://doi.org/10.1007/1-84628-210-1_18

Eisenhardt, K. M. (1989). Building theories from case study research. *The Academy of Management Review*, *14*(4), 532–550.

Ellström, P.-E. (2007). *Knowledge creation through interactive research: A learning perspective*. https://www.ltu.se/cms_fs/1.24923!/per-erik%20ellstr%C3%B6m.pdf

ElMaraghy, H. A. (2009). *Changeable and reconfigurable manufacturing systems*. Springer Science & Business Media.

ElMaraghy, H. A., & Abbas, M. (2015). Products-manufacturing systems co-platforming. *CIRP Annals - Manufacturing Technology*, *64*(1), 407–410. https://doi.org/10.1016/j.cirp.2015.04.110

ElMaraghy, H. A., & Wiendahl, H.-P. (2009). Changeability – An introduction. In H. A. ElMaraghy (Ed.), *Changeable and Reconfigurable Manufacturing Systems* (pp. 3–24). Springer. https://doi.org/https://doi-org.proxy.library.ju.se/10.1007/978-1-84882-067-8_1

Ferguson, S. M., Olewnik, A. T., & Cormier, P. (2014). A review of mass customization across marketing, engineering and distribution domains toward development of a process framework. *Research in Engineering Design*, *25*(1), 11–30. https://doi.org/10.1007/s00163-013-0162-4

Guba, E., & Lincoln, Y. S. (1989). *Fourth generation evaluation*. SAGE Publishing.

Halman, J. I. M., Hofer, A. P., & van Vuuren, W. (2003). Platform driven development of product families: Linking theory with practice. *Product Innovation Management*, *20*, 149–162.

Hayes, R. H., Pisano, G. P., Upton, D. M., & Wheelwright, S. C. (2005). *Operations, strategy, and technology: Pursuing the competitive edge*. John Wiley & Sons.

Henriksson, F., & Detterfelt, J. (2018). Production – as seen from product development: A theoretical review of how established product development process models address the production system. *Proceedings of NordDesign: Design in the Era of Digitalization, NordDesign 2018*. http://urn.kb.se/resolve?urn=urn:nbn:se:liu:diva-153121

Järvenpää, E. (2012). Capability-based adaptation of production systems in a changing environment. [Doctoral dissertation, Tampere University of Technology, Tampere, Finland] http://urn.fi/URN:ISBN:978-952-15-2940-5

Jiao, J. R., Simpson, T. W., & Siddique, Z. (2007). Product family design and platform-based product development: A state-of-the-art review. *Journal of Intelligent Manufacturing*, *18*(1), 5–29. https://doi.org/10.1007/s10845-007-0003-2

Jiao, J. R., Zhang, L. L., & Pokharel, S. (2005). Coordinating product and process variety for mass customized order fulfilment. *Production Planning and Control*, *16*(6), 608–620. https://doi.org/10.1080/09537280500112181

Joergensen, S. N., Hvilshøj, M., & Madsen, O. (2012). Designing modular manufacturing systems using mass customisation theories and methods. *International Journal of Mass Customisation*, *4*(3/4), 171. https://doi.org/10.1504/ijmassc.2012.047396

Johannesson, H. (2014). Emphasizing reuse of generic assets through integrated product and production development platforms. In T. Simpson, J. Jiao, Z. Siddique, & K. Hölttä-Otto, K. (Eds.) *Advances in product family and product platform design: Methods and applications* (pp. 119–146). Springer. https://doi.org/10.1007/978-1-4614-7937-6_5

Joergensen, S. N. (2013). Developing modular manufacturing system architectures - The foundation to volume benefits and manufacturing system changeability and responsiveness [Doctoral dissertation, Aalborg University, Aalborg, Denmark]. https://vbn.aau.dk/ws/files/177770469/Developing_Modular_Manufacturing_System_Architectures_Steffen_Nordahl_Joergensen_phd_thesis_print_file_2_.pdf

Koren, Y. (2010). *The global manufacturing revolution: Product-process-business integration and reconfigurable systems*. John Wiley & Sons.

Koren, Y., Heisel, U., Jovane, F., Moriwaki, T., Pritschow, G., Ulsoy, G., van Brussel, H., Heisel, U., Pritschow, G., van Brussel, H., Jovane, F., Koren, Y., & Ulsoy, G. (1999). Reconfigurable manufacturing systems. *CIRP Annals - Manufacturing Technology*, *48*(2), 527–540. https://doi.org/10.1016/S0007-8506(07)63232-6

Lager, T. (2017). A conceptual framework for platform-based design of non-assembled products. *Technovation*, *68*, 20–34. https://doi.org/10.1016/j.technovation.2017.09.002

Luo, X., Tang, J., & Kwong, C. K. (2010). A QFD-based optimization method for a scalable product platform. *Engineering Optimization*, *42*(2), 141–156. https://doi.org/10.1080/03052150903104333

Maganha, I., Silva, C., & Ferreira, L. M. D. F. (2021). The sequence of implementation of reconfigurability core characteristics in manufacturing systems. *Journal of Manufacturing Technology Management*, *32*(2), 356–375. https://doi.org/10.1108/JMTM-09-2019-0342

ManuFUTURE. (2018). Competitive*,* sustainable and resilient European manufacturing. *Report of the ManuFUTURE. EU High-Level Group*, *37*.

Mehrabi, M. G., Ulsoy, A. G., & Koren, Y. (2000). Reconfigurable manufacturing systems: Key to future manufacturing. *Journal of Intelligent Manufacturing*, *11*(4), 403–419. https://doi.org/10.1023/A:1008930403506

Meyer, M. H., & Lehnerd, A. P. (1997). *The power of product platforms: Building value and cost leadership.pdf*. The Free Press.

Michaelis, M. T., & Johannesson, H. (2011). Platform approaches in manufacturing - Considering integration with product platforms. *Proceedings of the ASME Design Engineering Technical Conference*, Vol. 54860, 1115–1124. https://doi.org/10.1115/DETC2011-48275

Miles, M. B., Hubberman, A. M., & Saldaña, J. (2020). *Qualitative data analysis: A methods sourcebook* (4th ed.). SAGE Publishing.

Napoleone, A., Andersen, A., Brunoe, T. D., Nielsen, K., Boldt, S., Rösiö, C., Hansen, D. G., & Andersen, R. (2020). Towards an industry-applicable design methodology for developing reconfigurable manufacturing. In B. Lalic, V. Majstorovic, U. Marjanovic, G. von Cieminski, & D. Romero (Eds.), *Advances in production management systems. The path to digital transformation and innovation of production management systems* (Vol. 591, Issue November, pp. 449–456). Springer International Publishing. https://doi.org/10.1007/978-3-030-57993-7_51

Napoleone, A., Pozzetti, A., & Macchi, M. (2018). Core characteristics of reconfigurability and their influencing elements. *IFAC-PapersOnLine*, *51*(11), 116–121. https://doi.org/10.1016/j.ifacol.2018.08.244

Nielsen, O. F. (2010). *Continuous platform development synchronizing platform and product development* [Doctoral thesis, Technical University of Denmark, Odense, Denmark].

Ørngreen, E.-L., & Levinsen, R. T. (2017). Workshops as a research methodology. *The Electronic Journal of E-Learning*, *15*(1), 70.

Oxford Learner's Dictionaries. (2022, December 19). *Capability, n.* Oxford Learner's Dictionaries. https://www.oxfordlearnersdictionaries.com/us/definition/english/capability

Pahl, G., & Beitz, B. (1996). *Engineering design: A systematic approach* (2nd ed.). Springer-Verlag.

Park, H.-S., & Choi, H.-W. (2008). Development of a modular structure-based changeable manufacturing system with high adaptability. *International Journal of Precision Engineering and Manufacturing*, *9*(3), 7–12.

Produktion2030. (2016). *Make in Sweden 2030*. https://produktion2030.se/wp-content/uploads/Produktion2030-agenda_161212.pdf

Repenning, N. P. (2001). Understanding fire fighting in new product development. *Journal of Product Innovation Management*, *An International Publication of the Product Development & Management Association, 18*(5), 285–300. https://doi.org/10.1016/S0737-6782(01)00099-6

Robertson, D., & Ulrich, K. (1998). Planning for product platforms. *Sloan Management Review*, *39*(4), 19–31.

Rösiö, C. (2012). *Supporting the design of reconfigurable production systems* [Doctoral dissertation, Mälardalen University]. Mälardalen University Press PhD Dissertations. http://www.diva-portal.org/smash/record.jsf?pid=diva2:591325

Säfsten, K., & Johansson, G. (2005). *Forskningsverksamhet inom produktframtagning i Sverige (in Swedish) [Research activity within product realisation in Sweden]*. Vinnova.

Sargent, R. G. (2013). Verification and validation of simulation models. *Journal of Simulation*, *7*(1), 12–24. https://doi.org/10.1057/jos.2012.20

Saunders, M. N. K., Thornhill, A., & Lewis, P. (2015). Research Methods for Business Students (5th Edition). In *Research Methods for Business Students* (5th ed.). Pearson Education Limited. https://doi.org/10.1007/s13398-014-0173-7.2

Sawhney, M. S. (1998). Leveraged high-variety strategies: To platform thinking. *Journal of the Academy of Marketing Science*, *26*(1), 54–61.

Schuh, G., Lenders, M., Nussbaum, C., & Kupke, D. (2009). Design for Changeability. In H. A. ElMaraghy (Ed.), *Changeable and Reconfigurable Manufacturing Systems* (pp. 251–266). Springer. https://doi.org/10.1007/978-1-84882-067-8_14

Seuring, S., & Gold, S. (2012). Conducting content-analysis based literature reviews in supply chain management. *Supply Chain Management*, *17*(5), 544–555. https://doi.org/10.1108/13598541211258609

Simpson, T. W. (2004). Product platform design and customization: Status and promise. *Artificial intelligence for engineering design, analysis and manufacturing: AIEDAM*, *18*(1), 3–20. https://doi.org/10.1017/S0890060404040028

Sorensen, D. G. H. (2019). *Developing manufacturing system platforms*. [Doctoral thesis, Aalborg University, Aalborg, Denmark]. https://doi.org/10.13140/RG.2.2.34010.29124

Sorensen, D. G. H., Bossen, J., Bejlegaard, M., Brunoe, T. D., & Nielsen, K. (2018). Production Platform Development Through the Four Loops of Concern. In S. Hammer, K. Nielsen, F. Piller, G. Schuh, & N. Wang (Eds.), *Customization 4.0. Springer Proceedings in Business and Economics* (pp. 479–493). Springer, Cham. https://doi.org/10.1007/978-3-319-77556-2_30

Sorensen, D. G. H., Brunoe, T. D., & Nielsen, K. (2018). Challenges in production and manufacturing systems platform development for changeable manufacturing. *IFIP Advances in Information and Communication Technology*, *535*, 312–319. https://doi.org/10.1007/978-3-319-99704-9_38

Sorensen, D. G. H., ElMaraghy, H. A., Brunoe, T. D., Nielsen, K. (2020). Classification coding of production systems for identification of platform candidates. *CIRP Journal of Manufacturing Science and Technology*, *28*, 144–156. https://doi.org/10.1016/j.cirpj.2019.11.001

Sterman, J. D. (2000). *Business dynamics: Systems thinking and modeling for a complex world*. Irwin McGraw-Hill.

Svensson, L., Brulin, G., Ellström, P.-E., & Widgren, Ö. (2002). *Interaktiv forskning - för utveckling av teori och praktik (in Swedish) [Interactive research – for the development of theory and practice]* (7th ed.). Arebetslivsinstitutet. www.niwl.se

Thuesen, C., & Hvam, L. (2011). Efficient on-site construction: Learning points from a German platform for housing. *Construction Innovation*, *11*(3), 338–355. https://doi.org/10.1108/14714171111149043

Tranfield, D., Denyer, D., & Smart, P. (2003). Towards a methodology for developing evidence-informed management knowledge by means of systematic review. *British Journal of Management*, *14*(3), 207–222. https://doi.org/10.1111/1467-8551.00375

Ulrich, K. (1995). The role of product architecture in the manufacturing firm. *Research Policy*, *24*(3), 419–440. https://doi.org/10.1016/0048-7333(94)00775-3

Ulrich, K., & Eppinger, S. D. (2012). *Product design and development* (5th International ed.). McGraw-Hill Education.

Vetenskapsrådet. (2017). *God forskningssed (in Swedish) [Good research practice]*. Vetenskapsrådet [Swedish research council]. https://www.vr.se/download/18.2412c5311624176023d25b05/1555332112063/God-forskningssed_VR_2017.pdf

Vielhaber, M., & Stoffels, P. (2014). Product development vs. production development. *Procedia CIRP*, *21*, 252–257. https://doi.org/10.1016/j.procir.2014.03.141

Voss, C., Tsikriktsis, N., & Frohlich, M. (2002). Case research in operations management. *International Journal of Operations and Production Management*, *22*(2), 195–219. https://doi.org/10.1108/01443570210414329

Watanabe, C., & Ane, B. K. (2004). Constructing a virtuous cycle of manufacturing agility: Concurrent roles of modularity in improving agility and reducing lead time. *Technovation*, *24*(7), 573–583. https://doi.org/10.1016/S0166-4972(02)00118-9

Wiendahl, H.-P. H., ElMaraghy, H. A., Nyhuis, P., Zäh, M. F., Wiendahl, H.-H., Duffie, N., & Brieke, M. (2007). Changeable manufacturing - Classification, design and operation. *CIRP Annals - Manufacturing Technology*, *56*(2), 783–809. https://doi.org/10.1016/j.cirp.2007.10.003

Williams, C. B., Allen, J. K., Rosen, D. W., & Mistree, F. (2007). Designing platforms for customizable products and processes in markets of non-uniform demand. *Concurrent Engineering Research and Applications*, *15*(2), 201–216. https://doi.org/10.1177/1063293X07079328

Williamson, K. (2002). *Research methods for students, academics and professionals: Information management and systems* (2nd ed.). Woodhead Publishing Ltd.

Wu, B. (1994). *Manufacturing systems design and analysis: Context and techniques* (2nd ed.). Chapman & Hall.

Yin, R. K. (2018). *Case study research and applications: Design and methods*. SAGE Publishing.

Zhang, G., Liu, R., Gong, L., & Huang, Q. (2006). An analytical comparison on cost and performance among DMS, AMS, FMS and RMS. In A. I. Dashchenko, (Ed.), *Reconfigurable manufacturing systems and transformable factories* (pp. 659–673). https://doi.org/10.1007/3-540-29397-3_33

Zhang, L. L. (2015). A literature review on multitype platforming and framework for future research. *International Journal of Production Economics*, *168*, 1–12. https://doi.org/10.1016/j.ijpe.2015.06.004

Zhang, L. L., Jiao, J. R., & Pokharel, S. (2005). Process platform-based production configuration. *International Design Engineering Technical Conferences & Computers and Information in Engineering Conference*, 1–12.

Appendix I

Interview guide Study I

Interview guide for Study I

INTRO

- What is your current position?
- Which department and / or group do you belong to? (Organizational wise?)
- How long have you been employed by the company?
- What does your background look like - education and previous professional experience (within the company / outside the company)?

PRODUCT REALISATION

- What does the product realisation process look like today in practice in your company?
- Do you have a product development model or project management methodology to support the work during product realisation?
- What parts of the product realisation process are you involved in?
- When it comes to the company's product realisation - what are your main challenges linked to requirements for variant management, development times and product life cycles?
- What long-term changes (e.g. new legal requirements, new technology, customer requirements) is it important that you as a company have an ability handle?
- What is required for you to succeed?
- What short-term changes (more or less daily) is it important that you as a company have an ability to handle?
- What is required for you to succeed?
- What top three development areas do you consider to be most important for increased ability to handle change in your area?

PRODUCT AND PRODUCTION DEVELOPMENT

PRODUCT PLATFORMS

- In what way do you reuse technical solutions (systems / components) in different products?
- How do you reuse models (e.g. CAD), engineering methods (e.g. calculations) or knowledge (e.g. design book / guidelines) in the development work?
- What do you do today to ensure / optimize manufacturability in product development?

- What challenges and opportunities do you see regarding your ability to ensure / optimize manufacturability in product development?
- How do you work today to achieve resource efficiency in production preparation (i.e. decide how the product should be produced / machined)?
- What challenges and opportunities do you see regarding your ability to increase resource efficiency in production preparation?

PRODUCTION PLATFORMS

- How do you work in the short, medium and long term with production development?
- Do you work with standards in the production system e.g. for production equipment, processes, working methods?
- Do you work proactively with production development?
- What challenges and opportunities do you see linked to long-term production development?

COMMON PLATFORM ISSUES

- How do you work to utilize knowledge and experience regarding product and production development?
- How do you work with reusing previous knowledge and experience in connection with product and production development?
- Are you familiar with the concept of product platform?
- Are you familiar with the concept of the production platform?
- Do you work with product or production platforms in your company?
- If the company works with both product platforms and production platforms - describe, how do you coordinate the platforms with each other.

INTEGRATION

- How does the company work today with integration between product development and production in connection with the development of new products?

DIGITALIZATION AND AUTOMATION

- Are any parts of the work with product or production development automated (e.g. add-ons in CAD programs that automatically create geometries, drawings or perform calculations based on specifications)?
- Is CAE (Computer Aided Engineering) (such as finite element calculations, flow calculations, process simulation) used today and if so, how?
- Which product data management (PDM) system(s) is/are used in product development and production?

- Do you have any commercial or proprietary software for connecting different engineering tools used for product development and production?
- Is data collected from production? If so, how? How is this data used?

BOUNDARY CROSSING AND BOUNDARY OBJECTS

- Can you describe a time when you have been particularly successful in integration between product development and production in connection with the development of new products.
- What was it that made it particularly successful?
- Can you describe an occasion where the integration between product development and production in connection with the development of new products has been particularly difficult / challenging.
- What was it that made it especially challenging?
- From your perspective, what do you think is required for integration between product development and production in connection with the development of new products to work in the long term?

FINAL QUESTIONS

- Is there anything else you want to address connected to the IDEAL project's issues, in addition to what we have talked about?
- Which people in the company do you think are relevant to talk to in order to create a good picture of your work linked to the IDEAL project's issues?
- Is there any of your projects that you think is particularly interesting for us to delve into?

Appendix 2

Interview guide Study II

Interview guide Study II

INTRO

- How long has the organisation been structured as it is today?
- What caused the organisational change?
- How did the organisational change affect the product realisation process?

PRODUCT AND PRODUCTION DEVELOPMENT

- Is it reasonable to believe that there exist a division into two playing fields of product development and production/production development?
- Regarding the collaboration your team has, what benefits/positive effects does it give you?
- Is it something that has become better and better over time? What could have caused this development?
- Is there anything that has become worse and worse over time? What could have caused this development?
- Are there any challenges that you have had internally on your side of the playing field (product/production) which does not affect the other side that much, but might affect e.g. lead time, rework, or cost negatively?
- Are there certain aspects/perspectives which you often try to argue for, but your counterpart does not understand?
- From your perspective, what is the hardest thing to compromise with in discussion with your counterparts?
- What type of reoccurring issues do you perceive that you have?
- To what degree are these issues connected to your own processes, and to what degree are they connected to the other sides processes?
- I you would think freely, are there any long-term solutions to these issues?
- What objectives are important for Product development/production development?
- Have you identified any conflicting objectives between product development and production development? How do you think these could be managed better?

NEW IDEAS AND INNOVATION

- Regarding new ideas and innovation (new functionality, product features, issues with future product features, new materials, etc.) how are these met by your counterparts?
- Are there any specific occasions during the product realisation process when new ideas arise?

- Do you believe that there is a need to be reserved with certain information, regarding when and what information that could be shared with your counterparts?

LONG-TERM PERSPECTIVE

- When you try address long-term aspects at [COMPANY] such as product/production strategies are any of the previously mentioned issues enhanced? Or do any new issues arise?
- Is there anything that has worsen over time that we have not already covered?
- Is there anything that has improved over time that we have not already covered?

Supporting Long-Term Production Development

Towards Production Platforms

With shrinking product life cycles and increasing competitive pressure, the traditional way of developing production systems is becoming obsolete. A longer-term perspective that considers the stream of product realisation projects to be implemented in the production system over its lifetime is required. Because of the success of different platform strategies in the product domain, platforms in the production domain are deemed a viable avenue for exploration to reach longevity in production capabilities. Therefore, the purpose of this thesis is to support a long-term view of production development through production platforms. This aim is addressed through two research questions (RQs). RQ1 is 'What challenges and enablers exist for long-term production development?' and should identify hindrances and good practices towards reaching long-term production development. RQ2 is 'How can a platform approach support long-term production development?' and describes how a platform approach for long-term production development could be. Four studies were conducted and reported in the four appended papers. The research is based on an interactive research approach with three empirically-based studies and one systematic literature review. The findings indicate that production development is conducted from a short-term perspective. Several challenges were identified regarding long-term production development, as well as the fact that the use of production platforms is not applied in industry. Further, the production platform literature is found to be still rather limited but it has been concluded that production platforms are an approach to describe the production system and its assets to facilitate reuse. Support for achieving long-term production development is presented, including production capability mapping (PCM) support. PCM support enables platform descriptions to be generated and used as a foundation in long-term production development to create a production system that possesses a higher ability to absorb changes.

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