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Management of the industrial- isation process in distributed geographical and organisational contexts

Paraskeva Wlazlak

Doctoral thesis in production systems

Management of the industrial-
isation process in distributed
geographical and organisational
contexts

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Abstract

Management of new product development (NPD) is one of the most critical capabilities of original equipment manufacturers (OEMs). The industrialisation process plays a major role in NPD, where the final verification of the product and production system takes place. It is during the industrialisation process that various disturbances arise; if these are not managed, they can delay the production start and prolong production ramp up.

Based on two dimensions, geographical and organisational distribution, the following four different types of contexts are defined in this thesis: industrialisation in the local and intra-organisational context (type 1), industrialisation in the local and inter-organisational context (type 2), industrialisation in the international and intra-organisational context (type 3) and industrialisation in international and inter-organisational context (type 4). This thesis addresses types 2–4 and contributes to the literature, which has primarily dealt with the type 1 context. The purpose of the research presented in the thesis is expanding the knowledge on the industrialisation process in distributed geographical and/or organisational contexts with a focus on challenges and mechanisms; this will serve to control the challenges during the industrialisation process.

The findings are based on data from three studies in the manufacturing industry, covering both single and multiple case studies. They reveal that there are some similarities between the type 2–4 contexts and challenges and mechanisms previously identified for the type 1 context. However, several unique challenges and mechanisms are found for the type 2–4 contexts. The findings also show that the challenges can be characterised as internal and external. Internal challenges appear in a single industrialisation site and are associated with internal organisational capabilities at the site. External challenges originate from the research and development (R&D) site and the integration between the R&D and industrialisation sites.

The findings also reveal that the identified challenges disrupt the industrialisation process in various ways and create uncertainty and equivocality during the industrialisation process. The studies presented in this thesis show that, to deal with challenges that create uncertainty and equivocality, it is wise to allow ad hoc mechanisms to be used. One of the key conclusions is that when the industrialisation processes are carried out in type 2–4 contexts, there is a need to allow for flexibility regarding the use of mechanisms depending on the dynamics associated with the specific context.

Keywords: new product development, industrialisation, distribution, integration, research and development, manufacturing

Sammanfattning

En av de viktigaste förmågorna hos ett industriföretag är att utveckla nya produkter. En viktig del i detta är arbetet med industrialiseringen, dvs det arbete som berör produktens överflyttning till produktion. Industrialisering är en del av produktsframtagningsprocessen och involverar såväl produktutveckling som produktion. Under industrialiseringsprocessen uppstår ofta olika störningar som kan försena produktionsstarten och förlänga produktionsupprampningen.

Med utgångspunkt i dimensionerna geografisk och organisatorisk distans, industrialiseringen studeras i denna avhandling i olika kontexter: industrialisering i lokal och intraorganisatorisk kontext (typ 1), industrialisering i lokal och interorganisatorisk kontext/ (typ 2), industrialisering i internationell och intraorganisatorisk kontext (typ 3), industrialisering i internationell och interorganisatorisk kontext (typ 4). Avhandlingen fokuserar på typ 2–4 kontexterna och bidrar till tidigare forskning som främst fokuserat på industrialiseringen i typ 1 kontexten. Syftet med denna avhandling är att bidra till ökad kunskap om industrialiseringsprocessen i geografisk och/eller organisatorisk distribuerad kontext med fokus på utmaningar och mekanismer för att hantera dessa utmaningar under industrialiseringsprocessen.

Avhandlingen bygger på data från enskilda och multipla fallstudier inom tillverkningsindustrin. Resultaten visar att det finns några likheter mellan kontexterna av typ 2–4 och de utmaningar och mekanismer som tidigare identifierats för typ 1 kontexten. Flera unika utmaningar och mekanismer för typ 2–4 kontexterna har också identifierats. Resultaten visar dessutom att utmaningarna är av intern och extern karaktär. Interna utmaningar förekommer inom den tillverkande enhet där industrialisering sker och är relaterade till intern organisatorisk förmåga. Externa utmaningar uppkommer inom enheten där forskning och utveckling sker (FoU) eller i integrationen mellan FoU och den tillverkande enhet där industrialisering sker.

Utmaningarna skapar störningar i industrialiseringsprocessen på olika sätt och kan leda till osäkerhet samt tvetydighet under industrialiseringsprocessen. Resultaten visar på behov av att använda ad hoc-mekanismer för att hantera de utmaningar som orsakas av denna osäkerhet och tvetydighet. En central slutsats är därför att när industrialiseringsprocesser genomförs i typ 2–4 kontexter är det nödvändigt att tillåta flexibilitet vad gäller användningen av mekanismer kopplat till den dynamik som finns i respektive kontext.

Nyckelord: produktutveckling, distribuerad, industrialisering, integration, FoU, tillverkning

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Jönköping, June 2019

Paraskeva Wlazlak

List of appended papers

This thesis is based on the publications below. The author contributions are also presented.

Paper 1

Wlazlak, P., Johansson, G. (2014). R&D in Sweden and manufacturing in China: a study of communication challenges. *Journal of Manufacturing Technology Management*, 25 (2), 258–278.

Contribution: Both Wlazlak and Johansson initiated the paper. Wlazlak wrote the paper, and Johansson wrote the case description included in the paper. Wlazlak performed the literature review, data collection and data analysis. Johansson contributed to data collection and quality assurance for the paper.

Paper 2

Wlazlak, P., Johansson, G. (2014). Bridging geographically distant R&D and manufacturing, *R&D Management Conference*, Stuttgart, Germany, 3–6 June 2014.

Contribution: Wlazlak initiated and wrote the paper. Wlazlak performed the literature review, data collection and data analysis. Johansson contributed with data collection, review and quality assurance for the paper. Wlazlak was the corresponding author and presented the conference paper. The paper was selected as one of the 10 candidates for the best paper award of the R&D Management Conference, 2014.

Paper 3

Wlazlak, P., Eriksson, Y., Johansson, G., company representative (2019). Visual representations for communication in geographically distributed new product development projects. *Journal of Engineering Design*. Status: Conditionally accepted for publication.

Contribution: Eriksson and Johansson initiated the paper. Based on improvement suggestions from the editor and reviewers, the initial version of the paper underwent a major revision, where Wlazlak was in charge of re-writing the article according to the suggested improvements. Wlazlak conducted the literature review, data collection and data analysis. Johansson and Eriksson were involved in writing. Johansson performed the review and quality assurance for the paper.

Paper 4

Wlazlak, P., Hilletoft, P., Johansson, G., Säfssten, K. (2019). Managing disturbances during the industrialisation process from a supplier perspective. Status: Submitted to *Journal of Engineering and Technology Management*.

Contribution: Wlazlak initiated and wrote the paper, as well as carrying out the literature review, data collection and data analysis. Hilletoft was involved in data collection. Säfssten reviewed and conducted quality assurance for the paper. Hilletoft and Johansson contributed with improvement suggestions.

Paper 5

Wlazlak, P., Säfssten, K., Hilletoft, P. (2019), Original equipment manufacturer (OEM)–supplier integration to prepare for production ramp-up, *Journal of Manufacturing Technology Management*, 30 (2), 506–530.

Contribution: Wlazlak initiated and wrote the paper, as well as completing the literature review, data collection and data analysis. Säfssten was involved in data collection, as well as conducting the review and quality assurance for the paper. Hilletoft provided comments on the paper's structure.

Paper 6

Wlazlak, P., Säfssten, K., Hilletoft, P., Johansson, G. (2018). Integration of suppliers' workflows in the OEMs' new product development process, *Procedia Manufacturing*, 25, 479–486.

Contribution: Wlazlak initiated and wrote the paper, as well as completing the literature review, data collection and data analysis. Säfssten and Hilletoft were involved in data collection. Säfssten, Hilletoft and Johansson reviewed and conducted quality assurance for the paper.

Additional publications not included in the thesis

Journal article

Ferreira, A., Pimenta, M., Wlazlak, P. (2019). Antecedents of cross-functional integration level and their organizational impact, *Journal of Business and Industrial Marketing*. Status: Accepted for publication.

Thesis

Wlazlak, P., (2016) Integration in global development projects: a study of new product development and production relocation projects, Licentiate Thesis, Jönköping University, Sweden.

Conference articles

Wlazlak, P., Johansson, G., Cederfeldt, M. (2012) A study of the R&D–manufacturing interface in distributed settings: experiences from a Chinese manufacturing site, 5th Swedish Production Symposium (SPS12), Linköping, 6–8 November.

Wlazlak, P., Johansson, G. (2012) Communication challenges in a product development project faced with culture and language differences: the Sweden/China case, R&D Management Conference, Grenoble, 23–25 May.

Wlazlak, P., Johansson, G. (2014). Management of international manufacturing relocation projects of new and existing products. 21st EurOMA Conference, Palermo, Italy, 20–25 June 2014.

Wlazlak, P., Hilletoft, P., Johansson, G., Säfsen, K. (2015), Supplier involvement in product development: critical issues from a supplier perspective. 22nd International Annual EurOMA Conference, Neuchatel, Switzerland (ISBN 978-2-9700901-2-0).

Hilletoft, P., Wlazlak, P., Johansson, G., Säfsen, K. (2015), Challenges with industrialisation in a supply chain network: a supplier perspective, MakeLearn and TIIM International Conference, Bari, Italy (ISSN 2232-3309).

Edh Mirzaei, N., Wlazlak, P., Sansone, C., Hilletoft, P., Löfving, M. (2016), Challenges with competitive manufacturing in high cost environment. 23rd International Annual EurOMA Conference, Trondheim, Norway (ISBN 978-82-303-3277-1).

Ferreira, A., Pimenta, M., Wlazlak, P. (2016). Proposition and validation of a model to measure the level of cross-functional integration between marketing, logistics and production, EnANPAD—Associação Nacional de Pós-Graduação e Pesquisa em Administração, 25–28 September, Costa do Sauípe, Brazil.

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1 Introduction

The introduction chapter is divided into several sub-sections. Section 1.1 presents the background to the research reported in this thesis. It addresses the importance of the industrialisation process and the main problems related to industrialisation carried out in the manufacturing context of today. Section 1.2 is concerned with the current knowledge on industrialisation in various contexts. It also pinpoints the main shortcomings of the prior research on industrialisation in the distributed geographical and/or organisational contexts. Section 1.3 presents the purpose of this thesis and the research questions. Section 1.4 outlines the scope of this thesis, and finally, the thesis outline is presented in section 1.5

1.1 Background

Management of a new product development (NPD) process is one of the most critical capabilities of the original equipment manufacturers (OEMs; Smulders and Dorst, 2007; Kleinsmann and Valkenburg, 2008; Ulrich and Eppinger, 2016). To stay competitive, it is crucial to develop new products with high quality and low cost and to do so in a short time. The industrialisation process plays a major role in this, where the final verification of the product and production system takes place (Johansen, 2005; Javadi, Bruch and Bellgran, 2016; Gustavsson and Säfsten, 2017).

Industrialisation precedes production ramp up (Bellgran and Säfsten, 2010). Inputs to the industrialisation process are the product drawings and specifications, as well as preliminary production plan and tooling/equipment designs (Almgren, 2000; Smulders, 2006; Le Dain, Calvi and Cheriti, 2011). During the industrialisation process, the tooling/equipment is produced and verified, that is, tested and approved, and pilot production is carried out (Säfsten, Fjällström and Berg, 2006). Johansen (2005, p. 3) defines industrialisation as the *‘process of transferring the product design into volume production (...): in effect, it bridges the gap between product design and production in order to adapt the product and the production system to each other’*.

During the industrialisation process, various disturbances arise; if not managed, they can delay the production start and prolong the production ramp up (Almgren, 2000). Therefore, in this thesis, a successful industrialisation process is associated with fewer disturbances, the timely start of production (SOP) and ramping up of production according to plan (Säfsten, Fjällström and Berg, 2006). Production ramp up according to plan includes preliminary

specified targets about product quality, cost and time. For example, engineering design changes during tooling/equipment verification can lead to the production system's inability to ramp up the required volume and quality (Surbier, Alpan and Blanco, 2014). Therefore, the objective of the industrialisation process is identifying and preventing various disturbances and facilitating timely SOP and rapid ramp up to volume production (Li *et al.*, 2014). The time to volume production will affect the product sales price and profitability; it is critical to ramp up quickly to volume production to reduce production costs and ensure return on investment (Almgren, 1999).

The industrialisation process requires collaboration and communication between individuals responsible for the product design activities, here referred to as research and development (R&D) actors; and the individuals responsible for the production system design activities, here referred to as manufacturing actors. This is required because of the interdependencies between the R&D and manufacturing actors' tasks. However, the collaboration may be challenging because these actors come from different organisational functions and have different backgrounds (Säfsen *et al.*, 2006; Berg, 2007). Task conflicts and disagreements caused by the actors' different viewpoints can potentially disrupt the industrialisation process (Vandeveld and van Dierdonck, 2003; Bellgran and Säfsen, 2010). Disagreements often lead to late engineering design changes, complex product designs, quality/tolerance problems and extra tests, which ultimately bring about costlier industrialisation processes (Olausson and Berggren, 2010). From a production point of view, R&D actors' deliverables and inputs (product drawings and specifications) are often insufficient for the production start. However, the R&D actors may think otherwise, perceiving that their inputs are enough for the manufacturing actors to execute their activities and tasks (Smulders, 2006). As Smulders and Dorst (2007) argue, during industrialisation, the willingness of the R&D and manufacturing actors to communicate is often problematic.

The industrialisation process is often executed under time pressure due to fixed product launch dates. It is often the case that, during an NPD process, a great deal of time is devoted to designing a product and verifying its functionality, that is, earlier stages of an NPD process, and hence, less time is left for the subsequent industrialisation process (Berg, 2007). This creates additional problems for the R&D actors, who may need to adjust the product

designs in terms of manufacturability according to the production system (Säfsten *et al.*, 2006; Säfsten *et al.*, 2014).

Responsibilities for industrialising and producing product components and/or sub-systems are often assigned to suppliers. Therefore, they are responsible for ensuring that there is a fit between those components and/or sub-systems design and their production systems. For this reason, the OEM's industrialisation process becomes distributed and integrates the suppliers, which calls for collaboration and frequent communication. In such a case, the R&D and manufacturing actors belong to different organisations, where the R&D actors are part of the OEM and the manufacturing actors belong to the supplier. Thus, the actors need to work not only across their organisational functions but also across organisations (Johansen, 2005; Fliess and Becker, 2006; Le Dain, Calvi and Cheriti, 2011). It has been argued that the distributed organisational context contributes to the complexity of the industrialisation process (Lakemond *et al.*, 2012; Säfsten *et al.*, 2014). The study by Bengtsson and Berggren (2008) indicates that organisational distribution between R&D and manufacturing actors decreases the OEM's in-house manufacturing knowledge, which complicates the transition from the product design to industrialisation process and from industrialisation to volume production.

Due to cost reduction factors, as well as the search for knowledge or capacity, OEMs often locate their production sites abroad, resulting in geographical distribution between the R&D actors and the manufacturing actors responsible for product design and the respective production system design activities (Lakemond *et al.*, 2012). The trend towards location of production abroad is not a new phenomenon, but the geographical distribution between the R&D actors and manufacturing actors continues to be challenging for the OEMs even today. NyTeknik (2014) reports the results of a survey conducted by the consulting company Montell & Partners in collaboration with Chalmers, covering 100 major companies in Sweden, which indicated that the trend towards relocating production for the European market abroad (Asia and Eastern Europe) will continue even during the year 2020. This indicates that the trend towards relocation of production sites abroad is relevant for the OEMs today. The survey further indicated that larger and international OEMs are more willing to move their production. Another survey conducted in 2010–2015 indicated a similar trend, showing that the rate at which companies move their production abroad is double that of moving their production back to Sweden (ArbetsVärlden, 2017; Svensk

Verkstad, 2017). At the same time, companies experience difficulties when locating R&D and manufacturing actors at different sites, especially when there are requirements for short product lifecycles. OEMs struggle with complicated logistics, political risks and cultural and linguistic differences between actors involved in industrialisation (Eriksson *et al.*, 2008). In general, industrialisation is complicated, and companies experience various production start-up disturbances affecting their long-term profitability.

1.2 Industrialisation in a distributed context

Based on the two dimensions of geographical and organisational distribution, four different types of distributed contexts can be defined in which the R&D and manufacturing actors operate (see Figure 1). Here, type 1 represents a context where the actors are in one country and belong to the same organisation, whereas type 2 represents a context where actors are in one country but belong to different organisations. In the type 3 context, the actors are in different countries but belong to the same organisation; finally, type 4 represents a context where the actors are in different countries and belong to different organisations.

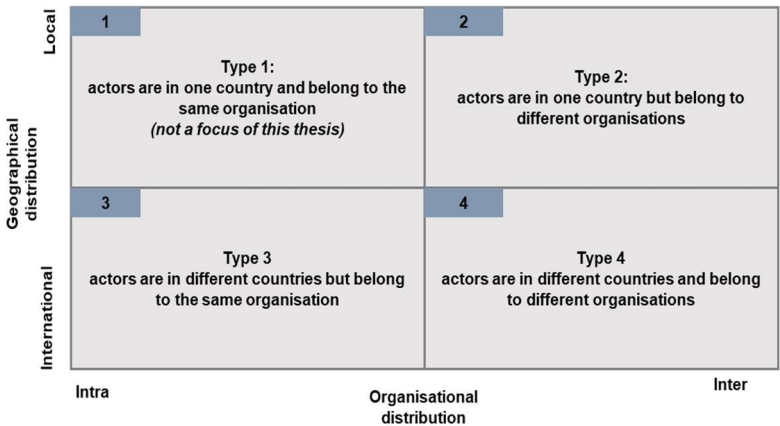


Figure 1 Industrialisation process in different contexts

The industrialisation process has been studied mainly in the type 1 context (see cell 1 in Figure 1). However, the current industrial context is different, and there is a need to expand the studies on the industrialisation process to cover the distributed context. Nevertheless, previous findings in the type 1 context have great implications for research on industrialisation, where the integration between the R&D and manufacturing actors is emphasised (Vandevælde and van Dierdonck, 2003; Smulders, 2006).

The success of the industrialisation process becomes evident during the production ramp up. Disturbances during this phase result from the actors' inability to either identify the source leading to the disturbance or take proactive action to control it (e.g. Almgren, 2000; Fjällström *et al.*, 2009).

In this thesis, the term *challenge* is used to refer to the sources of disturbances during the industrialisation process. A challenge is defined as 'something needing great mental or physical effort in order to be done successfully, or the situation facing this kind of effort' (Cambridge Dictionary, 2019). The term is appropriate for this thesis because it implies the need for an effort to successfully handle a situation and prevent potential disturbances.

In the prior literature, case studies have identified and categorised disturbances that occur prior to and during the production ramp up, thereby negatively affecting its realisation and performance (Terwiesch, Bohn and Chea, 2001; Carrillo and Franza, 2006; Berg, 2007; Winkler, Heins and Nyhuis, 2007; Surbier, Alpan and Blanco, 2009). To facilitate the control of these disturbances, the authors cited above grouped the disturbances into several categories. Fjällström's *et al.* (2009) categories of disturbances are related to the following aspects: (1) the production process (disturbances in the production line, additional work tasks, change of line balancing); (2) suppliers/supply (quality of the incoming material); (3) product/quality (engineering product design changes, too-limited laboratory tests on products before ramp up); and (4) equipment/technique (machine handling), personnel/education (e.g. assembly operators' education and skills, not enough time and too little training of assembly operators) and organisation (project leaders' insufficient skills, unrealistic time plan for the project). In their study Fjällström *et al.* (2009) do not refer to disturbances but to critical events, that are, issues affecting production ramp up in either a positive or negative way. Likewise, Surbier, Alpan and Blanco (2014) summarise the disturbances that arise during production ramp up. These categories are related to the following elements: (1) the product (insufficient product specifications,

product design engineering changes; disturbances arising from late engineering changes); (2) production process (disturbances related to the maturity of the production process, slow setups, manufacturability of the product); (3) supplier/supply (new components introduced in the suppliers' production system; on-time availability and quality of components from suppliers); (4) quality of the end product (maturity of the production process); (5) methods and tools for pilot production and ramp up (inaccurate resource planning); (6) personnel (improper definition of responsibility or lack of qualified personnel); and (7) cooperation and communication (trust problems on received information and information loss between organisational functions). Almgren (2000) categorises the disturbances based on their origins during the pilot production and production ramp up. These origins of the disturbances are related to the product concept, flow of components and material supply, production technology and personnel. The disturbances are engineering design changes, lack of quality and on-time availability of components from suppliers, machine breakdowns or minor machine stoppages and insufficient operator competence and skill levels. In common for all the categories is that they are developed from an OEM perspective, that is, the disturbances arise before and during the OEM's production ramp up. Following the abovementioned authors (Almgren, 2000; Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2009), in this thesis, a disturbance is defined as an event that can negatively affect the success of the industrialisation process. Successful industrialisation process is associated with fewer disturbances, the timely start of production (SOP) and ramping up of production according to plan.

Studies of the industrialisation process in the type 1 context stress the importance of integration of the R&D and manufacturing actors (Swink, 1999; Vandevelde and van Dierdonck, 2003; Dekkers, Chang and Kreutzfeldt, 2013). Well-integrated actors will ensure an industrialisation process with few disturbances (Smulders, 2006). The research on the industrialisation process emphasises the need for various mechanisms to support the collaboration and communication between the actors during the industrialisation process. A palette of mechanisms exists to enhance the product design manufacturability; among other things, this includes frontloading, rapid prototyping and utilisation of manufacturing and assembly guidelines, as well as mechanisms like early involvement of manufacturing actors (e.g. Carlile, 2002; Bechky, 2003; Kleinsmann, Valkenburg and Buijs, 2007; Smulders and Dorst, 2007;

Ulrich and Eppinger, 2016). The earlier the need for engineering design changes is detected, the less costly it is to implement them (Terwiesch and Loch, 1999).

As mentioned above, a shortcoming of the studies on the industrialisation process is their focus on the type 1 context. However, because companies' industrial situation has changed, where the actors involved in the industrialisation process are in different countries and belong to different organisations, there is a need to expand the studies on industrialisation and cover the distributed context. The literature offers poor insight into challenges that companies face when dealing with the distributed context, and therefore, this thesis focusses on the type 2, type 3 and type 4 contexts to study the industrialisation process (cells 2, 3 and 4 in Figure 1).

Facilitating integration between the R&D and manufacturing actors requires paying attention to the fact that the actors belong not only to different organisational functions but also to different organisations (see cell 2 in Figure 1). The literature would benefit from studies on the challenges the actors from the suppliers face when carrying out industrialisation processes according to OEM's technical specifications (Johansen, 2005).

Prior studies of the distributed organisational context can be found in the literature on supplier integration in NPD. A few studies from this research stream have discussed the aspects of the industrialisation process at the organisational level, often with a focus on inter-organisational integration (Twigg, 2002; Johansen, 2005; Fliess and Becker, 2006). Twigg (2002), for example, develops a typology of mechanisms that supports inter-organisational integration. In terms of industrialisation, it is suggested to use four groups of mechanisms, which are as follows: (1) standards (e.g. R&D's tacit knowledge of manufacturing), (2) schedules and plans (e.g. signoff, production prototypes), (3) mutual adjustment (e.g. producibility design reviews, producibility/manufacturing engineer, guest design engineer, site engineer) and (4) teams (e.g. transition team). However, most of the research in the area of supplier integration in NPD is focussed on inter-organisational integration during collaborative design that is primarily concerned with product design activities (Le Dain, Calvi and Cheriti, 2011). The focus in the literature on supplier integration in NPD is not on how to achieve a successful industrialisation process, but rather, questions regarding overall product development performance (Wynstra, Van Weele and Weggemann, 2001). However, the literature on supplier integration in NPD provides valuable

insights into what challenges may exist when actors from the OEM and supplier need to work on an NPD process, and potentially, what mechanisms are used to control these challenges.

Another shortcoming of the prior research is the limited studies on industrialisation in the distributed geographical context (see cell 3, Figure 1). It is clear from the prior research that communication tends to drop between the R&D actors and actors from other organisational functions when the geographical distribution increases (Allen, Tomlin and Hauptman, 2008). Prior research has related geographical distribution to physical distance (e.g. different time zones, lack of face-to-face meetings) and heavy reliance on technology mediation (e.g. e-mails, teleconferencing, messaging system) for communication (Ceci and Prencipe, 2013; Hansen, Zhang and Ahmed-Kristensen, 2013; Säfsten *et al.*, 2014). Challenges like the lack of shared context, heterogeneity (i.e. actors with diverse culture, education, experience or work norms), familiarity between sites and friendship potentially disrupt the communication and mutual understanding between actors in an NPD project (Kleinsmann and Valkenburg, 2008; Eris, Martelaro and Badke-Schaub, 2014). Moreover, because of the geographical distribution challenges are related to lack of facial expression, vocal inflections, and gestures (Bergiel, Bergiel and Balsmeier, 2008). Research dealing with communication in the geographically distributed context has made an important contribution to understanding the potential challenges with which R&D and manufacturing actors are faced when executing NPD activities. However, there is a lack of focus on the industrialisation process in these studies. Therefore, there is a need to gain more insights into the challenges and resulting disturbances during the industrialisation process in a distributed geographical context.

To summarise, there is a need for more studies of industrialisation in distributed organisational and/or geographical contexts (cells 2 and 3, Figure 1). Furthermore, both dimensions of distribution—organisational and geographical—have rarely been included in a single study. Therefore, there are merits to incorporating both dimensions of distribution in this thesis (cell 4 in Figure 1). It is likely that new mechanisms are needed to deal with the distributed context and establish the required level of integration between the R&D and manufacturing actors in terms of the industrialisation process. In accordance with the outlined shortcomings of the prior research on industrialisation, the purpose of this thesis is formulated below.

1.3 Purpose and research questions

The purpose of the research presented in this thesis is to expand the knowledge on the industrialisation process in distributed geographical and/or organisational contexts, with a focus on challenges and mechanisms to control them during industrialisation. To fulfil the purpose, the thesis focusses on the research questions (RQs) given below.

RQ1: Which challenges related to the distributed context disrupt the industrialisation process?

Answering RQ1 requires investigation of which challenges are faced by actors that can result in disturbances during the industrialisation process. A challenge is defined as the source of disturbance during industrialisation, and it requires effort to be managed. The answer to RQ1 requires investigation of the challenges in the three contexts presented in Figure 1, which are as follows: type 2, the industrialisation process in the distributed organisational context; type 3, the industrialisation process in the distributed geographical context; and type 4, the industrialisation process in the distributed geographical and organisational context.

RQ2: How do challenges related to the distributed context disrupt the industrialisation process?

Addressing RQ2 requires investigation of the types of disturbances that result from the challenges associated with the distributed context. A disturbance is defined as an event that negatively affects the success of the industrialisation process. Success is associated with fewer disturbances, the timely start of production (SOP) and ramping up of production according to plan. The answer to RQ2 requires investigation of the types of disturbances in the three contexts presented in Figure 1 (types 2, 3 and 4).

RQ3: How can different mechanisms be used to control the challenges?

RQ3 takes the research one step further by outlining mechanisms that can be used to control the challenges to prevent disturbances from arising during the industrialisation process. Such mechanisms are important for proactively managing industrialisation. Mechanisms are important to support collaboration and communication between actors during the process. Likewise, the answer to RQ3 requires investigation of the mechanisms in the three contexts presented in Figure 1 (types 2, 3 and 4).

1.4 Scope and delimitations

The scope of this thesis is an industrialisation process in distributed geographical and/or organisational contexts, with a focus on challenges and mechanisms to control the challenges during industrialisation. This thesis centres on the manufacturing industry, where organisational and geographical distribution during NPD projects is a common practice. The work focusses on the industrialisation process in three different types of context. A type 2 context refers to the industrialisation process in a distributed organisation, where the R&D and manufacturing actors are in one country but belong to different organisations. A type 3 context refers to the industrialisation process in a distributed geographical area, where the R&D and manufacturing actors are in different countries but belong to the same organisation. Finally, a type 4 context refers to the industrialisation process in distributed geographical and organisational context, where the R&D and manufacturing actors are in different countries and belong to different organisations. This thesis excludes the type 1 context, which refers to the industrialisation process in traditional context, where the R&D and manufacturing actors are in one country and belong to the same organisation; this context has been extensively studied in the prior literature, and hence, is not a focus here.

The industrialisation processes studied in this thesis include a certain degree of product/component and production system newness. The three studies presented in this thesis include new products or components where they are either industrialised internally at a relocated production site or the responsibility for the industrialisation of the new component/sub-system has been given to a supplier. The type of suppliers included comprises manufacturing suppliers responsible for the industrialisation processes of components/sub-systems according to the OEM's technical specifications. Suppliers that are involved in the OEM's component design during the early NPD process are excluded from this thesis. One of the studies from this thesis covers geographical distribution between the R&D actors and manufacturing actors. The countries involved in the study are Sweden and China. Other countries have not been included in this work.

The topic of industrialisation is covered in two literature streams, namely, NPD literature and manufacturing engineering literature. Both are discussed in this thesis. Because the research topic is interdisciplinary, establishing boundaries and limitations for the included literature is difficult.

When the focus is on the industrialisation process, the communication and collaboration between the R&D and manufacturing actors is stressed. The literature on boundary crossing contributes to understanding mechanisms necessary to support communication and collaboration between the R&D and manufacturing actors. From a boundary-crossing perspective, R&D and manufacturing actors come from two different organisational functions, which are two boundaries created by the differences in actors' backgrounds and experiences. For the success of an industrialisation process, these boundaries need to be crossed. This thesis does not focus on the boundaries created as a result of the different organisational functions between the actors. Rather, the focus is on the boundaries created from the organisational and geographical distribution between the actors. Finally, this thesis excludes any statistical attempt to define, discuss or predict the probability of any challenges or disturbances that occur during the industrialisation process.

1.5 Thesis outline

This thesis comprises six chapters. The content of each chapter is briefly presented below.

Chapter 1
Introduction

This chapter presents the background of the research area, followed by the main shortcoming of the prior research. Then, the purpose and research questions are presented. The chapter ends with an outline of the scope of the thesis.

Chapter 2
The industrialisation process

This chapter presents prior research on the industrialisation process. It is structured according to the industrialisation process in the different contexts, namely, the distributed contexts of types 1, 2, 3 and 4.

Chapter 3
Research design and methodology

In this chapter, the research design is introduced, presenting three separate studies. The criteria for validity and reliability in each study are discussed.

Chapter 4
Findings from the appended papers

This chapter presents a short overview of the appended papers. It further introduces the empirical findings from the three studies. The findings are related to the six appended papers of this thesis.

Chapter 5
Discussion

This chapter relates the main empirical findings to prior literature. It also includes reflection on the method chosen.

Chapter 6
Conclusions

The main conclusions are presented, followed by recommendations for future research. It outlines the theoretical contribution and managerial implications.

2 The industrialisation process

In this chapter, previous research related to industrialisation processes in distributed contexts is presented and summarised as a foundation for empirical study in this thesis. After the general introductory section on the industrialisation process, the next sections are structured according to the different contexts of industrialisation, illustrated in Figure 1 and presented in section 1.2. For each context, gaps in the prior research are pointed out.

The industrialisation process is positioned in both the NPD literature (Clark and Fujimoto, 1991; Le Dain, Calvi and Cheriti, 2011; Gustavsson and Säfssten, 2017) and manufacturing engineering literature (Almgren, 1999; Säfssten *et al.*, 2006; Bellgran and Säfssten, 2010). The NPD literature is primarily concerned with the overall performance of the NPD process (Ulrich and Eppinger, 2016) and not specifically with factors that affect and methods that improve the industrialisation process performance. However, the integration of actors from various organisational functions, such as R&D, manufacturing and marketing while executing parallel activities, is emphasised in the NPD literature (Krishnan and Ulrich, 2001). The industrialisation process is also discussed in the manufacturing engineering literature (Almgren, 1999; Bellgran and Säfssten, 2010). This literature is concerned with the negative effect of the incomplete product specifications and the resulting late engineering design changes (Terwiesch and Loch, 1999; Almgren, 2000). Engineering design changes that take place during the industrialisation process are likely to result in increased costs and reduced yields. Therefore, the manufacturing engineering literature stresses the avoidance of late engineering design changes through early involvement of the manufacturing actors in the product design decisions (Säfssten *et al.*, 2006).

Industrialisation—and the synonymous term, new product introduction—is defined differently by researchers. Some researchers refer to the industrialisation process as the transfer of a product from design to production, including all the activities necessary to prepare product and production systems for production in the required volumes (Johansen, 2005; Bellgran and Säfssten, 2010). Other researchers relate the industrialisation process to the overall NPD process and specify which stages and what activities of NPD are covered in industrialisation. However, the stages and activities described differ between the researchers. Often, it is the case that researchers use

different terminology to describe similar activities included in the industrialisation process. Table 1 presents the description of the activities included in the industrialisation process as defined by various researchers.

Table 1 Activities Included in the Industrialisation Process

Activities	References
Product and production system design	Juering and Milling (2005)
Production ramp up	
Product and production system design	Winkler, Heins and Nyhuis (2007)
Preparation	
Production ramp up	Berg (2007)
Test production	
Pilot production	
Production ramp up	Fjällström <i>et al.</i> (2009)
Product and production system design	
Product test and refinement	
Final verification	
Pilot production	Almgren (2000)
Production ramp up	
Product and production system design	Javadi, Bruch and Bellgran (2016)
Product test and refinement	
Pilot production	
Pre-series production	
Production ramp up	

The industrialisation process can be defined as the parallel design of product and production systems, as well as the realisation and adaptation of product and production systems to each other (Winkler, Heins and Nyhuis, 2007; Javadi, Bruch and Bellgran, 2016). In an ideal situation, the product and production system are designed in parallel and gradually adapted to each other. The aim is that, at the production start, the product and production system are fully adapted to each other (Säfsten *et al.*, 2006). Some researchers include the production ramp up as a part of the industrialisation process, arguing that adaption of the product and production system continues even during the final stage of the NPD process (e.g. Javadi, Bruch and Bellgran, 2016). Others (e.g. Almgren, 2000; Carrillo and Franza, 2006; Säfsten *et al.*, 2006) argue that the production ramp up is not included in the industrialisation process. According to these researchers, the industrialisation process concludes with the SOP where the products reach the market (Wheelwright and Clark, 1992). After the SOP, the production ramp up commences, where the volume of production increases gradually until predefined goals are met

(Surbier, Alpan and Blanco, 2014). In other words, the industrialisation process is perceived as a prerequisite for quick ramp up to volume production (Bellgran and Säfssten, 2010).

Some researchers (e.g. Fliess and Becker, 2006; Le Dain, Calvi and Cheriti, 2011) define the industrialisation process as a separate stage of NPD, and they do not include, for example, the product and production system design. The output of the product and production system design is perceived as input for the industrialisation process. Figure 2 represents the industrialisation process as the third stage of the overall NPD process. This thesis follows the description of the industrialisation process and its relationship with the NPD process presented below.

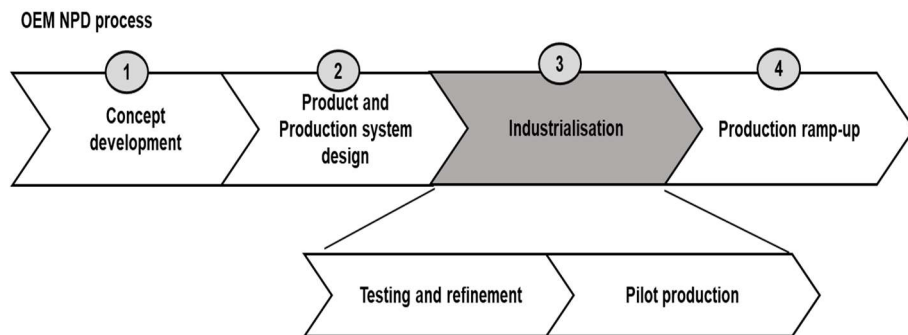


Figure 2 Industrialisation process as a part of the NPD process (modified from Le Dain, Calvi and Cheriti, 2011).

During the concept development (stage 1) and product and production system design (stage 2) of the NPD process, development of a new product or modification of an existing one takes place. During stage 2, the product and production system are designed in parallel; therefore, cross-functional teams are typically used. These teams allow for product design with consideration of the manufacturing capabilities and constraints (Johansen, 2005; Winkler, Heins and Nyhuis, 2007).

In the prior research on integration between the R&D and manufacturing actors, techniques associated with design for manufacture (DFM) and design for assembly (DFA), rapid prototyping, or concurrent engineering (CE), to name a few, are used (Dean and Susman, 1989; Adler, 1995; Swink, 1999). These techniques are important for ensuring the fit between the product and production system during stage 2, before entering the industrialisation process. The R&D actors need to be aware of capabilities and constraints of a

production process when designing and engineering a new product. To do this, the manufacturing input is consolidated in various guidelines, tools or algorithms. The DFM and DFA literature promote, for example, the use of the following: (1) reviews for assessment of product manufacturability; (2) guidelines for the R&D actors to follow during product design for a specific manufacturing process; and (3) general guidelines, such as standardisation of parts, reduction of the number of parts or maximisation of easy assembly operations (e.g. Dean and Susman, 1989; Boothroyd, Dewherst and Knight, 2002).

CE promotes parallel design of product and production systems in a cross-functional, integrated way. The main idea is integrating many upstream and downstream stages of the development process and bringing in many downstream considerations as early as possible in early decision making (Clark and Fujimoto, 1991). The concurrent way of working implies that the R&D actors and manufacturing actors, regardless of organisational belongings, are interdependent to the degree where each is constrained by the decisions and activities of the other party. Research acknowledges such interdependency, showing that the later this interdependency is dealt with, the costlier the consequences related to modifications of a component and manufacturing are; an example is engineering design changes during the industrialisation process (stage 3). This is why early release of information through early integration of the manufacturing actors in stages 1 and 2 of the NPD process is recommended (e.g. Maffin and Braiden, 2001; Humphreys *et al.*, 2007).

Wheelwright and Clark (1994) describe four modes of integration between the R&D and manufacturing actors, namely, serial mode, early start in the dark, early involvement and integrated problem solving. *Serial mode* means that the manufacturing actors do not start with their work until the R&D actors have completed their tasks. *Early start in the dark* links the actors at an early point in time but continues to employ batch-like communication, where the manufacturing actors obtain information when the task is completed. In the *early involvement* mode, the R&D and manufacturing actors are engaged in two-way communication of preliminary information, but the sequence of work between them is still evident. *Integrated problem solving* includes the establishment of an ongoing dialogue that supports the manufacturing to reach a running start in their work. This mode links the upstream and downstream

activities in terms of time, and it includes rich, mutual and intense communication and effective integration between the actors.

The output of stage 2 is the product specifications and specification for the subsequent industrialisation process (stage 3; Smulders, 2006). The industrialisation process is concerned with the preparation process for volume production involving detailed design and verification of the production methods and processes, production equipment tests and test equipment (Säfsen *et al.*, 2006). An important part of the industrialisation process is building and testing of prototypes that aim at verification of the product, as well as the production system. The purpose with the industrialisation process is product and production system verification (Le Dain, Calvi and Cheriti, 2011).

The industrialisation process covers several steps that are necessary for realising the product and production concepts in accordance with the specifications defined in stage 2. The steps included in the industrialisation process, as defined by some researchers, are testing and refinement and pilot production (Almgren, 1999; Säfsen *et al.*, 2006).

During the testing and refinement step, product design testing and refinement takes place, where the functionality of the product is tested with the help of engineering prototypes (Säfsen *et al.*, 2006). Engineering prototypes are used for verification of technological and functional solutions in the product design (Johansen, 2005). Prototypes can be used for verifying the fit of components in the product and the product manufacturability (Ulrich and Eppinger, 2016). In this stage, the parallel development and adaptation of the product and the production system continues, where design reviews emphasise mechanisms for ensuring integration between the R&D and manufacturing actors (Adler, 1995). Requiring feedback from the manufacturing actors on the engineering prototypes is important for discovering nonconformities between the product and production system (Lakemond *et al.*, 2007). Access to the engineering prototypes will facilitate the development of detailed production plants, including the time, sequences and instructions of production and assembly processes by the manufacturing actors (Bellgran and Säfsen, 2010; Ulrich and Eppinger, 2016).

The pilot production aims at verification and refinement of the production system (Almgren, 1999), as well as rehearsal of the volume production (Clark and Fujimoto, 1991). Pilot production, also referred to as factory prototypes, is used to validate the product adaptability with the final production process

(Johansen, 2005). During the pilot production, the first products are produced in the intended production system. The components should be made with the production equipment and assembled in a serial-like assembly line (Säfssten *et al.*, 2006). During the pilot production, products are built for internal customers, for example, for testing and marketing. Another purpose of pilot production can be to familiarise the assembly personnel with the product and production system (Terwiesch, Bohn and Chea, 2001). Pilot production is an opportunity for testing the product and production system under serial-like conditions, before the start of volume production. Adjustments in the product or production system are made to ensure the fit. After the industrialisation concludes, the production start and ramp up of production commence (Säfssten *et al.*, 2006). According to Le Dain, Calvi and Cheriti (2011), this is a separate stage of the NPD process (stage 4).

2.1 Industrialisation in the type 1 context

2.1.1 *Uncertainty and equivocality*

In the literature, it is argued that the NPD process is characterised by uncertainty and equivocality (Frishammar, 2005; Frishammar, Floren and Wincent, 2010). The NPD process aims at the reduction of uncertainty and equivocality from the concept development until the product reaches the market and is produced in the required volumes. This implies that, as a part of the NPD process, industrialisation is also characterised by uncertainty and equivocality.

Uncertainty is defined as *'the difference between the amount of information required to perform a particular task and the amount of information already possessed by the individual'* (Galbraith, 1973, p. 5). Uncertainty may be triggered by the novelty of the product or technology under development, novelty of a production system or novelty of the market (Wheelwright and Clark, 1992; Tatikonda and Rosenthal, 2000; Song and Montoya-Weiss, 2001); demand fluctuations (Lawrence and Lorsch, 1986); or changes in the customers' requirements (Wheelwright and Clark, 1992; Säfssten *et al.*, 2014). Moreover, the complexity of the product and production system (e.g. number of components in the system; Wheelwright and Clark, 1992; Novak and Eppinger, 2001; Koufteros, Vickery and Dröge, 2012), organisational complexity or involvement of multiple actors in simultaneous effort can lead to uncertainty (Baccarini, 1996; Griffin, 1997; Von Corswant and Tunälrv, 2002). Nightingale (2000) argues that, to avoid failures, complex

product development needs to be considered as different than less complex product development. Tatikonda and Rosenthal (2000) link the level of uncertainty with the notion of radical and incremental innovation. Uncertainty is further associated with the inability to predict future outcomes (Shenhar and Dvir, 1996). Uncertainty is connected not only to the unknown outcome of a situation but also the inability to predict the probability of different outcomes (Knight, 1933).

Some authors (e.g. Daft, Lengel and Trevino, 1987; Frishammar, Floren and Wincent, 2010) argue that not only uncertainty but also equivocality characterises the NPD process. Equivocality is associated with unclear, messy and ambiguous situations in which actors tend to interpret information differently (Daft and Lengel, 1986). Triggers of equivocal situations, for example, are differences in terms of education, experiences and background between the actors (Frishammar and Hörte, 2005; Koufteros, Vonderembse and Jayaram, 2005). The actors' functional specialisation and experience are likely to lead to different perspectives on the work and organisation, and hence, actors from different organisational functions develop local understandings (Dougherty, 1992; Kleinsmann and Valkenburg, 2008). Bechky (2003) demonstrates that the establishment of a shared understanding between actors involved in the industrialisation process is difficult due to the work context (i.e. distinct languages, conceptualisations of the product and processes). When faced with a problem, actors from different functions typically bring different understandings of the problem. For example, R&D actors—referred to as engineers in Bechky's (2003) study—have an understanding based on the conceptual context of their drawings, while manufacturing actors—referred to as assemblers in Bechky's (2003) study—have an understanding based on the concrete work of building machines.

Unlike uncertainty, which is associated with a lack of information, equivocality is concerned with confusion and different understandings between actors (Weick, 1995). Equivocality may not only be related to different understandings between actors about what the solution may be but also a lack of understanding of what the problem is. More recent research has suggested that the establishment of a shared understanding between actors from various organisational functions is still problematic (Goldschmidt, 2007; Kleinsmann, Valkenburg and Buijs, 2007; Cash, Dekoninck and Ahmed-Kristensen, 2017).

Uncertainty reduction is associated with acquiring additional information that may assist in predicting future outcomes and making decisions (Downey and Slocum, 1975). It is the gap between the current and required information that needs to be closed through acquiring additional information. A conclusion from the prior research is that reductions of uncertainty and equivocality differ (Schrader, Riggs and Smith, 1993). Unlike uncertainty reduction, which calls for acquisition of additional, objective information, equivocality reduction requires the exchange of subjective information between actors (Daft and Lengel, 1986). It is associated with defining the problem and overcoming disagreements, which in turn, allows for the development of a similar judgement of a situation (Daft, Lengel and Trevino, 1987). Likewise, Schrader, Riggs and Smith (1993) explain that equivocality reduction requires constructing and evaluating models to define the problem, leading to clarity. Instead of reducing equivocality, additional information may lead to the increase of equivocality (Daft and Weick, 1984; Weick, 1995).

If uncertainty and equivocality are not reduced, there is an increased risk of time delays and waste of resources during the NPD process. Although equivocality is an equally important characteristic of the NPD process, so far, the emphasis in the prior research has been on the uncertainty construct (Daft and Lengel, 1986; Souder, Sherman and Davies-Cooper, 1998; Brun and Sætre, 2009). The two constructions of uncertainty and equivocality have not been studied in terms of the industrialisation process.

2.1.2 Integration between actors

Daft and Lengel (1986) propose a framework that includes both constructs of the NPD process—uncertainty and equivocality—as two forces that influence the information processing of an organisation. Tushman and Nadler (1978) argue that there must be a match between the information processing requirements of the organisation and the information processing capabilities. Thus, organisations need to develop these information-processing capabilities. The more complex and interdependent the tasks are, the more information needs to be processed (Tushman and Nadler, 1978).

Reduction of uncertainty and equivocality is associated with the need for the integration and establishment of various mechanisms to achieve a state of integration between the actors during the NPD process. Lawrence and Lorsch (1986, p. 11) argue that integration is *‘the quality of the state of collaboration that exists among departments that are required to achieve unity of effort by*

the demands of the environment'. Hence, integration has been defined as the state of relationships between actors that belong to different organisational functions. In contrast, researchers have more recently referred to integration as the process and mechanisms by which this state is achieved (Adler, 1995; Koufteros, Vonderembse and Jayaram, 2005; Olausson, Magnusson and Lakemond, 2009). This thesis makes use of the definition provided by Vandevelde, van Dierdonck and Clarysse (2002, p.6), where integration is defined as an '*interaction process involving information exchange on the one hand and collaboration or cooperation on the other hand*'. Integration only in terms of information exchange has been criticised by scholars, who have argued that frequent information exchange does not guarantee the use of that information and emphasised the need for collaboration. Collaboration is perceived as important for the alignment of actors from various organisational functions that work together, share resources and achieve '*collective goals*' (Kahn, 1996, p. 139).

According to Adler (1995), the novelty level of the product and production system (i.e. degree of change in the product design and production system) defines the complexity the R&D and manufacturing actors need to deal with during the NPD process. A completely new product introduced in a new production system implies the highest complexity, whereas a modified product introduced in a modified production system implies less complexity during the industrialisation and production ramp up (Almgren, 1999). The need for integration varies with the nature of the NPD process. A more complex and uncertain situation calls for higher levels of integration (Säfsen *et al.*, 2014).

Wheelwright and Clark's (1992) research indicates that, when the degree of product/production system novelty increases, the integration between the R&D actors, the manufacturing actors and purchasing actors needs to include both formal (e.g. flows of standard documentation) and informal mechanisms. Adler (1995) hypothesises that a higher degree of integration, that is, mutual adjustments and teams, is more appropriate for novel product/production system fit and difficult to analyse product/production system fit problems. In contrast, low novelty and easy-to-analyse problems require integration between the R&D and manufacturing actors via standards, schedules and plans. According to Lakemond *et al.* (2012), these two hypotheses do not consider important factors related to complexity, which increases as a result

of geographical and organisational distribution between the R&D and manufacturing actors.

Mechanisms for facilitating integration and reducing uncertainty and equivocality are proposed by Galbraith (1973), Tushman and Nadler (1978) and Daft and Lengel (1986). Mechanisms that integrate actors from various organisational functions have been discussed as having varying capacities to process information, and hence, their advantages and disadvantages differ. Some mechanisms are suitable for handling large amounts of information, while others encourage information richness. Hence, during the NPD process, the mechanisms can assist actors who may suffer from a lack of information or interpret information differently in taking decisions. Typical mechanisms discussed are as follows: (1) group meetings, which may encourage information richness as they enable discussions and exchange of opinions; (2) integrators (e.g. liaison staff and integrative departments), which are suitable for reduction of disagreements; (3) lateral and informal relations, for example, through visits, are important for personal contact; (4) schedules and plans are appropriate for guidance of activities and actions of various functions; (5) special reports are necessary for obtaining objective information, and hence, reducing information gaps; (6) formal information systems, which include rapid exchange of information through, for example, computer databases; and (7) formalisation and standardisation through policies, rules or standard procedures (Tushman and Nadler, 1978; Daft and Lengel, 1986).

The media used by the actors as mechanisms to process information varies in their capacity to either exchange a great amount of information or allow for processing of rich information. In situations with high levels of equivocality, media should allow for processing of rich information, that is '*the ability of information to change understanding within a time interval*' (Daft and Lengel, 1986, p. 560). There are four dimensions that define the richness of media, which are as follows: (1) instant feedback; (2) transmission of multiple cues, that is, the number of ways information can be communicated—text, physical presence, verbal cues, voice inflection and nonverbal cues (gestures); (3) language variety, which includes a range of meanings that can be conveyed with language symbols; and (4) personal focus, which includes the possibility of adjusting the message in accordance with the current needs and situations of the receiver. In general, rich media allow the sender and receiver to reach an understanding more quickly, while less rich media (leaner media) are suitable for less equivocal tasks. According to the continuum of media

richness developed by Daft, Lengel and Trevino (1987), the richest media are face-to-face communication, followed by telephone communication, written addressed documents and unaddressed documents. Synchronous, face-to-face communication allows for instant feedback and multiple cues, in which the message can be adjusted instantly. It is considered that less rich media are appropriate for the processing of well-understood messages and information, since they involve cues and restrict immediate feedback (Bruch, 2012).

As described above, the integration between actors during NPD is important. When the focus is on the industrialisation process, the integration between the R&D and manufacturing actors is stressed (Vandeveldel and van Dierdonck, 2003; Lakemond *et al.*, 2013; Rosell, Lakemond and Wasti, 2014). The literature on boundary crossing contributes to the understanding of the need for integration, and various mechanisms are recommended to integrate the R&D and manufacturing actors (Gustavsson and Säfsten, 2017). The boundary-crossing literature perceives the R&D and manufacturing organisational functions as two boundaries created by the differences in the actors' backgrounds and experiences. For the success of the industrialisation process, the boundaries need to be crossed (Carlile, 2002; Bechky, 2003). The boundary-crossing literature targets the work relationships, in which the R&D and manufacturing actors (who belong to different boundaries) need to collaborate, such as the context of the industrialisation process. The literature on boundary crossing distinguishes diverse mechanisms that can be used to cross the boundaries around the R&D and manufacturing actors. Boundary spanners and boundary objects are two common types of mechanisms that can be used to cross boundaries. Below, these two types of mechanisms are explained, and some examples for the industrialisation process are provided.

Boundary objects have different capacities, and hence, their effectiveness is defined by the context and level of novelty that exists between the boundaries (e.g. Carlile, 2002; Gustavsson and Säfsten, 2017). According to Carlile (2004) when a syntax is shared and stable (the meaning of a word is shared between actors from different boundaries), there is a need for boundary objects, such as repositories. These boundary objects are enough since the differences (actors' specialisation), and their dependencies (dependencies between the actors' tasks and activities) are specified and agreed on in advance.

Boundary objects have a further capacity to reconcile different meanings between the R&D and manufacturing actors, when a message can mean

different things to the receiver and sender (Dougherty, 1992; Bechky, 2003; Majchrzak, More and Faraj, 2012). In such a context, the boundary objects need to provide a concrete means for translating and learning about the differences in kind and dependencies between actors that belong to different boundaries (Carlile, 2002; Carlile, 2004). The nature of a problem that requires crossing of boundaries defines what is adequate concreteness for a given boundary-crossing object. Examples of boundary objects to deal with such boundaries are standardised formats and methods, such as engineering change formats like design failure mode and effect analysis (D-FMEA) and process failure mode and effect analysis (P-FMEA). These are shared formats for solving problems, where the structure and language are mutually understood. Other boundary objects are sketches, drawings, prototypes porotypes or simulations (Carlile, 2002; Bechky, 2003; Boujut and Blanco, 2003). Prototypes are discussed as boundary objects between the R&D and manufacturing actors with various purposes during the industrialisation process (Gustavsson and Säfsten, 2017). In the boundary-crossing literature, prototypes are perceived as concrete objects that specify the relationships among parts and dependencies among functions. It is argued that tangibility of the physical parts allows for an easy specifying of the differences and dependencies. Maps, including Gantt charts, process maps and workflow matrices, are also helpful in clarifying differences and dependencies between members engaged in problem-solving efforts that share resources, deadlines and deliverables (Carlile, 2004).

Boundary spanners are individuals used to share expertise between actors from different organisations (Twigg, 2002), organisational functions, hierarchy levels or multiple sites (Levina and Vaast, 2005), as well as for resolving conflicts between actors from different cultures (Di Marco *et al.*, 2010). An example of boundary spanners in the industrialisation process is the involvement of manufacturing engineers in the cross-functional team to provide input on manufacturability issues (Gustavsson and Säfsten, 2017). In terms of industrialisation, Bechky's (2003) study addresses the role of the boundary spanner (technician) to overcome misunderstandings between the R&D and manufacturing actors. The boundary spanner's role is perceived as important for development common ground, which is associated with the re-contextualisation of local understanding of the R&D and manufacturing actors. It is argued that, in practice, it is difficult to find actors performing the role of boundary spanners since they need to be sensitive to social cues and

have competence in multiple domains. Levina and Vaast (2005) distinguish between nominated boundary spanners (i.e. actors officially assigned the role) and boundary spanners in practice (i.e. actors who act as boundary spanners between various organisational functions with or without nominations). Levina and Vaast (2005) further outline three factors that contribute to an actor becoming a boundary spanner in practice, which are as follows: (1) being a legitimate participant in the two organisational functions (or boundaries), that is, having some understanding of both boundaries; (2) being a legitimate negotiator, that is, being trusted as capable of spanning a boundary; and (3) being inclined to span the boundaries.

The prior research on boundary crossing suggests that objects and maps not only have the capacity to translate different meanings between the R&D and manufacturing actors, but they can also negotiate interests and make trade offs between the actors (Brown and Duguid, 2001; Boujut and Blanco, 2003). The process of negotiation requires constant explanation of the choices that the R&D actors make or design modifications they propose. The negotiation gradually leads to a common understanding of the product design and creates a common background for all participants. According to Gustavsson and Säfsten (2017), the establishment of integration between the R&D and manufacturing actors during the industrialisation process is still challenging.

2.2 Industrialisation in a distributed context

Suppliers (located nationally or internationally) are assigned and take responsibilities for the industrialisation processes of product components and/or sub-systems owned by the OEM (Johansen, 2005). These suppliers are responsible for production preparations of the components/sub-systems according to predefined specifications and volume requirements. Therefore, the industrialisation process becomes distributed, where the integration between the OEM and suppliers is important (Lakemond *et al.*, 2012). The distributed context implies increased complexity between the R&D actors (who belong to the OEM) and manufacturing actors (who belong to the supplier) during the industrialisation process. Facilitating integration between the R&D and manufacturing actors requires paying attention to the fact that the actors belong not only to different organisational functions but also to different organisations (Lakemond *et al.*, 2012; Säfsten *et al.*, 2014; Gustavsson and Säfsten, 2017).

Suppliers may face difficulties when performing the industrialisation process and fail to deliver on time and with sufficient quality to the OEM pilot production and production ramp up (Almgren, 2000; Fjällström *et al.*, 2009). In a study involving Siemens in France, issues related to components represent 55.1% of the identified problems during the OEM production ramp up (Surbier, Alpan and Blanco, 2009). This indicates that component suppliers (i.e. suppliers responsible for the industrialisation and production ramp up of components) often experience disturbances during their industrialisation processes and fail to deliver to the OEM production ramp up. To a large extent, the prerequisites for the production ramp up are settled during the industrialisation process (Bellgran and Säfsten, 2010). In Säfsten *et al.*'s (2006) study, one of the main disturbances during the final assembly was the timely delivery by the component suppliers. In this case, late engineering design change delayed the product design, and the time available for assessment of suppliers' capabilities to deliver in volumes corresponding to full-scale production was reduced. Consequently, the number of samples and verifications in the component supplier industrialisation process were limited, and the production ramp up was burdened with disturbances.

The literature describes various types of suppliers. Depending on the situation, a supplier can be responsible for the industrialisation process of a component/sub-system according to technical specifications provided by the OEM (which owns the component/sub-system design). In other cases, a supplier can be responsible for the design of a component/sub-system. Depending on the criticality and complexity of a component/sub-system, the supplier can take full responsibility for designing the component/sub-system or carry out the design in collaboration with the OEM (which provides functional specifications to the supplier; Le Dain, Calvi and Cheriti, 2011).

The literature shows that the industrialisation process is facilitated if the supplier and OEM establish relationships and the supplier has responsibilities in the component/sub-system design (Le Dain, Calvi and Cheriti, 2011). When the supplier only has responsibility for the industrialisation process (i.e. carries out the industrialisation process according to the OEM's technical specifications), the OEM and supplier first establish a contractual relationship when the supplier takes on the responsibility to carry out the industrialisation process of a component/sub-system (Fliess and Becker, 2006). Prior to the start of the industrialisation process, the supplier can be consulted on the component dimensions, choice of material and so on. Because of the new

relationship with the OEM, the supplier may face disturbances when conducting the industrialisation process. One challenge can be that the R&D actors at the OEM have frozen the component/sub-system technical specifications and design, and hence, are reluctant to consider the manufacturability improvements suggested by suppliers due to time and cost issues.

Lakemond *et al.*'s (2012) study indicates that late engineering design changes by the OEM disrupt the supplier industrialisation process. In their study, the OEM failed to deliver documents and information necessary for building prototypes during the industrialisation process carried out at the supplier. This required high flexibility by the manufacturing actors dealing with the industrialisation process. The pilot production was also delayed due to problems with material supply. The industrialisation process was facilitated in that the manufacturing actors at the production site were involved before the detailed design was fixed and had the opportunity to influence the design. Some researchers show that suppliers that industrialise according to OEM technical specifications need to have flexible manufacturing operations capable of managing late engineering design changes (Johansen, 2005; Fliess and Becker, 2006). In this respect, Melander and Tell (2014) argue that, when there is a lack of organisational fit (i.e. low degree of alignment) between the OEM and supplier organisations, processes, cultures, capabilities and strategies, the OEM is willing to change the supplier (especially when the market is saturated with suppliers with similar technologies capabilities) before changing a component design. There is scarce research on suppliers that are responsible for the industrialisation process according to the OEM technical specifications and drawings. The supplier industrialisation process of a component/sub-system can be described in relation to the OEM industrialisation process of the whole product (see Figure 3).

Based on the studies by Fliess and Becker (2006), Smulders (2006) and Rosell, Lakemond and Wasti (2014), the supplier industrialisation process can be divided into the following steps: (1) tool/equipment design and production; (2) tool/equipment verification, that is, testing and approval; and (3) tool/equipment installation and production system verification. Before the start of the industrialisation process, the quotation process is carried out. During the quotation process, the supplier prepares tooling and fixture layouts, preliminary production methods, measurement methods and procurement materials. Based on these preparations and the production capacity, the

supplier sends offers to the OEM, including the price and lead times for the industrialisation of the production tool and equipment and the component (Fliess and Becker, 2006; Le Dain, Calvi and Cheriti, 2011). The OEM evaluates several offers from suppliers and eventually selects one. The collaboration with the OEM starts with the purchase order (Rosell, Lakemond and Wasti, 2014).

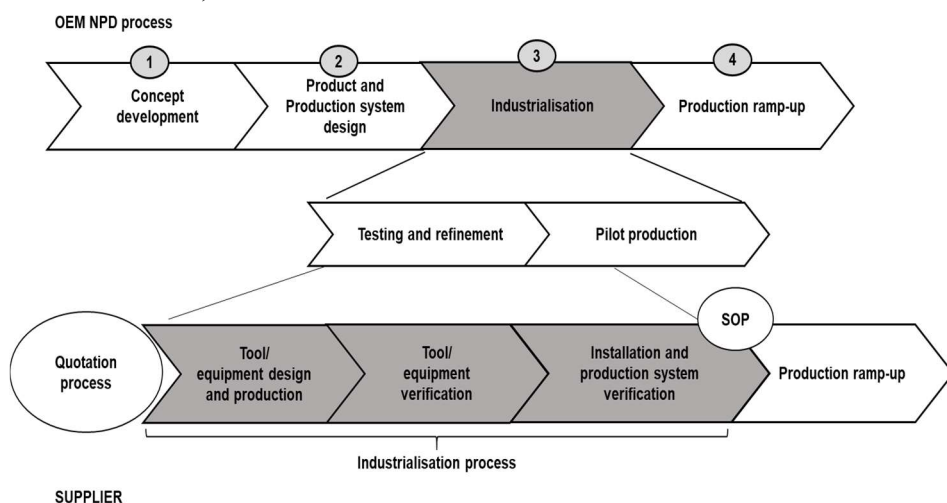


Figure 3 Supplier industrialisation process in relation to the OEM industrialisation process.

During the first step (i.e. tool/equipment design and production), the supplier accepts the released technical specifications and drawings from the OEM. This signals that the supplier should finalise the tool/equipment design that has been initiated during the quotation process. Next, the tools/equipment are produced either by the supplier or selected sub-suppliers (i.e. tool manufacturers; Smulders, 2006). During the tool/equipment verification step, initial samples are produced in the finished tooling with the correct materials and dimensions. The initial samples are then sent to the OEM's R&D for approval; these are used during product testing and refinement (Säfsten *et al.*, 2006). Often, field results are the reasons for the OEM changing the technical specifications and drawings, which in turn, affect the tool/equipment verification process at the supplier (Almgren, 2000; Johansen, 2005; Fjällström *et al.*, 2009).

During the third step (i.e. installation and production system verification), the verified tool/equipment is installed at the supplier's production site and put into operation. During this step, the capability of the production system to

start serial production is verified by the OEM (Säfsen *et al.*, 2006). A successful industrialisation process concludes with the timely SOP (see Figure 3). The production remains in a ramp up stage until the production targets are reached (Surbier, Alpan and Blanco, 2014).

During the industrialisation process carried out by suppliers, there are interdependencies between the supplier and OEM. Various forms of interdependencies have been addressed in the prior literature, and a field in which they have been addressed is the literature on supplier integration in NPD. The literature is vast, and it has addressed various topics ranging from relationships and power dynamics to operational practices and mechanisms used to enable the integration between the OEM and supplier (Wynstra and Pierick, 2000; Ragatz, Handfield and Peterson, 2002; Chen and Paulraj, 2004; Lakemond and Berggren, 2006; Sjoerdsma and van Weele, 2015). However, it does not focus on the industrialisation process. Most research concentrates on the supplier responsible for the design of components/sub-systems, which is typically carried out in the concept development and product and production system design of the NPD process (Figure 2; e.g. Handfield *et al.*, 1999; McIvor, Humphreys and Cadden, 2006). Furthermore, the research is primarily conducted from the OEM perspective, emphasising the challenges with which the OEM is faced when integrating various suppliers responsible for the design and/or industrialisation of various components/sub-systems (e.g. Wynstra and Pierick, 2000). Less research focusses on the challenges with which a supplier is faced when taking on various design or industrialisation responsibilities (Chung and Kim, 2003; Johnsen, 2009). Among other things, such challenges can be related to OEM exploitation of power or lack of commitment to agreements (Von Corswant and Tunäl, 2002). Wynstra, Van Weele and Weggemann (2001) state that a challenge for the supplier can be the need to carry out industrialisation processes of components/sub-systems of different OEMs simultaneously. According to Walter (2003), OEM's top management and relationship promoters, as well as suppliers' specific adaptations to OEMs (e.g. manufacturing process or information structure) have a positive effect on the supplier integration in NPD. Yenyurt *et al.* (2014) discover that an OEM's greater dependency on suppliers may lead to suppliers' unwillingness to make OEM-specific investments, while suppliers' dependency on OEM will increase the willingness to invest and share technologies.

High rates of technology change and misalignment between the OEM and supplier organisations (e.g. strategies, cultures, capabilities) encourage OEM to be flexible and not commit to one supplier. The OEM flexibility-seeking behaviour is likely to lead to the supplier's unwillingness to take on development responsibilities with the OEM (Melander and Tell, 2014). The supplier may also be less willing to collaborate with the OEM, because for example, the OEMs represent a very small share of suppliers' sales (Ellegaard, Johansen and Drejer, 2003). Wynstra, Van Weele and Weggemann (2001) argue that resistance from actors from different functions (e.g. R&D, purchasing) at the OEM may disrupt the relationship, and subsequently, the involvement of the supplier in collaborative design and development.

Stjernström and Bengtsson (2004) address suppliers that are responsible for the industrialisation and production of components. They indicate that OEMs often express a wish for close integration, but in practice, do not act as communicated, which confuses the suppliers and negatively affects their trust. Often, OEMs search for suppliers in low-cost countries, which affects the local suppliers' trust. These researchers' study further reveals that OEMs have a strong preference for price reductions, which result in extreme pressure for suppliers and inability to catch up with the technological developments. They conclude that open information exchange, top management commitment, development of trust, formalised risk/reward sharing and joint agreement in various collaboration scenarios have positive effects on the OEM–supplier relationships. Some researchers (e.g. McIvor, Humphreys and Cadden, 2006; Cadden and Downes, 2013) have found that common challenges facing suppliers with responsibilities limited to providing information on price and lead times (i.e. suppliers not responsible for the industrialisation and manufacturing processes) often struggle with OEMs that play several suppliers against each other until the most favourable contracts are reached. Furthermore, the authors reveal that, instead of working together with the suppliers to find ways to reduce costs, OEMs threaten future cooperation as a way to elicit cost reductions from suppliers. Cadden and Downes (2013) outline two important sources of integration challenges, which are as follows: (1) OEMs playing suppliers against one another to extract more favourable terms and (2) lack of support of the OEM's top management.

Today, the product design and industrialisation process is carried out not only across organisations but also across countries (Säfsen *et al.*, 2014). The distributed geographical context creates additional complexity to establish the

integration between the R&D actors and manufacturing actors during the industrialisation process (Lakemond *et al.*, 2012). At the same time, the ability to integrate the R&D and manufacturing actors contributes to the NPD process success, emphasising the importance of a smooth industrialisation process (Terwiesch, Bohn and Chea, 2001; Vandevelde, van Dierdonck and Clarysse, 2002).

The complexity associated with the distributed geographical context is connected to the fact that the probability of the actors interacting is reduced with the increase of the geographical distribution between them. The communication frequency between the R&D and manufacturing actors tends to drop with an increase in geographical distribution (Allen, Tomlin and Hauptman, 2008). The geographical distribution is associated with physical distance, which results in different time zones and lack of face-to-face meetings, as well as heavy reliance on technology for mediation (e.g. e-mails, video and teleconferencing, phone; Smulders *et al.*, 2002; Hinds and Bailey, 2003; Ceci and Prencipe, 2013; Hansen, Zhang and Ahmed-Kristensen, 2013; Säfsten *et al.*, 2014).

Lakemond *et al.*'s (2012) study reveals that, when the industrialisation process is carried out at a production site that is geographically distributed from the site where the R&D actors are located, one problem that arises is that the manufacturing actors from the distributed production site may not be involved during the product design in a timely manner. Instead, the R&D actors may consult the local manufacturing actors located in a production site due to proximity. In Lakemond *et al.*'s (2012) study, the participation of the manufacturing actors was sparse during the product design and the level of integration with the manufacturing actors was perceived as low. It appeared that the R&D and manufacturing actors from the production site paid little attention to the industrialisation process. This resulted in late deliverables from the R&D actors and quick fix solutions during the industrialisation process. A mediator (which can also be referred to as a boundary spanner) was appointed to facilitate the integration between the R&D actors (in Sweden) and the geographically distributed production site (in Poland; Lakemond *et al.*, 2012). However, the R&D and manufacturing actors' expectations about the role of the mediator differed.

Geographical distribution disrupts the establishment of collaboration between actors, and this cannot be entirely overcome by the use of media, such as video and teleconferencing (Bergiel, Bergiel and Balsmeier, 2008),

although some studies indicate that information technology can be useful in a distributed geographical context (Terwiesch, Bohn and Chea, 2001). Heavy reliance on media to exchange information reduces the social presence, which may negatively influence the establishment of collaboration between the actors. Some researchers position media like tele- and videoconferencing and e-mails on the continuum of media richness (discussed in section 2.1.2; Trevino *et al.*, 1990; Rice, 1992). For example, videoconferencing is less rich than face-to-face communication is but has greater capacity than the telephone does (as it provides visual cues). Teleconferencing is less personal than videoconferencing, which is why it is more appropriate for exchange of information than resolving conflicts. Markus (1994) positions e-mail on the media richness continuum between telephone and non-electronic written communication. In the NPD process in the distributed geographical context, it is suggested that the actors may circumvent the negative effects of mediation by the selection of richer media for communication.

The geographical distribution complicates the establishment of integration between the R&D actors and manufacturing actors, for example, because of national cultural diversity, a lack of shared context and diverse work culture (Armstrong and Cole, 2002; Cash, Dekoninck and Ahmed-Kristensen, 2017). These are perceived as challenges associated with the distributed geographical context that, if not managed, are likely to lead to various disturbances during the industrialisation process (Lakemond *et al.*, 2012; Säfsen *et al.*, 2014). The distributed geographical context leads to diversity between the actors, which is likely to prompt different perspectives and approaches to work, attitudes and expectations (Hinds and Bailey, 2003). Furthermore, the distributed geographical context prevents casual visual observations, and hence, inhibits familiarity between actors located at different sites. Information exchange between actors at different sites may be affected by the linguistic differences existing between the actors. Linguistic differences may affect the quality of the information exchange (Stringfellow, Teagarden and Nie, 2008), and hence, disrupt the integration between the R&D actors and manufacturing actors during the industrialisation process (Lakemond *et al.*, 2012). Therefore, Lakemond *et al.* (2012) argue that a geographically distributed context requires increased attention to the integration between the actors during the industrialisation process. The degree of integration between the R&D and manufacturing actors is associated with the fit between the product

specifications and production system capabilities (e.g. Langowitz, 1989; Terwiesch, Bohn and Chea, 2001; Säfsten *et al.*, 2014).

2.3 Summary

During the industrialisation process, various challenges and resulting disturbances occur. It is clear from the prior research that successful industrialisation depends on the integration between the R&D and manufacturing actors (Almgren, 2000; Vandevelde and van Dierdonck, 2003; Säfsten, Fjällström and Berg, 2006; Dekkers, Chang and Kreutzfeldt, 2013). A successful industrialisation process is associated with fewer disturbances, timely SOP and ramp up of production according to plan. Most of the studies on the industrialisation process are conducted in the type 1 context, meaning that the R&D and manufacturing actors are located in one country and belong to one company (Smulders, 2006; Javadi, Bruch and Bellgran, 2016).

The current situation for companies has changed, and organisational and geographical distribution increases the complexity—and hence, the uncertainty and equivocality—the R&D and manufacturing actors need to face for establishing the required level of integration (Lakemond *et al.*, 2012; Säfsten *et al.*, 2014; Gustavsson and Säfsten, 2017).

The distributed context is likely to result in many challenges that, if not controlled, will probably cause disturbances during the production ramp up. The literature provides few insights into industrialisation processes carried out in distributed contexts. As Lakemond *et al.* (2012) state, it is important to study how the complexity associated with the geographical and organisational distribution affects the management of the integration between the R&D and manufacturing actors. Mechanisms should create opportunity for the integration of the R&D and manufacturing actors (Twigg, 2002). There is a need for more knowledge on how to handle integration in the best way to support a successful industrialisation process in the distributed context. With some exceptions (Lakemond *et al.*, 2012; Gustavsson and Säfsten, 2017), the two dimensions of distribution—that is, the organisational and geographical dimensions—have rarely been included in one study. Therefore, there are merits to studying both dimensions simultaneously in relation to the industrialisation process.

3 Research design and methodology

This chapter starts by clarifying the research process presented in this thesis. This is followed by a description of the three research studies. The chapter concludes by delineating the role of the researcher and ethical considerations.

3.1 The research process

This thesis is based on two research projects. The first was titled ‘Distributed innovation projects: management of technological and organisational challenges in distributed settings’ (DINO). The DINO project focussed on challenges that an industrial product development project needs to manage when the product and production systems are organisationally and geographically distributed. The DINO project was carried out from January 2008 until December 2012. The research project team consisted of three researchers, including the author of this thesis. The second research project was titled ‘Efficient industrialisation supporting successful production ramp-up in supply chains’ (INDUS). The aim of the INDUS project was investigating critical factors for successful production ramp up in a supply chain. The INDUS project was carried out between April 2013 and November 2017. The research project team consisted of four researchers, including the author of this thesis.

In both research projects, the OEM involved was Company Alfa. Company Alfa was a large Swedish company acting on the global market and specialising in a wide range of outdoor products. The company’s competitive situation called for the frequent introduction of new products on the global market, and it had production sites in Europe, Asia, and the United States. In the frame of the two research projects, three research studies were conducted, namely, Study A, Study B and Study C (hereafter referred to as ‘the studies’), which are the focus of this thesis. Original empirical data related to the industrialisation process were collected in the studies by the author of this thesis in order to answer the research questions for this thesis. Data were also collected by the other researchers involved; such data were available and essential for this thesis but considered secondary data.

The studies of industrialisation process were conducted in three types of distributed context (see Figure 4). Study A included an industrialisation process in a distributed geographical context (type 3) and geographically and organisationally distributed context (type 4). Study B focussed on the industrialisation process in a distributed organisational context (type 2).

Finally, Study C centred on the industrialisation process in a distributed organisational context (type 2).

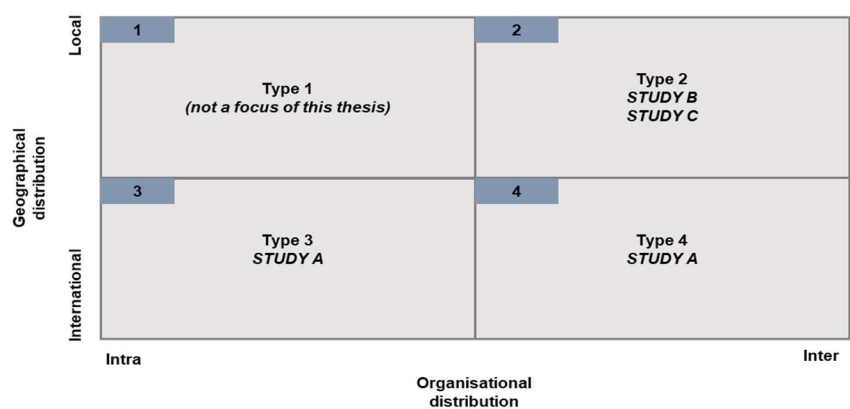


Figure 4 Studies' positions according to the industrialisation process context.

The timeline of the three studies is schematically illustrated in Figure 5. Study A was carried out between January 2011 and December 2012. Study B was conducted between August 2014 and July 2016. Study C, starting at the same time as Study B, was carried out between August 2014 and October 2017. The studies are visually illustrated as bars below the timeline. The dashed lines indicate that the study used secondary data collected in the frame of the respective research project.

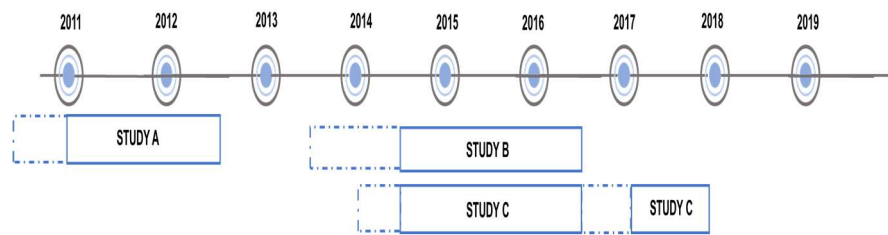


Figure 5 Illustration of the timeline of the three studies.

Studies A and C were carried out as real-time, longitudinal case studies that allowed grasping contemporary events (Yin, 2018). Such studies are rare in the literature (Page and Schirr, 2008). The focus was on investigation of the industrialisation process in depth, and a single case design was found to be appropriate in both studies.

Study B included two cases of medium-sized suppliers. The multiple case design was important for aggregating and comparing the findings derived from the cases. It further allowed to check if the context influenced the findings (Voss, Tsikriktsis and Frohlich, 2002; Yin, 2018). According to Yin (2018), in comparison with a single-case design, a multiple-case design is better for analytic generalisation. The two cases in Study B were performed retrospectively.

The literature reviews in each study are presented in the section below. The case studies and collection of data in each study are described separately in sections 3.2–3.4.

3.1.1 Literature reviews in Study A-C

In the three studies, the literature reviews covered books, journal articles, conference proceedings, doctoral dissertations, licentiate theses and reports (Williamson, 2002). Search engines, including Web of Science and Google Scholar, were employed. The databases that were directly searched were Scopus, ScienceDirect, ABI/Inform, Emerald, Business Source Premier and Academic Search Elite. Additional databases were SpringLink and Wiley Interscience. The articles were predominantly found in several journals, which were as follows: *Journal of Operations Management*, *Journal of Product Innovation Management*, *Technovation*, *Journal of Engineering and Technology Management*, *Journal of Supply Chain Management*, *Journal of Purchasing and Supply Management*, *R&D Management* and *Management Science*. Thus, these journals were searched specifically.

The collected publications for the three studies were analysed to identify the literature gap and discover similarities and differences between the prior research and findings from the case studies (Williamson, 2002; Yin, 2018). The publications were compiled, and content analysis was carried out and documented in a matrix.

In Study A, the matrix allowed for comparison of the publications in terms of the research method, findings and context. The context column indicated the context in which the R&D and manufacturing actors worked during NPD, if the study was conducted in a local or international context or if the study was conducted in an inter- or intra-organisational context. Furthermore, this column showed if a publication specifically discussed the communication and collaboration between the R&D and manufacturing actors or engaged in cross-

functional integration without specifying the actors. Some examples of the analysis of publications linked to Study A are presented in Table 2.

Like in Study A, relevant publications for Study B and Study C were compiled in a matrix and analysed, for an example see table 3. This comprised the three following columns: research method, findings and context. The context column included three dimensions, which were as follows:

- (1) The context in which the R&D and manufacturing actors work during NPD. This includes whether the study is conducted in a local or international context or in an inter- or intra-organisational context;
- (2) The type of supplier in accordance to supplier's areas of responsibility included in the publication. Supplier responsible for the OEM's component designs; suppliers in charge of industrialisation of components/sub-systems according to the OEM's technical specifications; or both types of suppliers are included in the publication.
- (3) The perspective taken in the publication, that is, the OEM perspective, supplier's perspective or both perspectives (that is the OEM's and the supplier 's perspectives are included in the publication).

Table 2 Examples of Publications from Study A

Publication	Method	Findings	Context
Vandevelde and van Dierdonck (2003)	Survey	<ul style="list-style-type: none">- Barriers to integration, personal barriers, organisational/functional barriers, cultural barriers- Formalisation * → (+) production start up- Empathy from R&D towards manufacturing → (+) production start up- More and better communication → (+) empathy from R&D towards manufacturing- Involving R&D in production start up → (+) empathy from R&D towards manufacturing	<ul style="list-style-type: none">- Local and intra-organisational context- R&D and manufacturing actors
Barczak and McDonough (2003)	Survey	<ul style="list-style-type: none">- Comparison between challenges in local and international context- Challenges in international context: trust; working to plan; meeting budget; cultural diversity; language barriers; geographical distance, incompatible technology infrastructure; few face-to-face meetings; different work norms, communication and decision-making norms- Suggested integration mechanisms; meetings and increased quantity and quality of communication	<ul style="list-style-type: none">- Local context- International context- General integration

(continued)

Publication	Method	Findings	Context
Smith and Blanck (2002)	Experience	<ul style="list-style-type: none"> - Divide challenges into different stages - Suggested integration mechanisms; role of the team leader, building trust, utilisation of various communication tools and technology for data transferring - Discuss the culture difference from a positive side (do not have to homogenise a team but make use of the differences) 	<ul style="list-style-type: none"> - International and inter-organisational context - R&D and manufacturing actors
Koufteros, Vonderembse and Doll (2002)	Survey	<ul style="list-style-type: none"> High uncertainty or equivocality will lead to need for adoption of practices like heavyweight product development practices, concurrent engineering and computer use 	<ul style="list-style-type: none"> - Local and intra-organisational context - General integration

* → (+): Indicates a positive effect.

Table 3 Examples of Publications from Study B

Publication	Method	Findings	Context
Stjernström and Bengtsson (2004)	Case study	Open information exchange, top management commitment, development of trust, formalised risk/reward sharing, joint agreement on effective collaboration *→ (+) OEM-supplier relationships	(1) Local and inter-organisational context (2) Both types of suppliers (3) Supplier perspective
LaBahn and Krapfel (2000)	Survey	OEM's exchange behaviour, OEM-supplier power asymmetry and OEM's technical innovativeness influence the degree to which the supplier is willing to form partnership with the customer	(1) Local and inter-organisational context (2) Supplier responsible for OEM's component design (3) Supplier perspective
Wynstra and Pierick (2000)	Case study	- Supplier-manufacturing interfaces defined in terms of the following: (1) direction of information flow, (2) communication medium, (3) amount of communication, (4) topics discussed, (5) functions involved - Impact on product cost, product quality and product development cost and time	(1) Local and inter-organisational context (2) Both types of suppliers (3) OEM perspective

(continued)

Publication	Method	Findings	Context
Takeishi (2001)	Interviews + question-naire	OEMs' integrated problem solving with suppliers and frequent face-to-face communication, architectural knowledge for component coordination by the OEMs' engineers → (+) quality of component development	(1) Local and inter-organisational context (2) Supplier responsible for OEM's component design (3) Both perspectives
Chen and Paulraj (2004)	Literature review	<ul style="list-style-type: none"> - Supplier involvement → (+) cost, quality of purchase materials, access to technology and reduced NPD time - Two-way communication, trust → (+) OEM-supplier relationships - The role of strategic purchasing enhances supplier integration → (+) OEMs' NPD performance 	(1) Local and inter-organisational context (2) Both types of suppliers (3) Both perspectives

* → (+): Indicates a positive effect.

3.2 Study A

3.2.1 Case study

The unit of analysis (UoA) in the case study was one NPD project. It is argued that it is possible to use subsidiary units of analysis (sub-UoAs), also referred to as ‘embedded cases’ (Yin, 2018). Therefore, the sub-UoA was the industrialisation process. The choice of UoA and sub-UoA was closely related to the research questions (Williamson, 2002). Appropriate criteria for selecting the case were developed. These were;

- (1) Investigating a real-time NPD project from the early start to full-scale manufacturing. This allowed investigating challenges occurring prior to the industrialisation process, disturbances during the industrialisation process and the success of the industrialisation process in terms of SOP and production ramp up according to plan;
- (2) The possibility to capture data from multiple sources. This was important due to the exploratory nature of the case (Yin, 2018);
- (3) Manufacturing of discrete products comprising several components, which implied a certain degree of complexity. The complexity level defines the product/production system fit uncertainty and affects the need for integration between R&D and manufacturing actors (Adler, 1995);
- (4) Major or minor modifications of the product design. The degree of newness contributes to the uncertainty during the industrialisation process and increases the requirements for integration;
- (5) A focus on the industrialisation process in type 3 and type 4 contexts.

In the DINO research project, an NPD project was studied, which was found to be appropriate case for the Study A in accordance to the selection criteria. The design of the new components/sub-systems included in the new product and management of the NPD project was carried out by a core project team located at the Swedish R&D site. This team included actors with the following positions: one project manager, two design engineers and two laboratory engineers. Company Alfa had recently acquired a new production site in China, which resulted in geographical distribution between the R&D and manufacturing actors during the studied NPD project. The industrialisation of the new product took place in the newly acquired production site, referred to here as the industrialisation site. The site included

a production engineer, assembly engineers, operators, R&D actors and purchasing specialists located in China. Furthermore, new suppliers were involved in the project because senior managers called for sourcing in China, which resulted in geographical and organisational distribution between the R&D actors and the suppliers responsible for the industrialisation of components and tooling production. The context of the case in Study A is illustrated in Figure 6.

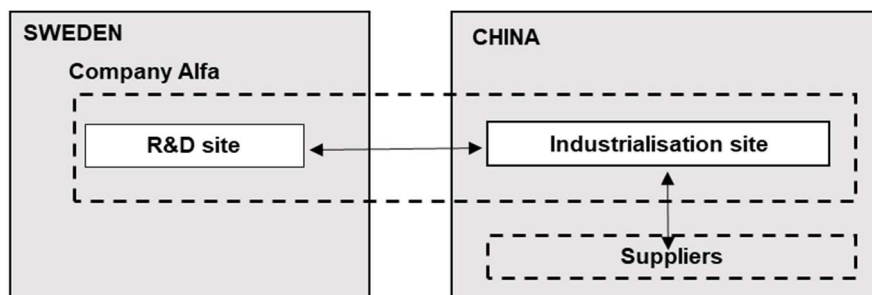


Figure 6 Context of the case in Study A.

The data collected from the NPD project continued throughout a 3.5-year period, from early project start until full-scale production. Several data collection techniques were used (see Table 4). Data were collected from the Swedish R&D site through semi-structured, open-ended interviews with a focus on the industrialisation process. The interview guide is shown in Appendix 1. Face-to-face interviews were conducted with respondents covering diverse project roles. The choice of the relevant persons for interviews was made with the help of the contact person at Company Alfa. The respondents were informed about the confidentiality of their participation and familiarised with the purpose of Study A. On several occasions, the respondents suggested other persons that were of importance to the case, and hence, additional interviews were carried out. All the interviews were audio recorded, and supplementary notes were taken.

Company documents were available upon request. These included the company's stage-gate procedure for the development of new products, a visual representation of a communication procedure developed in the project and picture books used for communication. Furthermore, one workshop was conducted in which various challenges related to NPD and industrialisation were discussed. The workshop involved 11 representatives from Company

Alfa and another company; it was audio recorded, and additional notes were taken.

Table 4 Overview of Data Collection Techniques and Data Collected

Collection technique	Swedish R&D site (number; minutes)	Documents used in analysis
Primary data		
Face-to-face interviews	7; 60–120	Transcripts, notes
Workshop	1; 420	Transcripts, notes
Documents	Company Alfa documents: stage-gate procedure for development of new products, visual representation of a communication procedure, picture books	Documents
Secondary data		
Access to transcripts from interviews at the Chinese industrialisation site	7	Transcripts and notes
Access to transcripts from interviews at the Swedish R&D site	15	Transcripts and notes
Access to notes from informal conversations	60	Notes
Access to observation protocol from project meetings at the Swedish R&D site	59	Observation protocol

Secondary data were also collected in Study A (see Table 4). At the Swedish R&D site, 15 interviews were carried out. In addition, seven interviews were carried out at the Chinese industrialisation site. The research project team developed the interview guide (see Appendix 2). The interviews were transcribed, and the transcripts were studied for the purpose of Study A. Furthermore, 59 observations in the project meetings at the Swedish R&D site were carried out. The observation protocol from the project meetings was used as secondary data for Study A. In connection with the observations at the project meetings, informal interviews were conducted. These were primarily meetings with the project manager about various project-related issues, such

as additional explanations about the project status, problems and ongoing activities. Notes were taken directly after the conversation.

The data analysis in Study A followed the steps prescribed by Miles, Huberman and Saldaña (2014), namely, data condensation, data display and conclusion drawing/verification. In the data condensation step, a case study protocol—also referred to as a case narrative—was developed. This included transcripts from the interviews, notes and Company Alfa documents (see Table 4). In addition, the case study protocol included the secondary data—that is, transcripts, observation protocol and notes—collected by the research project team. The UoA and sub-UoA guided the selection of relevant data. The focus of the case study protocol was on the following elements: (1) challenges related to the distribution context with which the R&D actors, manufacturing actors and actors from the suppliers were faced during the industrialisation process; (2) types of disturbances that resulted from the challenges; and (3) mechanisms used to control the challenges to prevent disturbances from arising during the industrialisation process.

In the data display step, the data in the case study protocol was organised into a matrix. An example of the matrix used in the Study A protocol can be found in Table 5. The first column contained the statement from the interview, while the second included the analysis. The third column showed whether the statement included a challenge, marked with a ‘–’ sign, or mechanisms, marked with a ‘+’ sign; in some cases, a statement contained both a challenge and a mechanism. The definition of the challenge, disturbance and mechanisms were derived from the prior literature; therefore, the categorisation of the data was considered theory driven (Saunders, Lewis and Thornhill, 2016). The last column indicated to which actors a challenge or mechanism referred.

Conclusion drawing was initiated during the data collection process, when various patterns, explanations and propositions started to appear (Miles, Huberman and Saldaña, 2014). However, final conclusions were drawn after the empirical data were related to the literature.

3.2.2 Validity and reliability

The traditional research quality criteria were used to judge the quality of the research in Study A, namely construct, internal and external validity and reliability (Yin, 2018). The validity was strengthened by the establishment of indicators that were considered operational measures for the theoretical

constructs. The definition of theoretical constructs and respective indicators is an approach used by (Olausson, 2009). The establishment of such indicators was important for minimising the risk of subjective judgments (Voss, Tsikriktsis and Frohlich, 2002; Yin, 2018).

Table 5 Example of Analysis with Distilled Challenges

Interview	Analysis	Challenge (-)/ Mechanism (+)	Actors
<i>Design engineer</i> Laboratory engineers from the Swedish R&D site visited the industrialisation site in China to help in the assembly of the first test series. It turned out that the assembly site was not prepared as expected, although the engineers had discussions with the project leader in China: <i>'So I think that this is one thing that it was a bit of Chinese culture that the project leader...if he was not high enough in the organisation, they (assemblers) didn't really react when he said now we should build EPs here'.</i>	Culture differences (Swedish R&D actors and Chinese manufacturing actors) influenced the communication during the industrialisation process. Disturbance: lack of preparation to carry out the first test series at the industrialisation site in China	(-) National culture differences	- R&D actors from the Swedish R&D site - Manufacturing actors from the Chinese industrialisation site

The literature review assisted in the indicator development. Examples of theoretical constructs and the respective indicators are shown in Table 6.

Table 6 Examples of Constructs and Their Indicators

Construct	Indicator	References
Successful industrialisation	<ul style="list-style-type: none"> - Timely start of production - Production ramp up according to plan - Time elapsed between the start of the industrialisation process and the start of production - Industrialisation cost and cost of the developed tools and production equipment 	<p>Almgren (2000), Säfsten <i>et al.</i> (2006), Surbier, Alpan and Blanco (2009), Fjällström <i>et al.</i> (2009),</p>
Communication between the R&D and manufacturing actors	<ul style="list-style-type: none"> - Face-to-face vs document-based communication - Frequency of the communication - Use of communication media (type) - Use of standardised and formalised processes - Early release of preliminary information vs late release of complete information 	<p>Daft and Lengel (1986), Wheelwright and Clark (1992), Twigg (2002), Vandevelde and van Dierdonck (2003), Olausson (2009), Kahn (1996), Vandevelde and van Dierdonck (2003), Frishammar (2005), Olausson (2009).</p>
Collaboration between R&D and manufacturing actors	<ul style="list-style-type: none"> - Actors use the received information - Actors are willing to share ideas and information - Actors are willing to assist other actors in the completion of their tasks - Presence of not-invented-here syndrome 	

To triangulate the collected data, evidence from different respondents and involving different methods was collected (Voss, Tsikriktsis and Frohlich, 2002; Yin, 2018). For example, the respondents from the Swedish R&D site indicated that the national cultural difference was a challenge that resulted in disturbances during the industrialisation process. The respondents from the Chinese industrialisation site also pointed out that the national cultural difference was indeed a challenge that affected the industrialisation process. To cross-validate the data, various techniques for data collection were used. For example, the interviews indicated the picture books as mechanisms to support the communication between the actors from the R&D site and actors from the suppliers. A similar finding was drawn from the secondary data, specifically, the observation protocol. To capture different challenges and mechanisms, many of the interviews were conducted with two company representatives, thereby minimising the risk that questions remained unanswered.

According to Christensen (2006, p. 52) internal validity is about ensuring that conclusions are unambiguously derived from their premises. The internal validity in the case was strengthened in that the data were collected in real time, and therefore, they did not depend on the participants recalling critical events. The internal validity was also ensured through conducted interviews with key persons involved in the industrialisation process, from both the R&D and Chinese industrialisation sites. To strengthen the internal validity, enfolding of literature during the analysis was carried out (Eisenhardt, 1989; Voss, Tsikriktsis and Frohlich, 2002; Christensen, 2006). The workshop and confirmation of the case study protocol by the contact person at the Swedish R&D site were important for strengthening the internal validity. The contact person did not contradict or disqualify any findings, but rather, provided further explanations and elaborated on certain issues that the contact person considered important. Before publishing a scientific paper related to Study A, the contact person had the opportunity to review the paper, provide comments and eventually approve the paper for publication.

External validity is important for determining the degree to which the conclusions drawn can be generalised outside the case (Christensen, 2006). Yin (2018) argues that case studies are generalisable to theoretical propositions rather than populations. In other words, generalisation from case studies should be considered as an analytical process rather than a statistical one (Dubois and Araujo, 2007). Contrasting literature to empirical findings

was important for strengthening the external validity. Guba and Lincoln (1994) argue that strengthening the external validity requires ‘thick description’ of a case. To ensure external validity, a rich description of the case, including the context, was provided. Moreover, non-generalisable findings associated with the exploratory research are important for further research in a certain field (Edmondson and McManus, 2007). The workshop was very important for validating the findings. The presence of representatives of another company provided opportunity to confirm that the findings from the case are also relevant for another company carrying out the industrialisation process in the type 3 and type 4 contexts.

Reliability refers to the possibility for the same results to be obtained regardless of who performs the investigation (Yin, 2018). To secure reliability, this thesis followed a systematic work procedure; that is, the collected data were documented on a continuous basis so that facts would not be lost. The interviews were recorded and transcribed.

3.3 Study B

3.3.1 *Case study*

Study B was a multiple case study. The focus of the cases was investigating the industrialisation process in the type 2 context. The UoA in each case was the supplier, while the sub-UoA was the supplier’s industrialisation processes.

As stated in section 2.2, there is a need for more research on suppliers responsible for the industrialisation of components/sub-systems according to OEM’s technical specifications. Therefore, the first criterion was selecting suppliers responsible for the industrialisation process of components/sub-systems according to the OEM’s technical specifications. Second, to minimise the variance between the way of working of different OEMs, the suppliers had to work with the same OEM. Third, the suppliers had to operate in two different industrial sectors, thereby retaining some variations in their industrialisation process.

Company Alfa was the starting point for identifying the cases. It was interested in improving the integration with their suppliers during the suppliers’ industrialisation processes to ensure that the right components, in the right volume and price, were delivered during the company’s industrialisation process and production ramp-up. Based on the specified selection criteria, Company Alfa helped identify two Swedish suppliers responsible for the industrialisation of components/sub-systems according to

Company Alfa's technical specifications. Hence, the two suppliers had in common Company Alfa, but the analysis also included suppliers' other large OEMs and key OEMs located in Sweden.

The design activities of components/sub-systems took place at the Swedish R&D site owned by Company Alfa. The two suppliers, from now on referred to as Company Metal and Company Polymer, industrialised the components/sub-systems at their production sites in Sweden, referred to as the industrialisation sites. Company Metal industrialised sheet metal components, while Company Polymer industrialised polymer systems and components. The context of the case in Study B is visually illustrated in Figure 7.

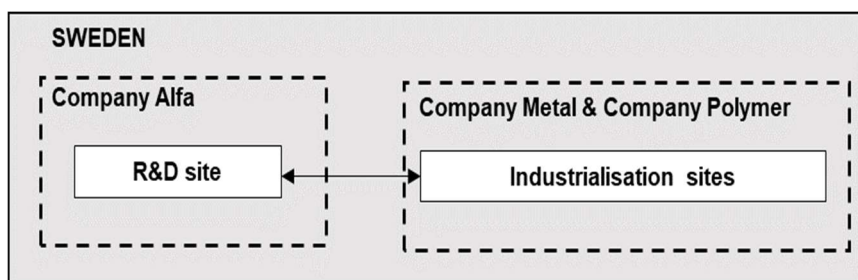


Figure 7 Context of the case in Study B.

Several collection techniques were used for collecting data. The data collection covered the period between 2014 and 2016 (see Table 7). The data were collected from eight face-to-face interviews and one telephone interview. The implementation of the industrialisation process at Company Metal was organised as a project, comprising cross-functional team. The team consisted of project leader, production engineer, quality engineer, tool purchasers, tool designer and key account manager. Therefore, respondents from these positions were interviewed. The interviews followed predefined interview guides that were partly adjusted according to each interviewee's role in the company. An interview guide is attached in Appendix 3.

In total, four workshops were carried out. Of these, two were common workshops, that is, they included both Company Metal and Company Polymer. The first common workshop provided the opportunity to gain feedback and reflections on the findings regarding the challenges for the organisational distribution that disrupted the suppliers' industrialisation processes. The second common workshop served as an opportunity to obtain feedback on the integration mechanisms. In addition to the common workshops, one internal workshop at each of the suppliers was carried out.

The aim of the internal workshops was to gain feedback on the various integration issues. Notes were taken during the workshops. Upon request, various Company Metal documents were provided. These included documents about the company organisation and work models for industrialisation.

Table 7 Overview of Data Collection Techniques and Data Collected

Collection technique	Company Metal (number; duration in minutes)	Company Polymer (number; duration in minutes)	Documents used in analysis
Primary data			
Interviews	9; 90–180	-	Transcripts, notes
Workshop	4; 420		Notes
Documents	Access upon request	-	Company Metal documents
Secondary data			
Access to transcripts from interviews at Company Metal	8		Transcripts
Access to transcripts from interviews at Company Polymer		10	Transcripts

The data were collected by the research project team in the frame of the INDUS research project. They were treated as secondary data in the Study B. Eight interviews were carried out at Company Metal and 10 at Company Polymer. The respondents from Company Polymer were the key accountant, production manager, supplier quality assurance engineer (SQA), toolmaker(s), tool purchaser and project leader. The interviews were recorded and transcribed. In addition, notes were taken. Access to the transcripts and notes were provided for the purpose of Study B.

Like in Study A, the analysis of the collected data followed the steps delineated by Miles, Huberman and Saldaña (2014), namely, data condensation, data display and conclusion drawing/verification. The first step

in data condensation included writing the case study protocol. This protocol included transcripts from the interviews, notes and Company Metal documents. The case study protocol included the secondary data as well: These were transcripts of interviews conducted at Company Metal and Company Polymer (see Table 7). Like in Study A, the UoA, sub-UoA and research questions guided the data analysis. For organising the data in the case study protocol, a matrix was used. This followed the same structure as shown in Table 5 in section 3.2.1. The third and final step was conclusion drawing/verification. The conclusions were drawn after collection of all the empirical data, and the empirical findings were compared with the prior research. Generally, the analysis was a continuous process that required repeated reading of the interview transcripts, notes, secondary data and reviewed literature.

3.3.2 Validity and reliability

Like in Study A, the case in Study B followed the traditional research quality criteria to judge the quality of the research (Yin, 2018). In Study B, the theoretical constructs and respective indicators described in Table 6, section 3.2.2 were used. The constructs and indicators were important for the construct validity. Evidence from key respondents that held various positions were gathered to ensure the construct validity. Interviewing respondents holding various positions was important for studying the industrialisation process from various perspectives.

To cross-validate the data, they were collected through various techniques like interviews and workshops. In many cases, interviews with the suppliers were conducted with two respondents, which reduced the risk that questions would remain. An example from Company Metal was that, during the interviews, several respondents mentioned that actors from the Swedish R&D site ignored manufacturability issues. The challenge for the R&D willingness to collaborate and support the supplier's industrialisation process was also confirmed during the workshop by respondents from Company Polymer.

Internal validity was strengthened because some of the interviews were conducted by two researchers, after which, the researchers examined the data and compared perspectives. The aim of using this procedure was reducing the potential investigator bias. The interviews had a retrospective character, which implied risk of long-term respondent memory loss. To compensate for this and reduce the risk of memory loss, several key respondents were interviewed. To

strengthen the internal validity, enfolding of the literature during the analysis was carried out (Eisenhardt, 1989; Voss, Tsikriktsis and Frohlich, 2002; Christensen, 2006). Furthermore, the case study protocol was reviewed by contact persons from Company Metal. This provided confidence in the accuracy of the case descriptions and ensured the validity of the data.

External validity was strengthened via enfolding of prior research. In this case, theoretical generalisation was aimed for. Like in Study A, the external validity was strengthened through rich description of the cases. Detailed description of the cases allowed for comparison with other cases from the prior research.

Like in Study A, the reliability was ensured by describing the research method in detail. This was important for providing transparency as to what had been done to answer the research questions. Moreover, during the case, the data were documented regularly and in a timely fashion. All the interviews were recorded and transcribed. Furthermore, the data analysis method was described, providing transparency as to how the findings were derived from the raw empirical material. One of the drawbacks associated with a retrospective case study is associated with the inability of the participants to recall important events (Voss, Tsikriktsis and Frohlich, 2002). To avoid researcher misinterpretations, the interview guide included shorter questions. This was to ensure that no leading questions were asked.

3.4 Study C

3.4.1 *Case study*

The UoA of the case was an NPD project, where the sub-UoA was the integration between the OEM and suppliers during the suppliers' industrialisation process. The case covered perspectives from the OEM and suppliers. The developed criteria for selecting the case were as follows: (1) studying a real-time NPD project from the development stage until production ramp up, (2) having access to data from multiple sources and (3) involving suppliers responsible for industrialisation of components/sub-systems according to OEM's technical specifications.

In the INDUS research project, an NPD project was studied, and it fit the criteria developed for the case in Study C. Company Alfa was interested in improvement of the integration with the suppliers to ensure that the suppliers would be able to deliver in time at the right cost. Company Alfa helped

identify five suppliers that fulfilled a number of criteria, which were as follows:

- (1) Involvement in the NPD project, and hence, being subject to the same NPD context;
- (2) Involvement in the industrialisation of components with different development risks. This meant that the components/sub-systems developed by the suppliers had different levels of complexity and criticality for the overall product; and
- (3) Pertaining to different industries, and hence, retaining some variation of their industrialisation and manufacturing processes.

The NPD project involved industrialisation of a product that was a substitute of a product to be phased out of the market. The new product comprised 220 components, of which, 100 were newly designed. The NPD project consisted of the core project team, which governed the NPD project, and an R&D department comprising R&D actors responsible for designing and testing various components included in the newly developed product. The core project team in Sweden consisted of an R&D actor, from the R&D department, who had the role of technical lead and was responsible for the product design; manufacturing engineer taking care of industrialisation issues; supplier quality assurance (SQA) engineer; purchaser; project coordinator; and project manager. The core project team and R&D department were located at the Swedish R&D site. Suppliers were responsible for the industrialisation process of components/sub-systems. The suppliers' production sites, where the industrialisation of the components/sub-systems took place, refers to the industrialisation sites. The suppliers were in Sweden and other countries; the components industrialised by the suppliers had different levels of complexity and criticality in the NPD project. The context of the case in Study C is visually illustrated in Figure 8.

Several data collection techniques were used in the case (see Table 8). Observations during weekly project meetings with the core project team at the Swedish R&D site were carried out between 2014 and 2017. Notes were taken according to a predefined structure and compiled in an observation protocol. The structure of the observation protocol is shown in Appendix 4.

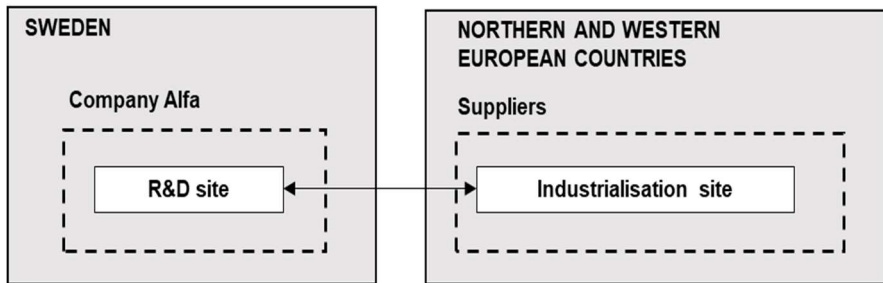


Figure 8 Context of the case in Study C.

Table 8 Overview of Data Collection Techniques and Data Collected

Collection technique	Number; duration in minutes	Documents used in the analysis
Primary data		
Observations at project meetings	25; 30	Observation protocol (notes)
Interviews with core project team	8; 60–120	Transcripts, notes
Interviews with suppliers	7; 60	Transcripts, notes
Company Alfa's documents	Access to documents upon request	Company Alfa documents
Workshop	1; 420	Notes
Survey	14	Survey protocol
Secondary data		
Access to observation protocol from project meetings	45; 30	Observation protocol

Semi-structured, open-ended, face-to-face interviews with the core project team were conducted before the SOP. The interview guide is shown in Appendix 5. After the SOP, interviews were conducted with the core project team to discuss experiences with it. All the interviews were audio recorded and complemented with notes. Furthermore, semi-structured, open-ended interviews with the suppliers were conducted. The interview guide is shown in Appendix 6. The key respondents at the suppliers held positions like key accountant, production manager and project leader. Many of the interviews included two representatives per supplier. The interviews were audio recorded and complemented with notes. When requested, documents were provided by the core project team. The documents included descriptions of the stage-gate

procedure, also referred to as the project model, Company Alfa's quality assurance process and production part approval process (PPAP). One workshop was held in October 2017, after the SOP. Several representatives of the core project team and two suppliers were present. The aim was discussing and verifying the challenges that led to disturbances during the suppliers' industrialisation process and elaborating on positive and negative factors that affected the SOP readiness during the NPD project.

Early in the industrialisation process marked as stage 3 from the stage-gate procedure, an event called Supplier Day was organised by Company Alfa. This was planned to ensure collaboration between the actors at the Swedish R&D site and suppliers during the NPD project. Supplier Day was held in May 2016 at Company Alfa's premises. During Supplier Day, a survey was carried out in the frame of Study C to gather additional data and complement the case study. The purpose of the survey was collecting insights about whether and how this event contributed to ensuring collaboration between the actors. For Company Alfa, it was also important to gain insights into what could be improved for this event. The questionnaire was descriptive and included three open-ended questions (see Appendix 7). The responses were collected from 14 suppliers, 5 of which had been initially selected for the case. The suppliers were from the metallurgical and polymer industries, and they were responsible for the industrialisation process of various components and sub-systems. Moreover, the suppliers ranged from large to medium and small suppliers, and they were locally and internationally located.

Data from 45 core project team meetings at the Swedish R&D site were collected. The observation protocol from these meetings was used as secondary data. Like in Studies A and B, the analysis of the collected data followed the steps by Miles, Huberman and Saldaña (2014), namely, data condensation, data display and conclusion drawing/verification. The first step, data condensation, included writing the case study protocol. This comprised transcripts from the interviews, notes, observation protocol, Company Alfa documents and secondary data (see Table 8). As in Studies A and B, the UoA, sub-UoA and research questions guided the analysis of the data. To organise the data in the case study protocol, a matrix was used. This followed the same structure as that shown in Table 5 in section 3.2.1.

The survey protocol was analysed separately because it included a larger sample of suppliers, that is, suppliers that were not initially selected for the case. The answers of the survey respondents were coded in an Excel sheet,

which facilitated comparison between similar answers (Maxwell, 2005). The answers were then clustered by sorting the coded answers into groups that had something in common, thereby creating data-driven categories (Saunders, Lewis and Thornhill, 2016). The third and final step was conclusion drawing/verification. The conclusions were drawn after collection of all the empirical data, and the empirical findings were compared with the prior research.

3.4.2 Validity and reliability

Like the two previous studies, Study C followed the traditional research quality criteria for judging the quality of the research (Yin, 2018). In Study C, the theoretical constructs and respective indicators described in Table 6, section 3.2.2 were used. The constructs and indicators were important for construct validity.

To strengthen the construct validity, evidence from various key respondents was collected. To capture different dimensions of the studied industrialisation process and integration between the OEM and supplier, the data were collected from both the OEM and suppliers. Data triangulation was achieved by collecting data from different techniques, such as interviews and surveys. For example, the survey on Supplier Day indicated that the event was a mechanism that could facilitate collaboration and communication between the actors from the core project team and the suppliers. The importance of the event for supporting the integration between the actors was also indicated via the interviews conducted with the actors from the Swedish R&D site and suppliers. Interviewing key persons that hold various positions from the Swedish R&D site and the suppliers provided the opportunity to study the industrialisation process and the integration from different viewpoints. This is in accordance with the recommendations by Voss, Tsikriktsis and Frohlich (2002).

Internal validity was ensured by the real-time case, where the data were not dependent on the respondents' memory. Writing down notes during observations and reflecting on the observations immediately after the fieldwork made it easier to recall important events. Furthermore, the interviews with the actors at the Swedish R&D site and suppliers were conducted by two researchers, following which, the researchers examined the data and compared perspectives. To strengthen the internal validity, enfolding of literature during the analysis was carried out (Eisenhardt, 1989; Voss, Tsikriktsis and Frohlich, 2002; Christensen, 2006). Discovering the difference

between the literature and empirical data reduces ambiguities in descriptions. The case study protocol was reviewed by contact persons at the Swedish R&D site and seven suppliers. This provided confidence in the accuracy of the case descriptions and ensured the validity of the data.

External validity was strengthened through enfolded prior research. In this case, theoretical generalisation was aimed for. Like in Study A, the external validity was strengthened through rich description of the case. Thorough description of the case allowed for comparison with other cases from the prior research.

Like in Study A, the reliability was ensured by describing the research method in detail, which allowed for transparency of the results. Moreover, the case followed a systematic work procedure, where the data were documented regularly to avoid losing them. All the interviews were recorded and transcribed. Furthermore, the data analysis method was described, making it possible for other researchers to follow the steps that led to formation of the findings.

3.5 Role of the researcher and ethical considerations

During the research process, the roles of the author shifted. On some occasions, it was that of an observer during meetings, while at other times, it involved leading meetings or workshops. This put different demands on the researcher. For example, when preparing workshops, it was necessary to take the initiative and become more of a facilitator during discussions. In contrast, during project meetings, a passive role was adopted that involved taking notes and observing. One important issue was that the researcher had to find a common language with the practitioners, since a gap was sometimes perceived between academic expressions and terms used by the practitioners.

Becoming acquainted with the practitioners did not only occur during the planned official meetings and interviews, but also, for example, during breaks and meals between formal meetings. During the research process, such informal dialogue often resulted in interesting insights and explanations about issues that had been unclear to the researcher. The informal dialogues also allowed the practitioners to become familiar with the researcher. This was important because it fostered the practitioners' willingness to share information with the researcher. Being better acquainted with the practitioners helped the researchers obtain better access to data.

Svensson, Ellström and Brulin (2007) state that the researcher should be active but not controlling, balancing distance from and closeness to the practitioners. The process of becoming acquainted was affected by the reorganisation-related changes that took place during the three studies. During the studies, reorganisations were carried out, and the practitioners changed. Some of them quit (e.g. in Study B), while others changed positions (e.g. the project manager of the NPD project in Study C).

There were ethical considerations concerning anonymity when conducting the interviews. For example, discussions were often centred on what did and did not work well during the NPD project and the industrialisation processes; therefore, the practitioners had to be assured that the shared information would not be disclosed. The interviews were recorded, and it was important to make clear to all the participants that the collected data would be used only to facilitate the documentation of the results, and the answers of single individuals would not be revealed. Fictitious names were used for the companies involved with the aim of eliciting honesty from the practitioners. Moreover, this facilitated the opportunity to disseminate the results without focussing on the names of the companies involved.

3.6 Overview of studies and appended papers

Based on the three studies, the appended papers in this thesis were written (Papers 1–6). The relationship between the three studies and papers is shown in Table 9. Various terms to refer to Company Alfa were used in the papers. Papers 1–4 refer to it as Company A. In Paper 5, the name Company is used, while in Paper 6, it is called Company Outdoor. The NPD project discussed in Study A is referred to as the Beta Project in Papers 1 and 3. The NPD project discussed in Study C is referred to as Project Alpha in Paper 5.

Table 9 Relation between the Studies and Appended Papers

Study	Paper
Study A	Papers 1, 2 and 3
Study B	Papers 4 and 6
Study C	Papers 5 and 6

4 Findings from the appended papers

This chapter starts with a short overview of the six appended papers. It continues by outlining the empirically derived findings presented in the appended papers. For each of the studied contexts of the industrialisation process (types 2–4), the identified challenges, disturbances and mechanisms are outlined.

4.1 Short overview of the appended papers

The overall purpose of the research presented in this thesis was to expand the knowledge on the industrialisation process in distributed geographical and/or organisational contexts. To fulfil the overall purpose of the thesis, three RQs were formulated:

- RQ1: Which challenges related to the distributed context disrupt the industrialisation process?
- RQ2: How do challenges related to the distributed context disrupt the industrialisation process?
- RQ3: How can different mechanisms be used to control the challenges?

The findings from the six appended papers contributed with knowledge about the industrialisation process by investigating challenges, the resulting disturbances and mechanisms in the three distributed contexts (see Figure 9). Papers 1, 2 and 3 contributed to the industrialisation process in the distributed geographical context (type 3 context). Furthermore, the same three papers contributed to the industrialisation process in the distributed geographical and organisational context (type 4 context). Papers 4, 5 and 6 contributed to the industrialisation process in the distributed organisational context (type 2 context).

All the papers contributed to the three RQs. Each paper included empirically derived challenges, disturbances and mechanisms. However, the focus of the papers varied, and the challenges, the disturbances or the mechanisms could be either a primary focus or a secondary focus in one paper.

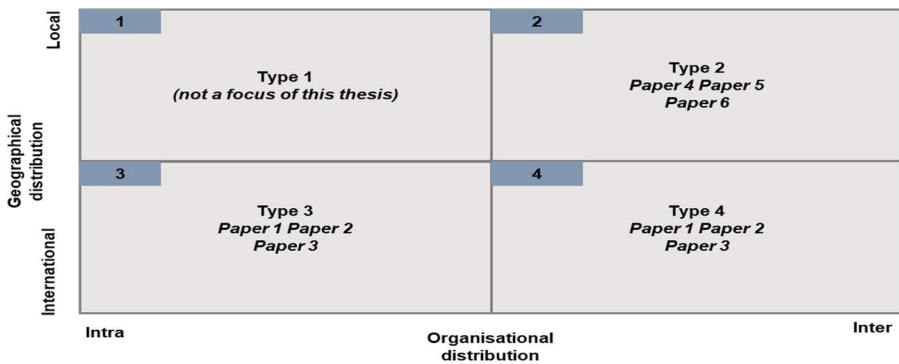


Figure 9 Overview of the papers.

The connection between the papers and RQs is shown in Table 10. The table indicates the primary and secondary focus in each paper. The dark grey nuance indicates that the challenge/disturbance/mechanism is a primary focus, while the light grey nuance indicates that the challenge/disturbance/mechanism is secondary focus.

Table 10 Relationships between the Papers and Research Questions

Papers	RQ1 Challenges related to distributed context	RQ2 Types of disturbances	RQ3 Mechanisms to control the challenges
Paper 1			
Paper 2			
Paper 3			
Paper 4			
Paper 5			
Paper 6			

Paper 1 addressed actors from the Swedish R&D site, Chinese industrialisation site and suppliers in China. The primary focus was on challenges related to the geographical distribution, with emphasis on linguistic and national cultural differences between the actors, and their effects on communication. As a secondary focus, various types of disturbances during the product industrialisation process, as well as several mechanisms were empirically derived and presented in this paper. The discussion in Paper 1 was related to literature on uncertainty and equivocality.

Paper 2 presented a study of the role of a boundary spanner in supporting communication between actors from the Swedish R&D site, Chinese industrialisation site and suppliers in China. Hence, the primary focus in Paper 2 was on the boundary spanner, seen as a mechanism that deals with national cultural differences and differences in linguistic skills between the distributed actors, and hence, supports communication and collaboration in the distributed geographical context. As a secondary focus, challenges and the resulting disturbances were addressed. The empirical findings in Paper 2 were related to the boundary-crossing literature.

Paper 3 presented a study on the role of visual representations in supporting communication between actors from the Swedish R&D site, Chinese industrialisation site and suppliers in China. The paper's primary focus was on the use of visual representations as mechanisms that were able to deal with challenges associated with differences in work experience, national culture and language between the distributed actors. By dealing with the challenges, visual representations could support communication and shared understanding between the actors in the distributed context. The challenges and resulting disturbances were mentioned, but they represented a secondary focus. The empirical findings in Paper 3 were related to communication in a distributed NPD project and analysed using the boundary-crossing literature.

Paper 4 focussed on the disturbances during the industrialisation processes of suppliers responsible for components/sub-systems according to the OEM's technical specifications. The technical specifications were developed by the Swedish R&D site belonging to the OEM. The primary focus of the paper was on challenges, the resulting disturbances and mechanisms used to control the challenges. The empirical findings in Paper 4 were related to the literature on the management of industrialisation from a supplier perspective, supplier integration in NPD projects and uncertainty.

Paper 5 presented a study on the integration between actors from the Swedish R&D site and actors from the suppliers. Challenges associated with the organisational distribution and mechanisms to control the challenges were the primary focus of the paper. In the paper, both the perspectives of the R&D site and supplier were used for the analysis. In Paper 5, the R&D site was referred to as the OEM. The disturbances during the suppliers' industrialisation processes were also addressed, but they were secondary focus of the paper. The empirical findings in Paper 5 were related to the literature

on industrialisation and production ramp up, as well as literature concerned with supplier integration in NPD projects.

Paper 6 presented a study on suppliers' industrialisation processes, investigating mechanisms in the organisational distribution context. The paper addressed actors from the Swedish R&D site, also referred to as OEM in Paper 6, and suppliers. The primary focus of the paper was on the mechanisms for supporting collaboration and communication between the actors from the Swedish R&D site and suppliers. Challenges and the resulting disturbances during the suppliers' industrialisation processes were also addressed, but they were secondary focus. The paper took both the Swedish R&D site and supplier perspectives. The discussion in Paper 6 was related to the organisational literature on uncertainty and equivocality.

This thesis focusses on the industrialisation process in three distributed contexts, namely, types 2, 3 and 4 (see Figure 1). A type 2 context refers to the industrialisation process in a distributed organisation, where the R&D and manufacturing actors are in one country but belong to different organisations. A type 3 context refers to the industrialisation process with geographical distribution, where the R&D and manufacturing actors are in different countries but belong to the same organisation. Finally, a type 4 context represents the industrialisation process with geographical and organisational distribution, where the R&D and manufacturing actors are in different countries and belong to different organisations. In sections 4.2–4.4, challenges, disturbances and mechanisms are presented for each of the three distributed contexts.

4.2 Industrialisation in the local and inter-organisational context (type 2)

Empirical findings from the industrialisation process in organisational distributed context (type 2) were addressed in Papers 4, 5 and 6 (see Figure 10). The findings are based on Studies B and C, addressing actors from the Swedish R&D site and suppliers. The empirically derived challenges and resulting disturbances are summarised in Table 11, and the mechanisms are summarised in Table 12. Challenges and mechanisms are denoted with abbreviation CH and M respectively. These symbols are used throughout the text. Each challenge/mechanism has a number that denotes first the type of the distributed context; type 2–4, and the number of the challenge/mechanism as listed in Table 11 and Table 12. Some of the mechanisms in the type 2 context

were suggested by the suppliers, and hence, they were seen as potential mechanisms; others were used by the suppliers. This is specified in Table 12.

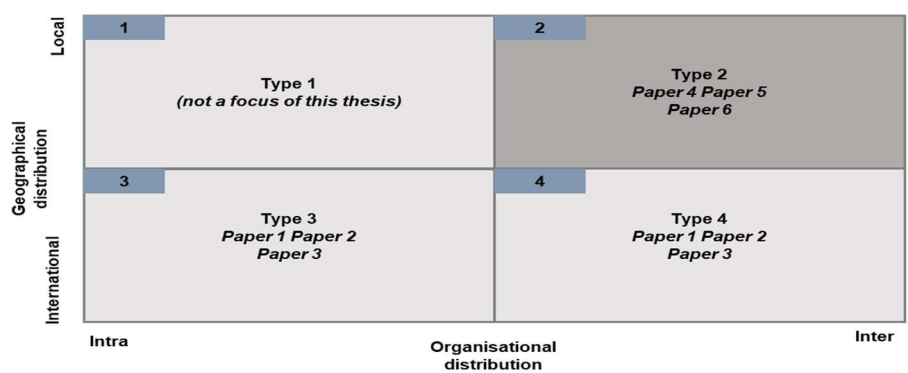


Figure 10 Papers related to the type 2 context.

The suppliers had work models that prescribed how they should organise and manage their industrialisation processes. These typically included critical tasks, responsible persons, deadlines and meetings. During the industrialisation process, suppliers were unable to follow their work models, since actors from R&D sites belonging to different OEMs had various requirements. Thus, the suppliers had to adapt quickly to what was required from the R&D sites at the various OEMs, at the expense of their work models. This meant that the suppliers ignored their models and skipped activities. The suppliers mentioned that they lacked a standardised work model that covered most of the requirements by the R&D sites (CH₂₋₁). It was difficult for the suppliers to plan and prioritise according to different requirements and orders from the R&D sites. For the suppliers, it was important to be able to adapt to the various requirements, but this needed to be done based on a standardised work model (M₂₋₁). The suppliers suggested that the standardised work model could include some degree of flexibility, which was important for coordination of the work internally at the supplier.

Suppliers explained that actors from the Swedish R&D site, and more specifically, the R&D actors, primarily focussed on new innovative solutions and ignored consideration of manufacturability aspects. The R&D actors were referred to as OEM (R&D) in Paper 5, while the R&D site was referred to as OEM. This often resulted in the need for engineering component design changes during the industrialisation process and the inability of the suppliers’

production systems to produce those components/sub-systems in accordance with set specifications and tolerances. The R&D actors lacked experience of consequences of tolerances placed on the component designs and imposed excessive requirements. The empirical findings indicated that the Swedish R&D site and suppliers did not share the same perspective on the timing of the integration of suppliers in the NPD process. While the actors from the Swedish R&D site considered that the suppliers were integrated into their NPD process in a timely manner, some suppliers experienced that they were integrated rather late (CH₂₋₂). For the suppliers, this meant that they had no possibility of influencing the component design. Thus, many components were difficult to produce. During the industrialisation process, the suppliers' input into components' producibility was appreciated by the Swedish R&D site.

The reasons identified in the study for the R&D actors not to consider the suppliers' inputs were associated with the fact that, first, the actors from the R&D site had in-house production competence, and second, the suppliers were responsible for industrialisation of low-risk components—that is, components with low complexity and criticality. Unwillingness of the R&D actors to collaborate and communicate with suppliers (CH₂₋₃) was explained according to the systemic interrelationships among components. This meant that component modifications would cause major effects on the product architecture. Furthermore, the R&D actors were pressed for time, and therefore, tried to minimise communication with the suppliers. The actors from the core project team at the Swedish R&D site indicated that one of the reasons for the unwillingness of the R&D actors to collaborate and communicate with the suppliers was that they were unused to interdisciplinary work.

Table 11 Challenges and the Resulting Disturbances

Number	Challenge (CH)	Disturbance	Identified in paper
(1)	Lack of standardised work model at the suppliers	<ul style="list-style-type: none"> • Inability of suppliers to plan industrialisation orders • Lack of training of project leaders on project organisation 	Paper 4
(2)	Late supplier integration	<ul style="list-style-type: none"> • Late engineering change orders (ECOs) 	Papers 4 – 6
(3)	R&D actors' attitude towards collaboration	<ul style="list-style-type: none"> • Late changes to the production process • Difficult for suppliers to verify the production system 	Paper 5
(4)	Late supplier selection decision	<ul style="list-style-type: none"> • Limited time for tool design and delivery by suppliers • Inability of suppliers to plan industrialisation orders 	Papers 4 and 6
(5)	Short NPD lead time	<ul style="list-style-type: none"> • Tool(s) are moved from overseas sub-suppliers before final verification • Transportation mode for tool(s) delivery not according to the quotation • Limited time for verification of the production system 	Paper 4

(continued)

Number	Challenge (CH)	Disturbance	Identified in paper
(6)	Incomplete component designs released by the R&D site	<ul style="list-style-type: none"> • Late ECOs • Not optimal tool(s) • Not possible to follow PPAP by suppliers 	Papers 4 and 5
(7)	Unclear agreements	<ul style="list-style-type: none"> • Full-run test completed after start of production • Difficult for suppliers to verify the production system 	Paper 4
(8)	Lack of formal process instructions to carry out transition from an industrialisation process to serial production at the suppliers	<ul style="list-style-type: none"> • Delayed start of production 	Papers 4 and 6
(9)	R&D site represented by various departments with different agendas	<ul style="list-style-type: none"> • Confusing information sent to suppliers from actors from different departments 	Paper 6

Table 12 Mechanisms

Number	Mechanism (M)	Potential role of suggested or used mechanisms	Discussed in paper
(1)	Standardised work model with degree of flexibility	<ul style="list-style-type: none"> • Suggested by suppliers to support the internal work and communication, including planning of industrialisation orders 	Papers 4 and 6
(2)	Supplier integrated before component design fixed	<ul style="list-style-type: none"> • Suggested by suppliers to support early release of information about the component design and specifications 	Paper 4
(3)	R&D site decision to select a supplier is transparent and made earlier	<ul style="list-style-type: none"> • Suggested by suppliers for motivational reasons • Suggested by suppliers to provide enough time for tooling design and production 	Paper 4
(4)	Suppliers communicate consequences of R&D site decisions	<ul style="list-style-type: none"> • Suggested by suppliers to improve communication between them and the R&D site 	Paper 4

(continued)

Number	Mechanism (M)	Potential role of suggested or used mechanisms	Discussed in paper
(5)	R&D actors conduct thorough investigations of the component design before first release to suppliers	<ul style="list-style-type: none"> Suggested by the suppliers to reduce the late engineering design changes 	Papers 4 and 6
(6)	Detailed full-run test agreements	<ul style="list-style-type: none"> Suggested by suppliers to control the relationship between them and the R&D site 	Paper 4
(7)	R&D site initiates NPD projects earlier	<ul style="list-style-type: none"> Suggested by suppliers to provide realistic timeframes for production system verifications 	Paper 4
(8)	Formal process instructions for transition from industrialisation process to serial production at the suppliers	<ul style="list-style-type: none"> Suggested by suppliers to support internal processes at the suppliers 	Papers 4 and 6
(9)	R&D-SQA-purchasing has discipline in internal communication	<ul style="list-style-type: none"> Suggested by suppliers and the R&D site to support communication between them 	Paper 6

(continued)

Number	Mechanism (M)	Potential role of suggested or used mechanisms	Discussed in paper
(10)	Suppliers' formal face-to-face meetings with the R&D site and internally	<ul style="list-style-type: none"> • Used by the suppliers to support communication and collaboration between them and the R&D site 	Papers 5 and 6
(11)	R&D site's face-to-face meeting on a project level	<ul style="list-style-type: none"> • Used by the R&D site to support communication with suppliers • Used by the R&D site to improve suppliers' commitment 	Papers 5 and 6
(12)	Mediator	<ul style="list-style-type: none"> • Used by the actors to support communication and collaboration between R&D site and suppliers 	Paper 5

Lack of collaboration and communication between the R&D actors and suppliers typically led to difficulties for the suppliers to obtain approval for components supplied by the PPAP. The PPAP is a process tool followed by the supplier responsible for industrialisation of components/sub-systems according to the OEM technical specifications (see Figure 3 in Paper 5). It ensures that the suppliers understand the OEM engineering design drawings and technical specification requirements. It is also important for the suppliers to show that their production systems can produce components consistently meeting those requirements during volume production.

The PPAP's fundamentals, as used by the Swedish R&D site, were based on the quality standards from the automotive industry's advanced product quality planning and OEM's requirements. The preparations for the PPAP submission were typically initiated with the purchase order. Design samples were the first step of approval of new components by the R&D actors from the Swedish R&D site, and it typically took several rounds to improve the component design. When a component had been successfully tested at the suppliers' location and verified, the component received the status of *technical release*. Following this, the R&D actors sent a PPAP call off, triggering examination of the capability of the production process for commencing series production. PPAP samples, that is, samples from serial-like production, were examined, and improvement rounds were carried out. The process ended with approval of PPAP samples by the R&D actors.

Some suppliers of components with high development risk, that is, components with high complexity and criticality, had the possibility to provide input before the component specifications were fixed. The reasons for this were that, first, the R&D actors had limited experience with polymer components, and therefore, the input of the polymer suppliers was sought. The suppliers explained that, in a successful industrialisation process, they were consulted earlier, and for example, assisted the R&D actors in defining the components' tolerances and dimensions (M₂₋₂). It was important that the R&D actors imposed requirements and tight tolerances only where they were really needed. The suppliers further stressed the important role of product design review meetings and use of product critique provided by the supplier with the offer.

A challenge faced by some of the suppliers was that the actors from the R&D site often involved several suppliers in competing during the quotation process and postponed the final selection decision (CH₂₋₄). This meant that the

actors from the R&D site started the collaboration and communication with the suppliers and initiated the tool design. However, the suppliers were selected when the tool design was ready. Furthermore, even if the R&D site decision to order was late, the actors from the R&D site required tool delivery as specified in the quotations. For the suppliers, this meant that they had less time for tooling design and production. Therefore, the suppliers expressed the need for the R&D site not only to involve suppliers but also select them early (M₂₋₃).

Tools were often produced by sub-suppliers, typically located in China. The challenge for one of the suppliers arose when the actors from the R&D site requested the supplier to transport the tools to the industrialisation site before final testing had been conducted by the sub-supplier and approved by the actors from the R&D site. This was because the product development project was pressed for time (CH₂₋₅). This conflicted with the supplier's desire to perform all tool modifications at the overseas sub-supplier due to cost issues. When engineering component design changes had to be implemented, the changes were carried out in the costlier environment in Sweden. Furthermore, the time pressure during tool testing and approval often required transportation by plane and not by boat, as specified in the quotation. This led to costlier tools. Some suppliers explained that it is important to communicate consequences and potentially increased costs to the actors from the R&D site if tooling is transported from the sub-suppliers prior to final approval (M₂₋₄).

The suppliers described that some actors from the R&D site often released technical specifications without conducting thorough investigations during the concept development stage if the technical specifications could be fulfilled (CH₂₋₆). Consequently, field tests of the product resulted in engineering change orders (ECOs) during tool verification, and many engineering design and tooling changes had to be carried out. Therefore, on many occasions, the PPAP call off preceded the technical approval of the components. The suppliers explained that a successful industrialisation process requires the actors from the R&D site to finalise the component designs before release to the suppliers (M₂₋₅). Then, costly tooling changes can be avoided and correct tooling ensured.

A challenge faced by one of the suppliers was that the agreements with the actors from the R&D site were not always clear as to who should cover the costs for components produced during the full-run test (CH₂₋₇). Full-run tests were part of the PPAP, and they were required by the R&D site to ensure that

the suppliers could produce in serial production. These tests were carried out at the suppliers prior to production start. One supplier explained that the actors from the R&D site did not need the components produced from the full-run test. Therefore, the suppliers did not produce those components. This meant that the suppliers' production system was not verified and the full-run test was postponed after SOP, that is, during the first production batch in the serial production. The supplier stated that agreements concerning full-run tests must be detailed (M₂₋₆).

The suppliers mentioned that the lead time requested from the actors from the R&D site seldom included potential time needed for improvement rounds. If included, the actors from the R&D site estimated an extremely short time for them (CH₂₋₅). When engineering component and tooling design changes took place as a result of failed tests at the R&D site, the suppliers were under extreme time pressure and needed to accelerate the production system verification process due to fixed market deadlines. The suppliers suggested that the R&D site should start the NPD project earlier so that there would be enough time for improvement rounds (M₂₋₇).

The suppliers indicated that some challenges also originated in their organisations. They reported that their organisations often lacked formal instructions to carry out transitions between the industrialisation process and serial production (CH₂₋₈), which influenced the verification of the production system before serial production. At the supplier side, this meant that the production organisation was not well informed about the new components, or in several cases, operators had no written production instructions. The suppliers suggested a formalised transition from the industrialisation process to serial production (M₂₋₈).

Communication during the industrialisation process was disrupted because the R&D site was represented by actors from various departments, including representatives from R&D, purchasing and supplier quality assurance, who communicated with the supplier. However, the actors had independent agendas, and it happened that they communicated conflicting requirements to the suppliers (CH₂₋₉). Therefore, it was important that different actors from the R&D site communicated internally to ensure consistency in communication with the suppliers (M₂₋₉).

One mechanism for supporting both collaboration and communication between the OEM and suppliers was formal, face-to-face meetings with the R&D site, as well as internal meetings in the supplier organisations (M₂₋₁₀).

The suppliers indicated that, to improve the communication during industrialisation, they initiated formal, weekly, face-to-face meetings with the actors from the R&D site. These meetings included actors from the R&D site to address engineering change requests and other production-related issues. Likewise, one of the suppliers explained that, to quickly address queries by the actors from the R&D site regarding components, a formal group consisting of various competences was formed internally. This group consisted of competences like production quality, purchasing and sales.

Another mechanism that supported the communication between actors from the R&D site and supplier during industrialisation was the R&D site's face-to-face meeting on a project level, also referred to as Supplier Day (M_{2.11}). This mechanism facilitated the commitment of the suppliers during component industrialisation. Many ideas concerning product design choices and component producibility originated during Supplier Day, where the suppliers had the opportunity to meet face-to-face with actors from the R&D site and observed their component application in the whole product. This mechanism was not planned at the beginning of the NPD project; however, the actors from the R&D site decided that there was a need for a face-to-face meeting with the suppliers at the beginning of the industrialisation process.

The technical lead from the R&D site supported the communication and collaboration between R&D actors from the R&D site and the suppliers (M_{2.12}). The person in the technical lead role was new to the R&D site and the R&D department, but this individual had previous experience with executing product development in a project organisation. The role of the technical lead expanded as a result of the disagreements between the R&D actors from the R&D site and the suppliers, who had different expectations for the approach to collaboration and communication between the distributed actors. The technical lead was not formally assigned as mediator, but the mediator's role emerged during industrialisation. The mediator forced intensive communication during the toolmaking process, with increased focus on product producibility during the PPAP.

4.3 Industrialisation in the international and intra-organisational context (type 3)

Empirical findings from the industrialisation process in a geographical distributed context (type 3) were addressed in Papers 1, 2 and 3 (see Figure 11). The findings are based on Study A, and they addressed actors from the R&D and industrialisation site. The empirically derived challenges and resulting disturbances are summarised in Table 13, and the mechanisms are summarised in Table 14.

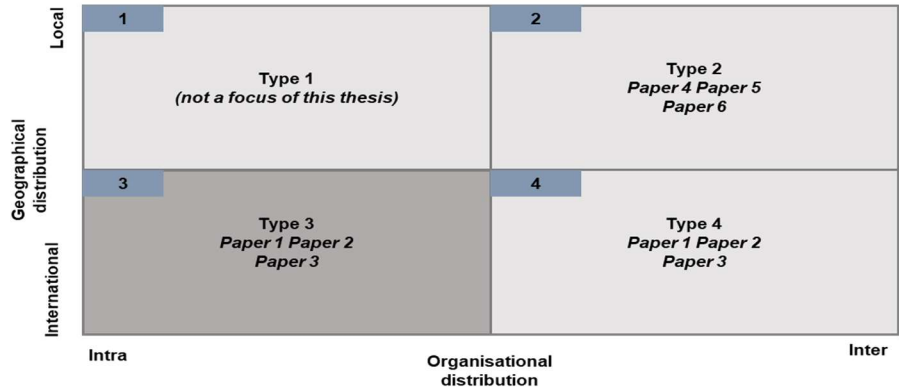


Figure 11 Papers related to the type 3 context.

The actors from the Swedish R&D site and Chinese industrialisation site had no experience working together (CH₃₋₁), despite the fact that they were part of the same company. When the NPD project was initiated, the industrialisation site had been recently acquired, and the product was one of the first to be industrialised at this site. This challenge led to actors who were unaware of their colleagues' work and did not know where to find information.

Bi-weekly project meetings via teleconferences were planned and held between the distributed actors from the R&D and industrialisation site. During the meetings, different issues were discussed that required the participation of actors from production planning, purchasing production and quality assurance from the industrialisation site. However, due to differences in linguistic skills (CH₃₋₂) among the actors, teleconferencing was not a proper means of communication.

The communication challenge was unexpected in the project. To cope with it, the R&D engineer from China, who was skilled in English, was involved

in the project meetings, although this actor had competence and expertise in another domain. The R&D engineer's primary role was technically supporting the newly acquired industrialisation site; however, as a result of the differences in linguistic skills, the engineer's role expanded, and he became facilitator and translator between the R&D site and industrialisation site. That is, the engineer acted as a mediator (M₃₋₁). Although the engineer had expertise in a specific engineering domain, the role as mediator involved disseminating information covering other domains. The Swedish R&D actors expected that the mediator would ensure that problems arising during the industrialisation process would be solved. The mediator had to conduct two types of meetings, one with the R&D site and one locally in China to transfer the information. The respondents mentioned that this extended communication often led to loss of information; alternatively, the information was modified in the translation process, especially when the mediator did not have the required expertise. As information was lost in the translation from English to Chinese, the actors from the industrialisation site had to ask for more information to understand the task at hand. Actors from the industrialisation site preferred to do this via e-mail (M₃₋₂), because it provided opportunities for clarification of tasks.

Table 13 Challenges and the Resulting Disturbances

Number	Challenge (CH)	Disturbance	Identified in paper
(1)	Lack of experience of working together	<ul style="list-style-type: none"> • Difficult to find necessary information 	Papers 1 and 3
(2)	Differences in linguistic skills	<ul style="list-style-type: none"> • Ineffective project meetings • Ineffective telephone meetings • Information lost and/or modified • Lengthier communication process 	Papers 1–3
(3)	National culture difference	<ul style="list-style-type: none"> • Unprepared industrialisation site • Improvement suggestions lost 	Papers 1 and 2

Table 14 Mechanisms

Number	Mechanism (M)	The role of used mechanisms	Discussed in paper
(1)	Mediator	<ul style="list-style-type: none"> Used by the distributed actors to support communication with the industrialisation site Used by the R&D site to facilitate and translate during project meetings 	Papers 1 and 2
(2)	E-mail	<ul style="list-style-type: none"> Used by the distributed actors for clarification of messages 	Paper 1

The national culture differences (CH₃₋₃) were not anticipated by the distributed actors, but during the industrialisation, evidence showed that this was a challenge. The national culture difference was manifested as differences in the actors' work behaviours. On some occasions, the actors from the industrialisation site did not reveal or share information with the actors from the R&D site because they did not perceive this to be part of their responsibilities. Another example was that, in China, the actors accepted tasks from managers high on the organisational hierarchy. However, this was not known by actors from the Swedish R&D site, who learned about Chinese cultural characteristics during the industrialisation process. One example of the national cultural difference as a challenge was when the laboratory engineers from the Swedish R&D site visited the industrialisation site to help with the assembly of the first test series. During the industrialisation, components were first produced and assembled in the first test series, denoted as the engineering pilot (EP1). It turned out that the site was not prepared as expected, although the industrialisation site was requested to prepare fixtures

for assembly, assembly sequence and assembly instructions. When the laboratory engineers arrived, no such preparations had been made. The actors from the Swedish R&D site explained that they understood later that this was because the information to start with the preparations was not supplied by an actor higher in the organisational hierarchy.

4.4 Industrialisation in the international and inter-organisational context (type 4)

Empirical findings from the industrialisation process in a geographical and organisational distributed context (type 4) were addressed in Papers 1, 2 and 3 (see Figure 12). The findings were based on Study A; hence, the findings in this section refer to the NPD project already described in section 4.3. However, in this section, the findings address actors from the R&D site and actors from the suppliers in China. The empirically derived challenges and resulting disturbances are summarised in Table 15, and the mechanisms are summarised in Table 16.

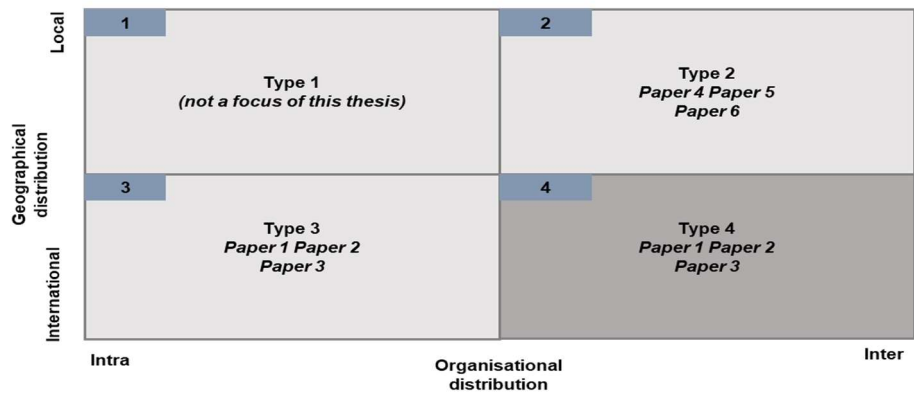


Figure 12 Papers related to the type 4 context.

Because the NPD project was already discussed in section 4.3, and the dimension of geographical distribution was present, it was not surprising that some of the challenges outlined between actors from the Swedish R&D site and Chinese industrialisation site also occurred between the actors from the Swedish R&D site and Chinese suppliers. These were the challenges related to differences in linguistic skills and national culture differences. The text

below describes how the challenges occurred between the R&D site and suppliers, as well as what the resulting disturbances were. One of the mechanisms that was studied in this thesis, namely the mediator, appeared to be important not only for supporting the communication and collaboration between the Swedish R&D site and Chinese industrialisation site but also between the Swedish R&D site and Chinese suppliers. More details about the role of the mediator in the type 4 context are described below.

The Swedish R&D site was keen to receive feedback from the suppliers in China regarding component manufacturability. However, the suppliers did not speak or read English. This was not anticipated by the R&D site and came as a surprise. Differences in linguistic skills between the distributed actors (CH₄₋₁) was a challenge that made it impossible to conduct external drawing reviews between the R&D site and suppliers. Therefore, the communication between the R&D site and suppliers had to occur via the Chinese industrialisation site, which differed from the conventional (direct) way of communication. This resulted in a lengthier communication process than expected. This initially caused confusion at the R&D and industrialisation sites about the roles and responsibilities of the actors, as well as the information flows with the suppliers. For reducing confusion and clarifying the information flow between the distributed actors, the project manager devised a visual illustration of the communication process, including annotations, text and arrows. The annotations showed the information flow between the actors. In this thesis, this is referred to as visual representation of a communication procedure (M₄₋₁). It was also referred to as an explicit communication procedure in Paper 1. The visual representation of the communication procedure was presented to the R&D and Chinese industrialisation site. The project manager explained that, after this was done, the questions regarding the communication process with the suppliers were reduced to a minimum. The M₄₋₁ mechanism was not planned at the outset of the NPD project, but it was devised when the differences in linguistic skills became apparent.

Table 15 Challenges and the Resulting Disturbances

Number	Challenge (CH)	Disturbance	Identified in paper
(1)	Differences in linguistic skills	<ul style="list-style-type: none"> • Ineffective external drawing reviews with suppliers • Lengthier communication process • Difficult to ensure suppliers' understanding of the required engineering design changes • Suppliers not delivering according to specifications • Unplanned, additional engineering pilot (EP) • Ineffective updated drawings and documentations used between R&D site and suppliers 	Papers 1–3
(2)	Different work experience	<ul style="list-style-type: none"> • Difficult to ensure suppliers' understanding of the required engineering design changes • Unplanned, additional engineering pilot • Ineffective updated drawings and documentations used between R&D site and suppliers 	Papers 1–3

(continued)

Number	Challenge (CH)	Disturbance	Identified in paper
(3)	National culture difference	<ul style="list-style-type: none"> Unplanned, additional engineering pilot 	Papers 1–3

Table 16 Mechanisms

Number	Mechanism (M)	Role of used mechanisms	Discussed in paper
(1)	Visual representation of a communication procedure	<ul style="list-style-type: none">• Used by the R&D site to support communication between distributed actors by clarifying ambiguities concerning actors' responsibility and establishing clear standards for how to exchange information	Papers 1 and 3
(2)	Mediator	<ul style="list-style-type: none">• Used by the distributed actors to support communication• Used by the distributed actors to support communication media like pictures, e-mails, external drawing reviews• Used by the distributed actors to support understanding and resolve conflicts between them	Papers 1 and 2
(3)	Picture books	<ul style="list-style-type: none">• Used by the distributed actors to support communication	Papers 1 and 3

As already mentioned, the communication between the R&D site and suppliers took place via the industrialisation site. At this site, the R&D engineer, referred to as the mediator in section 4.3 was involved. The initial responsibility of the R&D engineer was providing technical support to the newly acquired industrialisation site in China. However, during the project, due to differences in linguistic skills between the distributed actors, the role of the engineer expanded, and the engineer became a mediator (M_{4.2}). The mediator supported the communication between the R&D and industrialisation sites via the following measures: (1) collecting ECR drawings, (2) carrying out internal drawing reviews with the Swedish R&D site, (3) carrying out external drawing reviews with the suppliers and collecting feedback, (4) translating suppliers' feedback from Chinese to English and (5) delivering the feedback to the Swedish R&D site. The mediator had to agree once with the suppliers and then with the Swedish R&D site on the components' technical specifications.

Differences in linguistic skills (CH_{4.1}) and different work experiences (CH_{4.2}) between the distributed actors led to a lack of responsiveness to the received information. On several occasions, the actors experienced that, when ECOs—modifications for tooling to ensure component tolerance—were sent to the suppliers, the required changes were not implemented or implemented incorrectly. Hence, the components failed to meet the specifications. This was evident when the components arrived for EP2 for testing and verifications at the R&D site. Then, the R&D site discovered that the requested component changes had not been made. This made it difficult to verify design solutions. Actors from the R&D site suspected that updated drawings and documentations used to communicate the requested changes were ineffective. It turned out that the suppliers were not familiar with the existing drawing conventions and standards used by R&D (e.g. complex geometrical tolerances; CH_{4.2}). Moreover, they did not communicate this to the Swedish R&D site. The actors from the R&D site explained that this was associated with the Chinese culture; however, the R&D site was not prepared to expect any potential national culture difference (CH_{4.3}) at the beginning of the project. The lack of modifications during the engineering pilot (EP2) led to an additional, unplanned EP that had to be developed and tested to conduct tests with the modified components.

To ensure the implementation of the requested engineering component design changes, actors from the R&D site started to take photos of delivered

components that were not produced according to specifications, as well as making drawing printouts of components. The R&D site added annotations to these photos and printouts, including text and arrows to explain what was produced incorrectly and what needed to be modified. The collections of these photos and printouts are referred to as picture books (M_{4.3}); these were not planned for at the outset of the project, but they turned out to be crucial for the implementation of requested engineering design changes when challenges like differences in linguistic skills and work experiences emerged. After the introduction of the picture books, the suppliers started to implement the requested engineering design changes. The mediator had to ensure that the changes were implemented and was involved in translation of the annotations added to the pictures (M_{4.2}).

The communication with the suppliers took place via the mediator (M_{4.2}). The mediator facilitated and translated the messages exchanged by the distributed actors. On several occasions, there was a conflict between the R&D site and a supplier that delivered components that did not meet the specifications. The communication took place via e-mails, where the mediator translated the messages between the actors. However, the mediator did not always translate the messages between the actors directly; sometimes, the messages were modified, and some parts could even be omitted. The mediator was Chinese, and hence, familiar with the Chinese culture in terms of values and behaviour. At the same time, the mediator had experience with collaboration with the Swedish R&D actors, and hence, familiarity with the Swedish way of working and open communication style. The mediator tried to reduce the conflicts between the distributed actors. When suppliers thought that the Swedish R&D actors were demanding and did not understand why they should execute the drawing 100%, the mediator had to explain why it was necessary to be accurate when working with the actors from the Swedish R&D site. The mediator brought together distributed actors with different understandings of the communication process and translated and aligned perspectives.

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5 Discussion

This chapter discusses the main findings of the research by relating it to the prior literature. First, empirically identified challenges and disturbances are described in terms of the literature. Following this, the discussion of the empirically identified mechanisms is presented and related to the literature. The chapter ends with some conclusions and reflections on the research method used.

5.1 Challenges and disturbances during the industrialisation process

This section discusses the empirically derived challenges and disturbances related to the industrialisation process. The following sub-sections present the findings for the three types of contexts (types 2–4). As defined in this thesis, challenges are used to denote the sources of disturbances that occur during the industrialisation process, while a disturbance is defined as an event that negatively affects the success of industrialisation.

5.1.1 Industrialisation in the local and inter-organisational context (type 2)

The empirically identified challenges in the type 2 context are presented in Figure 13. These challenges are related to the prior literature on the industrialisation process.

In this thesis, challenges that suppliers face when responsible for the industrialisation process of components/sub-systems according to OEM's technical specifications are identified. Thus, the research complements the prior literature on the industrialisation process in the type 1 context, which has shown that many disturbances during the OEM's industrialisation process and production ramp up are related to the suppliers and their inability to deliver according to quality and on time (Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2014).

Prior research on industrialisation in the type 1 context has argued that the challenges that lead to disturbances during the OEM's industrialisation process and ramp up originate from inside the OEM or externally from the supplier (Almgren, 2000).

Geographical distribution	Local	1	2
		Type 1 (not a focus of this thesis)	Type 2 <ul style="list-style-type: none"> • Lack of standardized work model at the suppliers • Late supplier integration • R&D actors' attitude towards collaboration • Late supplier selection decision • Short NPD lead time • Incomplete component designs released by the R&D site • Unclear agreements • Lack of formal process instructions to carry out transition from an industrialisation process to serial production at the suppliers • R&D site is represented by various departments with different agendas
International		3	4
		Type 3 <ul style="list-style-type: none"> • Lack of experience of working together • Differences in linguistic skills • National culture difference 	Type 4 <ul style="list-style-type: none"> • Differences in linguistic skills • Different work experience • National culture difference
		Intra	Inter
		Organisational distribution	

Figure 13 Empirical challenges identified in the type 2 context.

The findings of this thesis corroborate the prior findings. They reveal that the challenges that lead to disturbances during the supplier's industrialisation process of components/sub-systems according to OEM's technical specifications originate internally from the supplier's industrialisation site, externally from the R&D site at the OEM or from the integration between the actors from the R&D site and the industrialisation site. Internal challenges, for example, include the *lack of formal process instructions to carry out the transition from an industrialisation process to serial production*; CH₂₋₈; or *lack of standardised work models at the suppliers*; CH₂₋₁. In contrast, external challenges include *incomplete component designs released by the R&D site*; CH₂₋₆; *short NPD lead time* without time for improvement rounds; CH₂₋₅; or *unclear agreements* between the distributed actors; CH₂₋₇.

Previous research classified limited tests on products before production ramp up as product-related disturbances (Fjällström *et al.*, 2009). The findings in this thesis confirms that an insufficient full-run test before the SOP is a disturbance. However, the findings further indicate the challenge that leads to this disturbance, which is *unclear agreements*; CH₂₋₇. This challenge belongs to communication-related issues rather than product-related ones. Therefore,

it shows that effort should be made towards better communication through agreements to ensure the necessary tests are performed. The literature on supplier integration in NPD states that a lack of communication and unclear agreements may result in diverging expectations about the responsibilities and terms of collaboration between the supplier and OEM (Wynstra, Van Weele and Weggemann, 2001; Childerhouse and Towill, 2011).

In contrast to the prior research on the industrialisation process in the type 1 context (Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2014), a holistic view is adopted in this thesis, covering not only the disturbances but also the challenges that lead to them. For example, the prior research argues that personnel-related disturbances during the OEM's industrialisation process include too little training for the assembly operators (Fjällström *et al.*, 2009). This thesis reveals the lack of training of project leaders on how to organise projects as a disturbance during the supplier's industrialisation process. Importantly, this thesis reveals the challenge that leads to this disturbance; in this case, it is related to suppliers' internal organisation and refers to the *lack of a standardised work model at the supplier side*; CH₂₋₁. Thus, this thesis stresses the importance of identification not only of the disturbances but also challenges that lead to them. Hence, it corroborates Almgren's (2000) recommendation to investigate the challenges resulting in disturbances during the industrialisation process. However, Almgren (2000) does not investigate the challenges that lead to disturbances during the supplier's industrialisation process, instead perceiving the suppliers as a challenge that lead to disturbances during the OEM's industrialisation process. Some of the challenges identified in this thesis are related to personnel or the actor's experiences and competences; an example is *R&D actors' attitudes towards collaboration*, CH₂₋₃. Thus, the challenges identified in this thesis are organisation related, communication related and personnel related or related to the actors experiences and competences. Similar categories have been discussed for the classification of disturbances in the prior literature (Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2014).

Some challenges and disturbances identified in the type 2 distribution context are similar to those shown in the literature for the type 1 context. The findings of this thesis indicate that engineering design changes are disturbances during the supplier's industrialisation process. Engineering design changes as disturbances during the OEM's industrialisation process have been discussed in the prior literature (Fjällström *et al.*, 2009). Late

engineering design changes lead to the inability of the suppliers to update tools or production systems and manage integration with sub-suppliers (Almgren, 2000; Lakemond *et al.*, 2012). The findings of this thesis corroborate prior research arguing that *incomplete component design release by the R&D site; CH₂₋₆*; leads to engineering design changes, which disturb the suppliers' industrialisation process. In contrast to prior research (Twigg, 2002), the findings of this thesis reveal that the suppliers responsible for industrialisation are not encouraged by the R&D site to provide inputs on design changes from a manufacturing perspective before the start of the industrialisation process.

The findings of this thesis show that engineering design changes after tool ordering are unacceptable, since they affect the tooling performance in terms of product quality and productivity. These findings corroborate prior research on industrialisation in the type 1 context (Almgren, 1999; Terwiesch, Bohn and Chea, 2001), arguing that the cost of the tool change depends on its timing, that is, before the start of the prototype tooling, before the SOP or after the SOP (Terwiesch and Loch, 1999).

The findings of this thesis suggest that *incomplete component designs released by the R&D site; CH₂₋₆*; could disrupt the PPAP—followed by suppliers of components/sub-systems responsible for industrialisation. In the type 2 context, the PPAP fails to support communication between the distributed actors and ensure that the suppliers can meet the manufacturability and quality requirements of the components supplied to the R&D site. This is especially difficult when the technical specifications change continuously. It is also difficult for the suppliers to respond quickly to changing technical specifications, and hence, there is a failure to provide evidence that the technical specifications are understood and fulfilled by the suppliers.

Fjällström *et al.* (2009) find that an unrealistic project time plan is an organisation-related disturbance during the OEM's industrialisation process and production ramp up. The findings of this thesis show that a *short NPD lead time; CH₂₋₅*; is an organisation-related challenge that results in disturbances associated with tool production and verifications during the supplier's industrialisation process. Moreover, Fjällström *et al.* (2009) report communication-related disturbances like information loss between the organisational functions. The findings of this research indicate that a communication-related challenge could be that the *R&D site is represented by various departments with different agendas; CH₂₋₉*. Hence, the findings of this thesis show that what have been considered as disturbances in prior literature

can be perceived here as challenges that result in various disturbances during the supplier's industrialisation process. However, the findings of this thesis associated with the type 2 distribution context confirm what has been found in the type 1 distribution context.

Unique challenges are also identified in this thesis, that is, challenges not presented in the prior literature. These are the *lack of standardised work model at the suppliers*; CH₂₋₁; *R&D actors' attitudes towards collaboration*; CH₂₋₃; *late supplier selection decisions*; CH₂₋₄; and *late supplier integration*; CH₂₋₂. Some of these challenges are organisation related, for example, the *lack of a standardised work model*; others are personnel related, that is, related to actors' experiences and competences, as in *R&D actors' attitudes towards collaboration*.

The findings of the thesis show that these challenges disrupt suppliers that industrialise components/sub-systems. However, some of the challenges have been addressed in the literature on supplier integration in NPD but not directly associated with the industrialisation process. The findings of this thesis stress actors' experiences and competences as challenges corroborating prior research. As Ellegaard, Johansen and Drejer (2003) argue, the success of the integration between the OEM and the supplier relates to the human factor.

A power imbalance between the OEM and supplier responsible for industrialisation could be one possible explanation for some of the challenges. The technology competences of the suppliers from the metallurgical and polymer industries studied in this thesis are not unique; other suppliers exist that can deliver similar technology. As found by prior researchers (Hoegl and Wagner, 2005; McCarthy, Silvestre and Kietzmann, 2013), the lack of supplier uniqueness could be a reason for the OEM to have power over the suppliers. Therefore, when there are organisational differences—that is, a low degree of alignment between the OEM and suppliers' organisations, processes, cultures and capabilities—the OEM tends to be flexible and not commit to a single supplier (Melandar and Tell, 2014). This could be a possible explanation for the *R&D actors' attitude towards collaboration*; CH₂₋₃; and *late supplier selection decision*; CH₂₋₄.

This thesis corroborates prior research (Stjernström and Bengtsson, 2004; McIvor, Humphreys and Cadden, 2006), revealing that suppliers responsible for industrialisation are played off by the OEM to extract better industrialisation offers in terms of price and lead time. The findings of this thesis show that a powerful OEM may lack a holistic perspective on how their

decisions influence the suppliers' abilities to achieve initially specified targets in terms of volume quality and cost. Unwillingness of R&D actors to collaborate could be explained with the findings from Lichtenthaler and Ernst's (2006) literature review regarding 'not-invented-here' (NIH) syndrome or negative attitudes towards ideas from external sources. NIH syndrome could help explain the observed behaviour of the R&D actors that exhibited negative attitudes and resisted adoption of innovations and improvement suggestions by the suppliers, that is, sources outside the OEM or R&D organisational unit.

The findings of this thesis indicate complexity during the industrialisation process in the type 2 context. This is because, during industrialisation, inputs from actors from the industrialisation site and R&D site are required. The actors come not only from different organisational functions but also different organisations. Complexity is typically associated with involvement of actors from different functions and organisations in a simultaneous effort (Olausson and Berggren, 2010). This is referred to as organisational complexity, and it can create uncertainty (Baccarini, 1996; Griffin, 1997; Von Corswant and Tunälv, 2002). The findings show that complexity can lead to disturbances during the industrialisation process, as the complexity leads to increased lead times in NPD (Clark and Fujimoto, 1991). Thus, the findings in this thesis corroborate prior research arguing that a distributed organisational context, where the R&D and manufacturing actors belong to different organisations, creates complexity during the industrialisation process (Lakemond *et al.*, 2012; Gustavsson and Säfsten, 2017).

The findings show that the reluctance of some of the actors to collaborate and a lack of standardised processes contribute to complexity during the industrialisation process. The complexity is typically dealt with via formalisation. However, in the type 2 distribution context, some of the process tools, such as the PPAP, are not followed, which contributes to complexity. Complexity is further associated with the degree of change in the product design and production system (Säfsten *et al.*, 2014). The novelty of the components designed by the R&D site and tooling designed by the industrialisation site contributes further to complexity. In accordance with the prior research, it also contributes to increased levels of uncertainty (Wheelwright and Clark, 1992; Tatikonda and Rosenthal, 2000; Song and Montoya-Weiss, 2001).

Frequently changing technical specifications create uncertainty at the industrialisation site, for example, during the tool verification process. This is in accordance with the prior research arguing that changes in the customer requirements create uncertainty (Galbraith, 1973; Wheelwright and Clark, 1992; Säfsten *et al.*, 2014).

5.1.2 Industrialisation in the international and intra-organisational context (type 3)

The empirically identified challenges in the type 3 context are presented in Figure 14.

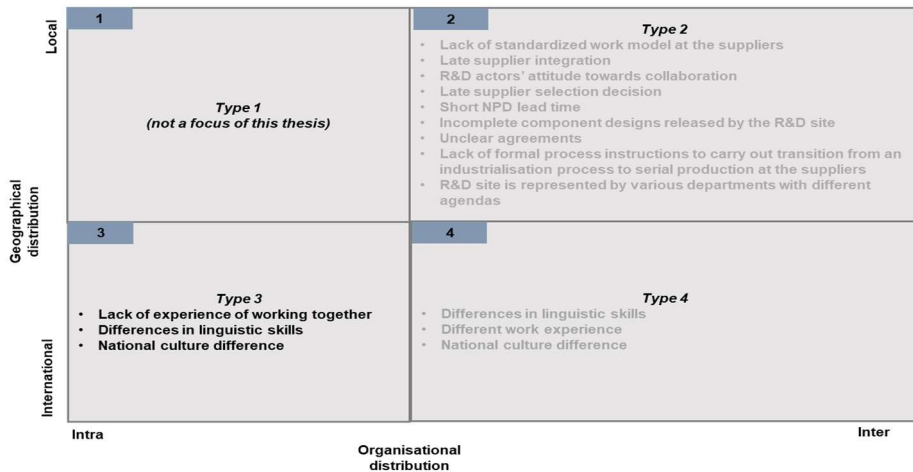


Figure 14 Empirical challenges identified in the type 3 context.

In this context, some unique challenges are identified, and hence, add to the prior research on the industrialisation process. Challenges like actors' *lack of experience of working together*; CH_{3-1} ; *differences in linguistic skills*; CH_{3-2} ; and *national culture differences*; CH_{3-3} ; have not been related to the industrialisation process context. All three challenges are tied to the actors' experiences and competences. The prior literature has identified personnel and education factors, such as assembly operators' education and skills or a lack of qualified personnel, as disturbances during the industrialisation process (Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2014). This thesis argues that the challenges that lead to the disturbances can also be categorised as personnel related, or here, also related to the actor's experiences and competences.

All the challenges identified in the type 3 distributed context originate from the integration between actors from the R&D and industrialisation sites. As stated in section 5.1.1, these challenges are considered external. Actors' *lack of experience of working together*, *differences in linguistic skills* and *national culture differences* result in disturbances like lengthier communication processes during industrialisation. Communication-related disturbances during the industrialisation process, however, are not a unique finding; rather, this result confirms prior research (Surbier, Alpan and Blanco, 2014). Challenges like national cultural diversity, lack of shared context and diverse work culture have been discussed as challenges during the NPD process, but they are rarely discussed in relation to the industrialisation process (Armstrong and Cole, 2002; Hinds and Bailey, 2003; Säfsten *et al.*, 2014; Cash, Dekoninck and Ahmed-Kristensen, 2017).

Because of challenges associated with the actors experiences and competences, which are *different linguistic skills* and *national culture differences*, actors are unwilling to share information regarding improvement suggestions or communicate on other decisions taken. Furthermore, information is lost and modified in the lengthier communication process. A lack of available and up-to-date information creates difficulties for actors to make decisions, and hence, this increases the sense of uncertainty during the industrialisation process. As defined above, uncertainty is the difference between the available information to carry out a task and the amount of information possessed by the actors (Galbraith, 1973).

The findings of this thesis show that novelty of the integration between the actors, as well as the geographical distribution—understood as differences in language and culture—creates equivocality during the industrialisation process. Prior research has mainly discussed equivocality during the NPD process, and specifically, its early stages (e.g. Daft, Lengel and Trevino, 1987; Frishammar, Floren and Wincent, 2010). The findings of this thesis show that the challenges associated with the type 3 context create equivocality during the industrialisation process. Prior research shows that equivocality occurs because of differences in terms of education, experiences and the background between the actors (Frishammar and Hörte, 2005; Koufteros, Vonderembse and Jayaram, 2005). While more information needs to be processed to reduce uncertainty (Galbraith, 1974), the findings of this thesis indicate that, in the type 3 context, where the R&D and manufacturing actors are distant from each other and *differences in national culture*; CH_{3-3} ; and *linguistic skills exist*;

CH₃₋₂; production of more information to reduce uncertainty (e.g. during project meetings) induces a risk of increasing the level of equivocality. Because information can be modified in the translation process, additional information can be interpreted differently, thereby leading to an increased sense of equivocality.

A unique finding in the type 3 context is that the challenges associated with actors' experiences and competences result in ineffective communication media like project meetings and teleconferencing. Communication media are devised to support the communication about actors' tasks and responsibilities across geographical boundaries. In contrast to the findings of Terwiesch, Bohn and Chea (2001), who indicate that information technology can be useful in the distributed geographical context, the findings of this thesis show that, when actors are geographically distant and work during the industrialisation process, some communication media may be ineffective. Thus, the findings corroborate some of the research on distributed NPD processes, arguing that geographical distribution disrupts the integration between the distributed actors (Bergiel, Bergiel and Balsmeier, 2008; Säfsen *et al.*, 2014; Cash, Dekoninck and Ahmed-Kristensen, 2017).

The findings of this thesis agree with prior research arguing that the distributed geographical context complicates the establishment of integration between the R&D and manufacturing actors during industrialisation (Lakemond *et al.*, 2012). Many disturbances during the industrialisation process may be a result of the challenges associated with the establishment of integration between the R&D and manufacturing actors in the distributed geographical context. The uncertainty and equivocality resulting from the distributed geographical context implies that previously established routines for industrialisation have become less useful in their current form.

5.1.3 Industrialisation in international and inter-organisational context (type 4)

The empirically identified challenges in the type 4 context are presented in Figure 15.

In this context, where the R&D actors and the actors from the suppliers are geographically distributed and belong to two different organisations, some unique challenges are identified. The challenges are *differences in linguistic skills*; CH₄₋₁; *actors' different work experience*; CH₄₋₂; and *national culture differences*; CH₄₋₃. All three challenges are related to the actor's experiences

and competences. As mentioned in section 5.1.2, the research on industrialisation in the type 1 context has identified the personnel’s skills and qualities as a disturbance during the industrialisation process (Fjällström *et al.*, 2009; Surbier, Alban and Blanco, 2014). This thesis argues that the challenges that lead to the disturbances can also be categorised as personnel related, or here, referred to as related to the actors’ experiences and competences.

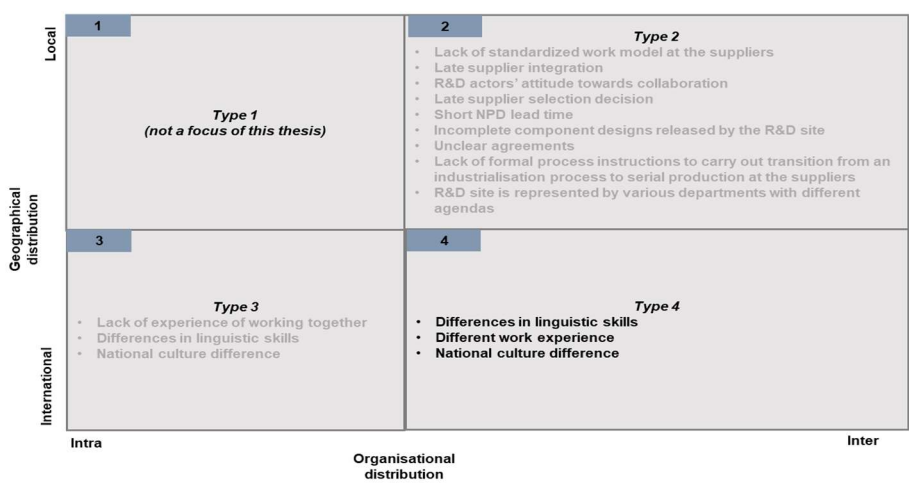


Figure 15 Empirical challenges identified in the type 4 context.

All the challenges identified in the type 4 context originate from the integration between the actors from the R&D site and industrialisation site, and thus, they are considered external. *Actors’ different work experiences, differences in linguistic skills* and *national culture differences* result in disturbances like lengthier communication processes during industrialisation. As previously stated, communication has been identified as a disturbance during the industrialisation process (Fjällström *et al.*, 2009). The findings in the type 4 context show that the challenges associated with actors’ experiences and competences result in ineffective communication media like external drawing reviews and updated drawings and documentations. The challenges also result in EPs.

In the type 4 context, actors’ experiences and competences affect the shared understanding between them. This means that the information is not understood by the receiver as intended by the sender. In the case, the actors

from the suppliers could not understand the engineering design changes requested by the actors from the R&D site. The lack of shared understanding between the distributed actors contributes to a sense of equivocality during the industrialisation process. The presence of complex, new situations and organisational unit specialisation are typical sources of equivocality indicated in the prior research (Daft, Lengel and Trevino, 1987; Frishammar, Floren and Wincent, 2010). The findings of this thesis indicate that, in the type 4 context, *differences in linguistic skills* can lead to actors interpreting information in various ways and a lengthier and more complex communication process. In the specific context, national culture differences could affect the quality of received information and responsiveness to the information received. This, in turn, creates a sense of uncertainty, where information that is available to actors may not be enough to complete a task.

5.2 Mechanisms

To control the challenges and prevent disturbances during the industrialisation process, various mechanisms are suggested or implemented in practice by the R&D site and/or industrialisation site.

5.2.1 Industrialisation in the local and inter-organisational context (type 2)

In the type 2 context, mechanisms are intended to control the challenges and deal with uncertainty and complexity (see Figure 16). In general, the mechanisms identified intend to integrate actors at the industrialisation site or R&D site, as well as between the R&D site and industrialisation site. The findings show that internal integration at the industrialisation site is important for external integration with the R&D site. The findings suggest that the supplier's internal capabilities and motivation are prerequisites for improved integration with the R&D site. They also show that internal integration at the R&D site, like *R&D-SQA-purchasing discipline in internal communication*; M_{2.9}; is important for external communication with the industrialisation site. Hence, the findings confirm the prior literature's finding that internal integration at the OEM improves external integration with the suppliers (Von Corswant and Tunälvy, 2002; Hillebrand and Biemans, 2004; Lakemond and Berggren, 2006).

Geographical distribution	Local	1	2
		Type 1 (not a focus of this thesis)	Type 2 <ul style="list-style-type: none"> Standardised work model with degree of flexibility Supplier integrated before component design is fixed R&D site decision to select a supplier is transparent and made earlier Suppliers communicate consequences of R&D site decisions R&D actors conduct thorough investigations of the component design before first release to suppliers Detailed full run test agreements R&D site initiates NPD projects earlier Formal process instructions for transition from industrialisation process to serial production at the suppliers R&D-SQA-purchasing discipline in internal communication Suppliers' formal face-to-face meetings with the R&D site and internally R&D site's face-to-face meeting on a project level Mediator
International		3	4
		Type 3 <ul style="list-style-type: none"> Mediator E-mail 	Type 4 <ul style="list-style-type: none"> Visual representation of a communication procedure Mediator Picture books
		Intra	Organisational distribution
		Inter	

Figure 16 Empirical mechanisms identified in the type 2 context.

Some mechanisms encourage early release of information from the R&D site to the industrialisation site through early integration, that is, in *supplier integration before the component design is fixed*; M_{2-2} . In this way, actors from the industrialisation site will start production preparation earlier and have more time for the industrialisation process. These mechanisms are intended to deal with communication-related challenges, such as late supplier integration. It is also important that the actors from the *suppliers communicate the consequences of R&D site decisions*; M_{2-4} . Early involvement of actors from production or the supplier has been found to be important in the previous research for reducing the late engineering design changes (Johansen, 2005; Kleinsmann, Valkenburg and Buijs, 2007; Smulders and Dorst, 2007; Winkler, Heins and Nyhuis, 2007; Ulrich and Eppinger, 2016). The earlier the need for engineering design changes is detected, the less costly it is to implement them (Terwiesch and Loch, 1999; Twigg, 2002; Olausson, Magnusson and Lakemond, 2009). In the literature on supplier integration in NPD, early supplier integration has also been the focus. However, the prior research has mostly been concerned with early involvement of suppliers in the component design. Early release of information from the R&D site is also related to the issues of early supplier selection. The findings of this thesis show

that it is important that the *R&D site decision to select a supplier is transparent and made earlier*; M_{2-3} .

The mechanisms are also intended to control some of the organisation-related challenges, such as a lack of instructions for transition, and communication-related challenges, such as unclear agreements, through increased formalisation. These mechanisms, for example, are *standardised work models*; M_{2-1} , *detailed full-run test agreements*; M_{2-6} ; and *formal process instructions from the industrialisation process to serial production at the suppliers*; M_{2-8} . The findings of this thesis recognise that formalisation is one way of improving the supplier's industrialisation process. Engwall, Kling and Werr (2005) conclude that standardised work models are effective mechanisms for facilitating integration between actors during projects and assisting in unifying divergent actors' perspectives on project goals and work processes. Formalisation is also recommended by Twigg (2002), who stresses the importance of work models that provide a template and guidance for actions. To deal with challenges related to actors' experience and competence, detailed agreements are important. According to the prior research on supplier integration in NPD, detailed agreements can reduce the OEM's power over suppliers (LaBahn and Krapfel, 2000). Such agreements are important for facilitation of integration through goal congruence (Li *et al.*, 2014), as well as the commitments of the distributed actors (Madenas *et al.*, 2014). Standards, schedules and plans are recommended by Twigg (2002) to increase formalisation during the industrialisation process in the distributed organisational context.

Because of the uncertainty during the industrialisation process, there is a need for flexibility through utilisation of organic mechanisms (Burns and Stalker, 1961; Olausson and Berggren, 2010; Säfsen *et al.*, 2014). Therefore, to cope with uncertainty, some of the mechanisms are intended to increase the intensity of communication through meetings, for example, in *suppliers' formal, face-to-face meetings with the R&D site and internally*; M_{2-10} ; project plans, such as in the *R&D site's earlier initiation of the NPD project*; M_{2-7} and *standardised work models with a degree of flexibility*; M_{2-1} . To cope with challenges related to actors' experiences and competences, the findings of this thesis show the importance of, for example, *R&D site face-to-face meetings on a project level*; M_{2-11} .

To reduce the negative consequences of engineering design changes for production tooling, the findings of this thesis stress the need for the *R&D site*

to conduct thorough investigations of the component design before first release to suppliers; M₂₋₅. In addition, it is important that the design is frozen before tools are ordered, as well as that tools are developed in steps (i.e. prototype and production). The findings of this thesis corroborate the prior research (Langowitz, 1989).

In the type 2 context, because of the challenges related to organisation, communication and actors' experience and competence, ad hoc mechanisms are devised and emerge as important. To support the communication between the organisationally distributed actors, the actors from the R&D site devise the *R&D site face-to-face meeting on a project level, M₂₋₁₁*. Furthermore, the role of the *mediator; M₂₋₁₂*; emerges as important for dealing with the challenges and supporting integration between the distributed actors. In the type 2 context, the mediator can support the communication and collaboration between the OEM and suppliers responsible for the industrialisation process of components/sub-systems according to OEM's technical specifications. This is because the mediator is new to the OEM and the R&D site and has previous experience of tight collaboration between R&D actors and actors from the suppliers working on the industrialisation process. The role of integrators or the liaison staff is discussed as a mechanism that assists in resolving disagreements rather than obtaining a large amount of information for reducing uncertainty (Galbraith, 1974; Daft and Lengel, 1986). The findings of Lichtenthaler and Ernst's (2006) review suggest that avoiding the negative consequences of NIH syndrome requires gatekeepers and promoters.

5.2.2 Industrialisation in the international and intra-organisational context (type 3)

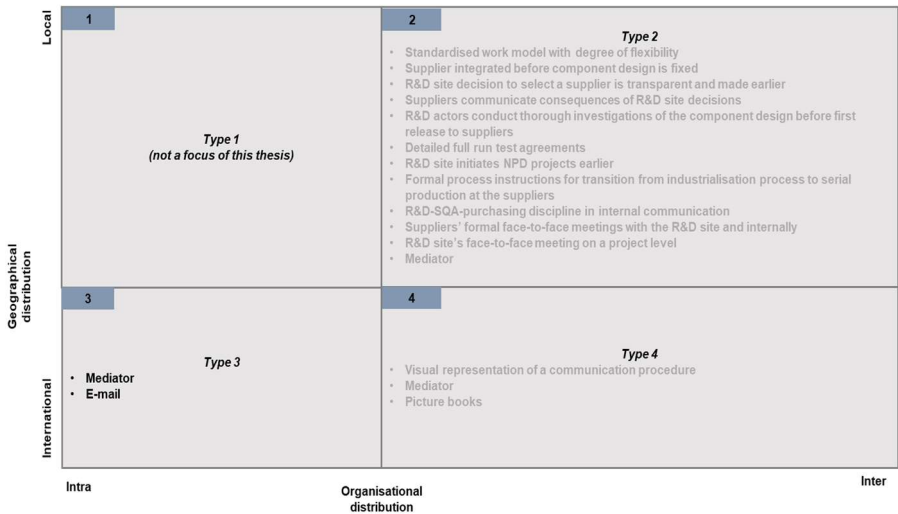


Figure 17 Empirical mechanisms identified in the type 3 context.

In the type 3 context (see Figure 17), to control the challenges associated with actors’ experiences and competences, the findings of this thesis show the important role of *mediators*; M_{3-1} ; and *e-mail*; M_{3-2} . Because of the challenges, some of the conventional mechanisms become ineffective; that is, as seen in project meetings, the mechanisms cannot be used as initially intended. Therefore, new mechanisms are devised and used to cope with the challenges and ensure integration, that is, communication and collaboration between the distributed actors.

Because of the challenges associated with actors’ experiences and competences, an actor who initially has other responsibilities becomes a *mediator*; M_{3-1} . The findings of this thesis show that the role of the mediator emerges as important to support the communication and collaboration between geographically distributed actors located in Sweden and China. As argued in prior research (Nochur and Allen, 1992; Levina and Vaast, 2015), the emergence of actors as mediators is more important than formally designated ones. Thus, the findings of this thesis corroborate prior research that promotes the role of mediator during the industrialisation process in the distributed organisational context (Lakemond *et al.*, 2012). In Lakemond *et*

al.'s (2012) study, a mediator is officially assigned to facilitate integration between the R&D actors (in Sweden) and the geographically distributed production site (in Poland) during the industrialisation process. In their case, the mediator is officially assigned and does not emerge due to challenges. However, despite being officially assigned to the role, the R&D and manufacturing actors' expectations of the mediator role differ.

The findings of this thesis show that, in the type 3 context, the *mediator* could support the communication and collaboration between the distributed actors because he had the following attributes: (1) familiarity with the Chinese culture (values and behaviour patterns) coupled with tight collaboration with the Swedish R&D site and (2) good English skills, which assisted in translating and supporting various types of communication media, such as the project meetings, during the industrialisation process.

Prior literature states that equivocality is best dealt by using rich communication media like face-to-face communication (Daft and Lengel, 1986; Weick, 1995). In the geographically distributed context, prior research recommends the use of rich media like video and teleconferencing (Barczak and McDonough, 2003; Hinds and Bailey, 2003; Ceci and Prencipe, 2013). According to Daft, Lengel and Trevino (1987), rich media enable the sender and receiver to arrive at a shared understanding, and hence, reduce equivocality, in a faster manner. However, in the type 3 context, where the actors are distributed and have little prior experience of working together, the use of rich media is not possible. The findings of this thesis show that, instead of telephone meetings—considered a rich communication medium in the literature—the medium that truly helped to reduce equivocality was *e-mail*. This thesis shows that the use of less rich communication media like e-mail could support communication and shared understanding between the distributed actors about their tasks. This thesis shows that the media with the most rapid feedback may not be the most suitable when the aim is to reduce the equivocal tasks. The thesis is in line with Markus' (1994) study finding that media of low richness, such as text-based e-mails, are appropriate for dealing with complex communication and equivocal tasks. This can be explained in that e-mail, as an asynchronous communication medium, gives the receiver time to understand the shared information and prepare proper feedback.

5.2.3 Industrialisation in the international and inter-organisational context (type 4)

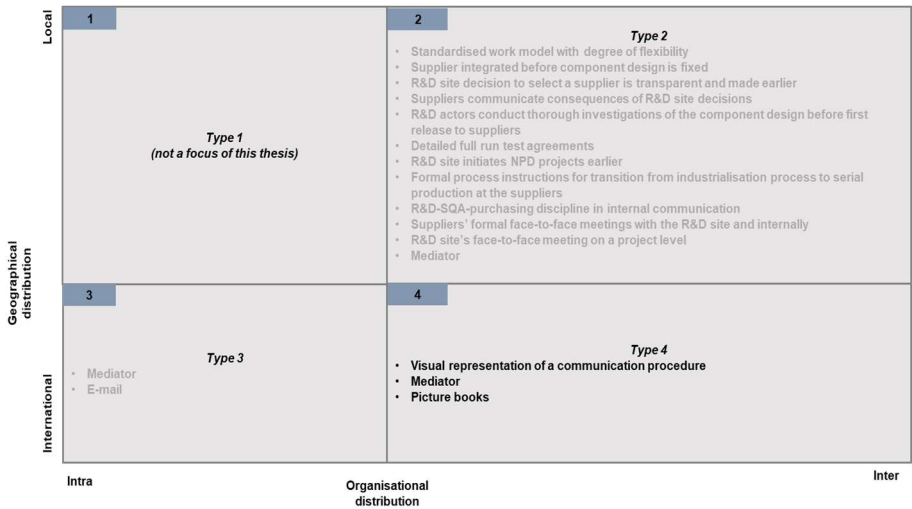


Figure 18 Empirical mechanisms identified in the type 4 context.

In the type 4 context (see Figure 18), to control the challenges associated with actors’ experiences and competences, the findings of this thesis show the important roles of the *visual representation of a communication procedure*; $M_{4.1}$; the *mediator*; $M_{4.2}$, and *picture books*; $M_{4.3}$. These are unique mechanisms that have not been discussed in the prior research on the industrialisation process.

The role of *mediator*; $M_{4.2}$; emerges as important for supporting communication and collaboration, not only between the R&D and manufacturing actors, as discussed in section 5.2.2, but also between the R&D actors and the actors from the suppliers in the type 4 context. Furthermore, to deal with the challenges, the R&D site starts to use picture books and visual representations of the communication procedure to support communication between the distributed actors. The findings in the type 4 context show that, when the initially devised mechanisms do not work as intended, it is likely that new mechanisms will emerge to cross the boundaries between the actors created by various challenges. This is in line with Levina and Vaast’s (2005) study emphasising the ‘in-use’ mechanisms.

The findings of this thesis show the use of visual representations, such as *visual representation of the communication procedure*; $M_{4,1}$; and *picture books*; $M_{4,3}$, to support communication when challenges associated with actors' experiences and competences emerge. Some researchers refer to visual representations as boundary objects that have the capacity to support communication (cf. Carlile, 2002; Bechky, 2003; Boujut and Blanco, 2003). The literature shows that visual representations in the form of sketches, drawings or simulations can support communication and ensure that multidisciplinary actors understand each other (Bechky, 2003; Majchrzak, More and Faraj, 2012). The literature primarily addresses visual representations where actors are co-located (either temporarily or on a full-time basis) and face-to-face interactions are possible for both formal and informal communication (Kleinsmann, Valkenburg and Buijs, 2007; Ewenstein and Whyte, 2009; Luck, 2014; Tjell and Bosch-Sijtsema, 2015). Visual representations help to translate and learn about the dependencies between the actors (Carlile, 2002). The findings of this thesis show that visual representations are helpful in the type 4 context and could support the communication between the distributed actors.

Visual representation of a communication procedure could support the communication between the distributed actors by providing clarity regarding the information flows, as well as the actors' roles and responsibilities. Picture books, in contrast, were devised in this case to ensure that the requested engineering design changes were correctly implemented by the suppliers in China.

In the type 4 context, it appears that the product-oriented picture books are useful for transmitting the requested design changes to the suppliers because of their familiarity with the components. This means that the suppliers could recognise the components and relate the information transmitted in the picture books based on their experience with the components. The suppliers are familiar with the components requiring modifications because they have produced the incorrect or incomplete ones. The R&D site and suppliers share a common project context, where the actors from the R&D site designed the components and the suppliers have become familiar with them. The findings of this thesis show that the shared context between the distributed actors facilitates the actors' decoding of the transmitted information. In the type 4 context, the suppliers decoded the information transmitted with the picture books.

This thesis further shows that, in a geographically distributed context, graphical elements and annotations (e.g. arrows, colour blocks, text) can fulfil a role that would normally be fulfilled by gestures in informal communication. The annotations could facilitate the use of visual representations. Arguably, to a certain degree, the use of visual representations with annotations can complement or even replace face-to-face communication, where gestures are frequently used.

Visual representations are objects that can cross the boundary between the distributed actors created by the differences in language and experience. This thesis shows that visual representations add to the use of information and communication technologies to overcome challenges associated with geographical distribution. Visual representations can be effective in transmitting information that fosters action. In a geographically distributed context, prior research recommends the use of rich media like video and teleconferencing (Barczak and McDonough, 2003; Hinds and Bailey, 2003; Ceci and Prencipe, 2013). The media that helped reduce equivocality between the distributed actors in the present case was picture books. This shows that less rich communication media like picture books could support communication and shared understanding between the distributed actors in relation to their tasks and the developed components.

5.3 Comparison

In this section, the findings outlined in the contexts of types 2–4 are compared. The findings of this thesis show that, in the type 2 context, the challenges are related to the following categories: (1) organisation, for example, the lack of a standardised work model; CH₂₋₁; (2) communication, for example, unclear agreements; CH₂₋₇; and (3) actors' experience and competence, for example, R&D actors' attitudes towards collaboration; CH₂₋₃. In the type 3 context, the challenges are related to actors' experiences and competences, for example, differences in linguistic skills; CH₃₋₂, and have a direct influence on the communication and collaboration between the actors. Similarly, the challenges in the type 4 context are related to actors' experiences and competences, for example, national culture differences; CH₄₋₃. In all three contexts, the challenges concern actors' experiences and competences, while in the type 2 context, the challenges are related to organisation and communication. The categorisation of the challenges is important for gaining

insights into the origin of challenges to be able to control them and prevent the resulting disturbances.

The challenges can originate internally from the industrialisation site, but they can also emerge externally from the R&D site or the integration between the actors from the R&D and industrialisation sites. The challenges in the type 2 context are both internal and external, while the challenges identified in the types 3 and 4 contexts are only external and originate from the integration between the distributed actors. The findings of this thesis show that the challenges do not originate only externally, i.e. outside the industrialisation process, but also internally, at the industrialisation site. Both internal and external challenges disrupt the industrialisation process and result in late engineering design changes, costlier tooling, delay of production start, ineffective mechanisms like PPAP and project meetings.

In all three types of contexts, the challenges associated with actors' experiences and competences disrupt the mechanisms devised at the outset of the industrialisation process. In the type 2 context, the PPAP fails to support the communication because the R&D site requirements change constantly. In types 3 and 4, the communication media may fail to support the communication and shared understanding because the actors do not share the same language and experience. Using boundary-crossing literature (e.g. Carlile, 2002; Gustavsson and Säfsten, 2017), these mechanisms—that is, the PPAP and communication media—are seen as objects devised at the outset of the industrialisation process to cross the boundaries created by the challenges associated with the organisational and geographical distribution. The conventional boundary objects cannot be used as initially intended: Because of the context in which these boundary objects are implemented, they do not have the capacity to support the communication between the distributed actors. This is in line with the literature on boundary crossing arguing that boundary objects have different capacities to facilitate communication between actors, and therefore, their role differs depending on the context in which they are implemented (e.g. Carlile, 2002; Bechky, 2003).

Because of the challenges, ad hoc mechanisms are devised and emerge. The role of mediator emerges as important for supporting the integration between the actors from the R&D site and actors from the industrialisation site in all three types of context. The role of the mediator in the type 3 and 4 contexts is important for resolving conflicts, supporting other mechanisms, translating and exchanging information, ensuring the establishment of a

shared understanding and ensuring that actors complete their tasks. In the type 2 context in this study, the mediator could assist in conflict resolutions between R&D and the suppliers by bringing them together and helping align their perspectives.

In the type 4 context, to deal with the challenges, the R&D site in this study started to use picture books and visual representation of a communication procedure to support communication and collaboration between the distributed actors. The findings show that the mechanisms that have the capacity to support communication and collaboration and deal with differences in actors' experiences and competences are not always the ones devised at the outset of the industrialisation process. On the contrary, this thesis shows that the mechanisms that address various challenges in a specific context are devised in the course of the industrialisation process as a response to the specific challenges that occur in a given context. Consequently, this thesis argues that the choice of mechanisms should not be prescribed. Instead, actors should be empowered to choose the mechanism that best suits the unique context in which the industrialisation process is carried out.

Similarly, the mechanisms identified in the three contexts support product- and process-related communication. Mechanisms like picture books (type 4 context) and the OEM's face-to-face meeting on a project level (type 2 context) support product-related communication and align actors' perspectives on product/component design. Mechanisms like visual representation of the communication procedure (type 4 context) and a standardised work model with a degree of flexibility (type 2 context) support process-related communication between the distributed actors. They help the actors to obtain a transparent overview of the industrialisation process, their roles and decisions to be made.

5.4 Discussion of the method

This research is based on case studies, which have been identified as an appropriate research method in relation to the purpose and RQs stated in this thesis. One important reason for the choice of case study was the focus on the context of the studied phenomenon, that is, studying the industrialisation process in three different contexts (types 2–4). The case study approach provided very detailed and rich data concerning the challenges, disturbances and mechanisms regarding the industrialisation process. To manage the extensive amount of data, they were continuously analysed during the study,

and each data collection occasion was thoroughly prepared, in alignment with the recommendations by Miles, Huberman and Saldaña (2014). However, it is important to acknowledge that each scientific method has certain limitations that influence the findings and conclusions.

The case study method made it possible to explore the topic in depth and the complexity of the phenomenon under study. It has added to the prior knowledge on the industrialisation process via studying organisationally and geographically distributed contexts, from which the conclusions in this thesis are drawn. However, one limitation is that the data collected in this thesis are entirely qualitative. In the present research, the number of studies—only three—limited the possibility of capturing the full set of potential challenges, disturbances and mechanisms in the industrialisation process in distributed contexts.

In all three studies, the same OEM—Company Alfa—from the mechanical engineering industry, was studied. Experience gained by the researcher regarding Company Alfa's NPD process and way of work from Study A, was also used in Studies B and C. This is why having the same OEM in three different studies was considered beneficial rather than limiting.

One limitation could be that Study A included only two countries for studying the context of the industrialisation process, namely, Sweden and China. This made the findings specific to these two countries and could have limited the generalisability of the findings. Furthermore, Studies B and C included suppliers responsible for the industrialisation of components/sub-systems according to the OEM's technical specifications. Hence, the findings are limited to these supplier types.

The data analysis in case studies is subjective and influenced by the researcher's interpretations of events, documents and interviews (Williamson, 2002). This is why Yin (2018) recommends constantly revising the findings and collection techniques during the research. It is important to acknowledge that the process of analysis starts during the data collection (Maxwell, 2005). Therefore, what seems to be pure data may be an interpretation of the data. To avoid early conclusions, in this thesis, the data collection and data analysis were separated. In some places, annotations were used to comment on the case study protocols and separate the researcher comments from the raw data. When writing the case study protocol, it was important to maintain the traceability of the analysis and conclusions to the raw data supporting them.

The strategies to secure reliability and validity have been consistent. Sometimes, however, the strategies had to be changed due to the circumstances. For example, the initial plan was to record all formal conversations, but this did not seem appropriate during observation of project meetings (Study C), since this could disturb the meetings; instead, notes were taken.

6 Conclusions

This chapter presents the conclusions from the research presented in this thesis, organised in relation to the RQs. It outlines the theoretical contribution and managerial implications and ends with recommendations for future research.

The purpose of the research presented in this thesis was to expand the knowledge on the industrialisation process in distributed geographical and/or organisational contexts, with a focus on challenges and mechanisms for controlling them during the industrialisation process. To fulfil this purpose, three RQs were formulated. The conclusions drawn in this thesis are presented in relation to these questions.

RQ1: Which challenges related to the distributed context disrupt the industrialisation process?

Based on the findings presented in this thesis, it can be concluded that some identified challenges are unique to the type 2–4 contexts, whereas other challenges are similar to those presented in the literature about the type 1 context. Based on the three studies in the three types of context, it can be concluded that the challenges have internal and external origins. Internal challenges originate from the industrialisation site, while external challenges originate from the R&D site or the integration between the actors from the R&D site and industrialisation site. Furthermore, this thesis concludes that the challenges related to context types 2–4 are organisation related, for example, a lack of standardised work model; communication related, for example, unclear agreements; and related to actors' experiences and competences, for example, R&D actors' attitudes towards collaboration and actors' differences in linguistic skills or work experiences.

RQ2: How do challenges related to the distributed context disrupt the industrialisation process?

The identified challenges disrupt the industrialisation process in various ways. It can be concluded that the challenges associated with the distributed context create uncertainty and equivocality during the industrialisation process. For example, because of differences in skills and competences between the actors from the R&D and industrialisation sites, actors interpret the information differently, thereby creating a sense of equivocality during the

industrialisation process. Thus, this thesis concludes that uncertainty and equivocality are two constructs that occur during the industrialisation process and have to be dealt with. Moreover, this thesis puts forward that equivocality in a distributed context is best addressed by employing less rich communication media.

RQ3: How can different mechanisms be used to control the challenges?

In this thesis, unique mechanisms for each type of distributed context—type 2, type 3 and type 4—were found. Other mechanisms identified were similar to those identified in the industrialisation process in the type 1 context. This thesis concludes that the challenges could influence the effectiveness of devised mechanisms intended to support the communication and collaboration between actors during the industrialisation process. Because of the challenges, ad hoc mechanisms could emerge to deal with the challenges related to the distributed context and reduce uncertainty and equivocality during the industrialisation process, for example, mediators and picture books. This thesis concludes that the environment in which an industrialisation process is carried out should allow for a flexible choice from a set of mechanisms in accordance with the dynamics that emerge in the specific context. Through comparison of the three distributed contexts, it can be concluded that the role of mediator emerges as important in supporting the integration between the actors from the R&D and industrialisation sites. Furthermore, this thesis highlights the use of visual representations to support communication and shared understanding between geographically distributed actors.

6.1 Theory contribution

The industrialisation process has been studied mainly in the type 1 context (Almgren, 2000; Vandevelde and van Dierdonck, 2003; Smulders, 2006). However, today's manufacturing industry faces a different situation, and there is a need to expand the studies on the industrialisation process to cover the type 2–4 contexts as well (Lakemond *et al.*, 2012; Säfsen *et al.*, 2014). The research presented in this thesis overcomes the shortcoming of the prior research by investigating the industrialisation process in the distributed geographical and/or organisational context. Prior research has investigated and classified the disturbances during the industrialisation process and production ramp up (e.g. Almgren, 2000; Winkler, Heins and Nyhuis, 2007; Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2009). The research

presented in this thesis delved further and investigated the potential challenges that could result in disturbances during the industrialisation process. In this way, the challenges can be controlled through various mechanisms and potential disturbances prevented. Hence, this thesis expands the existing knowledge on the industrialisation process.

This thesis offers insights into disturbances during the industrialisation processes for the suppliers responsible for the industrialisation of components/sub-systems according to OEM's technical specifications. Prior research has primarily discussed suppliers as the source of disturbances during OEM industrialisation (Almgren, 2000; Fjällström *et al.*, 2009; Surbier, Alpan and Blanco, 2014).

6.2 Managerial implications

Manufacturing companies today are facing the distributed context when carrying out the industrialisation process. Therefore, there is a need for awareness of challenges and mechanisms to control the challenges and prevent the resulting disturbances during the industrialisation process in the distributed context. This thesis could assist companies and practitioners to better prepare for the industrialisation process in terms of better awareness of potential challenges and possible mechanisms to control them. The tables developed in this thesis, Tables 11–16, could be used by practitioners as checklists of potential challenges, disturbances and mechanisms in the three distributed contexts. The utilization of mechanisms to control the challenges would lead to a successful industrialisation process. A successful industrialisation process is associated with less disturbances during industrialisation, for example, fewer and more timely engineering product/process design changes, as well as a better fit between the product design and production system. This, in turn, will ensure a shorter lead time for the product/component industrialisation process, less costly and better quality production tools, timely SOP and rapid ramp up to volume production.

This thesis further indicates that actors from the R&D site should be aware of challenges faced by suppliers responsible for the industrialisation of components/sub-systems according to OEM's technical specifications. Actors from the R&D site who acknowledge the challenges have better prerequisites to prepare for production ramp up. This thesis directs the attention of practitioners at the OEM not only to the strategic suppliers involved in product design but also suppliers responsible for industrialisation of components

according to OEM's technical specifications. It is suggested that practitioners at OEMs should not only focus on systematising and standardising internal operations associated with industrialisation but also consider interactions and relationships with their suppliers that affect the supplier industrialisation processes. One implication for practitioners at the suppliers relates to the need for improvement in internal capabilities to assist in the effective external involvement in OEM industrialisation. This relates to processing information faster, and hence, providing a rapid response to information requested from the OEM. Another practical implication of this thesis is that it reveals the need for a dynamic and context-dependent view on communication in NPD projects, where project managers allow the emergence of new means of communication that best fit a specific project situation.

6.3 Future research

Based on the findings, several areas of opportunities appear for future research. The findings of this thesis show that, depending on the context of the industrialisation process, different challenges, disturbances and mechanisms could occur. This thesis focussed on geographical distribution and included only Sweden and China. Thus, it would be interesting to explore whether similar challenges, disturbances and mechanisms would appear during the industrialisation process when other nations are involved.

Second, this research is limited to three studies involving the same OEM. Therefore, it would be interesting to study how other OEMs in the same and other industries cope with the industrialisation process in distributed contexts. This would reinforce the validity of the findings.

Third, this thesis emphasised that a power asymmetry between the OEM and supplier plays an important role when integration between organisationally distributed actors involved in the industrialisation process is studied. Future studies could include suppliers that have proprietary technology, where the customer is relatively dependent on the supplier. In this way, it would be interesting to investigate how the OEM and supplier cope with the industrialisation process.

Fourth, one of the findings in the thesis highlighted the role of individuals in supporting communication and collaboration between organisationally and geographically distributed actors. The emergence of individuals to support communication in the distributed context can be explored in future work.

Fifth, this thesis discussed the OEM-supplier interface in general, and the specific interface between actors from R&D at the OEM and supplier. However, other functions, such as quality assurance engineering and purchasing at the OEM, play an important role for OEM–supplier integration (Schiele, 2010). Hence, it is advisable for future work to focus on the roles of actors from other functions and not exclusively actors from the R&D.

Sixth, to strengthen the analytical generalisability of the qualitative findings in this thesis, a quantitative study, such as a survey, could be used in future; surveys are appropriate for statistical generalisation (Williamson, 2002).

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Appendix 1

Interview guide for respondents at the Swedish R&D site: April 2012 (Study A)

(1) General information

Please briefly describe your background (education, work experience, current position, tasks and responsibilities, etc.).

(2) About the NPD project

Please briefly describe the project and your role in it.

(3) Product technology

How much new/existing technology, in comparison with other NPD projects, was incorporated into the newly developed product?

-To what degree was the new technology verified when incorporated into the new product?

-What type of technology was incorporated—electronics, mechanics, software, new materials, new design?

(4) Collaboration with the industrialisation site or suppliers in China

Which departments (roles) from the industrialisation site in China are you collaborating with? Did you collaborate with the suppliers?

- How did you experience the collaboration with the industrialisation/suppliers? (willingness, relationships)
- What has your part in the collaboration been?
- In the collaboration with the industrialisation site/suppliers, what worked well and what could be done differently?
- Was the collaboration more difficult to achieve due to the geographical distribution? In what way? (language, company cultures, leadership styles, etc.)
- How could the collaboration be improved?

(5) Communication with the industrialisation site or suppliers in China

What was your experience with the communication with the industrialisation site in China? What was it like with suppliers?

- How has the information been shared between the distributed sites/actors?
- What have you communicated about?
- What information has been sent to the industrialisation site/suppliers?
- What information has been received from the industrialisation site/suppliers?
- Which communication media/tools have been used? (telephone, e-mail, drawings, video equipment, etc.)
- How frequent has the communication been?
- How did you perceive the Chinese industrialisation site's openness to share information concerning technology or processes?
- How did you perceive the Swedish R&D site's openness to sharing information with the Chinese industrialisation site?
- Were there any difficulties related to the geographical distribution? How did you solve them?
- Were you aware of the expertise of actors at the industrialisation site?

(6) Industrialisation process (before the start of production)

How was the industrialisation process carried out?

- How did the transition/handover of the product from the drawing boards at the R&D site to the industrialisation site take place?
- What did you perceive as critical for the handover?
- Was the handover documented? If yes, how?

What were the challenges following from the fact that the industrialisation process was carried out between actors from two geographically distributed sites?

- Why did those challenges emerge?
- In what way was the industrialisation process disrupted?
- How did you manage those challenges?

What was the need for modification of the existing production systems? (minor or major changes)

How was the fit between the product design and production system ensured?

(7) After the industrialisation process (start of production and production ramp up)

Were there any problems associated with the production start? Why?

- What were the causes of the problems?
- How did you solve the problems?

Which key targets have been set for production? (volume, cost, time for delivery, etc.)

- Which difficulties may hamper achieving these targets?
- Were there any delays of the production start up? What were the reasons for them?

What was done to ensure the rapid increase of the production from zero until the defined targets were met?

Appendix 2

Interview guide for respondents from the industrialisation site in China: November 2011 (Study A)

(1) **Background information**

Please describe your current position with Company Alfa and the industrialisation site in China (role, tasks, etc.).

(2) **About the NPD project**

Please briefly describe the project and your role in it.

- From your perspective, what are critical events during an NPD project? (activities, problems, decisions)
- What were they and when did they occur during the NPD project?
- Had they been foreseen? How were they handled?

(3) **Collaboration with the Swedish R&D site**

What is your opinion regarding the collaboration with the Swedish R&D site?

- What is your role in the collaboration?
- What have been the key challenges related to the collaboration? (language, company culture, leadership style, etc.)
- What has worked well? Why?
- What can be improved? Why? How?

(4) **Communication with the Swedish R&D site**

Is there confusion about who is doing what and when at the Swedish R&D site?

- Is it difficult to schedule meetings?
- If so, how do you handle this problem?
- How do you experience asynchronous work and communication? What are the advantages/disadvantages?
- How frequently does communication occur and what approaches are used?
- How has it been done? What tools are used?
- Is it satisfactory? If not, what should be changed? In what way?

(5) **Way of working**

Do you experience differences regarding ways of working between the industrialisation site in China and the Swedish R&D site?

- How? Regarding what?

(6) **Industrialisation**

How has industrialisation been carried out?

- What are the responsibilities and actors/competences involved from the industrialisation site in China and Swedish R&D site? What is done by each part? When and how is it done?
- How would you describe the relationships with and selection of suppliers?
- Do problems arise? Why? How are they avoided or handled?
- What preparatory measures are done for starting production? What is your involvement in this?

What are the main challenges for the industrialisation when there is geographic and/or organisational distribution?

What do you do to fit the product design with the production system? (approach, methods, techniques)

- Do obstacles arise?

(7) Start of production (SOP) and production ramp up

What is a successful start of production in your view?

- How has the start of production been prepared?
- What has your involvement been?

What are the lessons learned from the project?

Appendix 3

Interview guide for respondents at Company Metal (Study B)

(1) Background questions on individuals

What is your position? Which department do you belong to?

- How long have you been employed by Company Metal?
- What is your education? Experience?

(2) General information about Company Metal

Can you say a bit about your company? (production facilities, warehouses, suppliers)

- What is the product assortment? What are your biggest competitors?

(3) Relations with Company Alfa (the OEM)

What components/sub-systems does your company deliver to Company Alfa?

- How do you work with the Company Alfa? Do you have a long customer–supplier relationship with Company Alfa?

(4) Industrialisation and production ramp up in general

Can you describe the industrialisation process—that is, the production preparation process—in general? What are the various steps, and how much time does it take for each step? What is the quotation process?

- What happens in the industrialisation process of components/sub-systems to be delivered to Company Alfa? What does it look like when components/sub-systems are delivered to other OEMs? What are the differences and similarities?
- How do you make sure that the you can start production on time and ramp up the production according to plan? What is critical for starting production on time and ramping up the production according to plan?
- What are typical challenges related to the collaboration with Company Alfa that disturb the industrialisation process? What are challenges related to the collaboration with other OEMs? Why? How do you handle them? How do the challenges affect the industrialisation process?
- What are typical challenges related to communication with Company Alfa that disturb the industrialisation process? What are the challenges related to communication with other OEMs? Why do they arise? How do you handle them? How do the challenges affect the industrialisation process? What types of disturbances emerge?
- How would you like to work with Company Alfa during the industrialisation process so that you start production on time and ramp up the production according to plan?

(5) Final questions

Is there something else that you would like to add related to industrialisation?

- What persons do you think are relevant for participation in further interviews to obtain a better overview of the industrialisation process and challenges for communication and collaboration with Company Alfa?

Appendix 4

Observation protocol used to collect notes in a structured way during the project meetings (Study C)

NPD project								
<i>Time plan for the NPD project</i>								
Gates from the Company Alfa stage-gate model	Specific- ation	Develop- ment	Invest- ment	Industrialisa- tion	Pre- produc- tion	Production gate	End gate	
Plan/date to pass a gate								
Result/date when the gate was passed								

Continued

Core project team (standing meeting 30 minutes): Every function reports the important activities in the short and long runs

Stage from the Company Alfa stage-gate project model: specification (stage 1), development (stage 2:1), development (stage 2:2), industrialisation (stage 3:1), industrialisation (stage 3:2), production (stage 4)				
Function (core project team)/name	Data/researcher collecting the data	Data/researcher collecting the data	Data/researcher collecting the data	Data/researcher collecting the data
Technical lead/name				
Manufacturing engineer/name				
Purchasing/name				
Supplier Quality Assurance (SQA) engineer/name				
Project co- ordinator/name				
Project management/name				

Appendix 5

Interview guide for the core project team at the Swedish R&D site, before start of production: April 2017 (Study C)

(1) Background questions on individuals

What is your educational background, position at the company, date of joining the company?

(2) NPD project: timeline, critical events and factors

When did you join the NPD project? At what stage of the project?

What is your experience with the NPD project? If you compare this NPD project with other (previous) projects at Company Alfa, what is unique about this project? In what way?

Which events in the NPD project do you perceive as critical? (when they occurred during the NPD project, cause, consequences for the time plan, way of working, etc; action taken—was it successful or unsuccessful?)

- Are there, for example, events that affect your possibility of communicating internally in the project team?
- Do you feel that you have obtained the right information at the right time when you needed it? Has there been a lack of information? Is there something you would like to change concerning the communication in the project?
- Are there events that affect the possibility to collaborate within the project? How would you like to collaborate internally for the project?

(3) Suppliers in the NPD project

Can you categorise the different types of suppliers involved in the NPD project?

- What does the communication and collaboration with the different types of suppliers look like?
- Did the communication with the suppliers differ in accordance with the types of suppliers? Why?
- Was the way of communication and collaboration with the suppliers unique in some way when compared to other projects at Company Alfa?
- Can you provide examples of events that affected the opportunity to collaborate/communicate with the suppliers in the NPD project?
- How would you like to collaborate and communicate with the suppliers in the NPD project?
- Do you think that there has been a lack of information for you on some occasions?

(4) Way of working and routines

Which activities in the NPD project are considered critical for the possibility for the suppliers to carry out the industrialisation process of the components and their production ramp up?

- Why are they critical? Are they unique for the NPD project? What are their consequences?
- How do you work with the PPAP?
- What are the late design engineering changes and consequences for the industrialisation process?

(5) Interfaces and points of contact

What interfaces do you experience between the NPD project and suppliers?

- Between what and whom do these interfaces arise? (actors, functions, organisations)
- Can you describe them?
- What is the role of the interfaces?
- In what way are the interfaces bridged? How are the contact points created? (between actors, groups, organisations)

(6) Start of production

Before SOP, what is your assessment of how it will go? What are the biggest dangers?

Appendix 6

*Interview guide for suppliers, before start of production:
June 2017 (Study C)*

(1) Background questions on individuals

What is your background and position at the company? When did you join the company?

(2) Company description

Describe the company, products and production activities.

(3) Type of supplier

What relationship do you have with Company Alfa? Is it longstanding? Close? Good? Less good?

- What components have you delivered in the NPD project?
- What responsibility for the development of components did your company take on for the NPD project?
- How did your company become involved? What did you receive from the OEM? (functional, technical specifications)
- How critical was the component for the OEM?

Can you describe your company supply network with respect to the NPD project?

- Where are your production facilities, warehouses and sub-suppliers located, and what are the flows between them on an overall level?
- What is your company position? (first, second, third tier)

(4) The NPD project's timeline, critical events and factors

Can you describe the NPD project?

- Is there, for example, a product development model/work model or project management methodology that you have followed for this project? What steps did it involve?

Which events related to industrialisation and the production ramp up have been especially critical/challenging for you as a supplier and have affected your company's ability to deliver according to plan? (internal events or those involving the OEM)

- When did they occur? Why? What consequences did they have?
- How did you handle them?
- Did these events occur frequently/rarely?

What factors (may be related to collaboration, working methods, tools, methodology, relationships or other) for industrialisation and production ramp up were especially critical (either for the project's success or as a barrier) for you as a supplier to deliver as planned to the OEM NPD project?

- How and why?

(5) Way of working

What is your experience with the PPAP?

(6) Interfaces and points of contact

What interfaces do you experience between the OEM's NPD project and you as a supplier?

- Between what and whom do these interfaces arise?

- Can you describe them?
- What is the role of the interfaces?

In what way are the interfaces bridged? How are the contact points created?

- Between what and whom is this done?
- Are the interfaces between individuals, groups or companies?
- What is achieved?

(7) Communication

Describe the communication with Company Alfa over the project course.

- From what roles (from Company Alfa) did you need information?
 - Do you feel that you have received the information at the right time and with sufficient quality?
 - Have you experienced a lack of information? When?
 - How did you handle this? What were the consequences?
-

Appendix 7

Questionnaire used in Study C

Evaluation of the Supplier Day at Company Alfa, May 2016

To further improve Company Alfa's way of working with suppliers in product development projects, we would highly appreciate it if you could take a few minutes and answer some questions.

1. Considering today, what was the most valuable part of the day for you as a supplier to be able to deliver on time, at volume and with quality? Why?
2. Did you miss something today that you think is required for you as a supplier to deliver on time, at volume and with quality? Why?
3. In what way do you think that the collaboration between you as a supplier and Company Alfa can be improved for you to be able to deliver on time, at volume and with quality? How? Why?