The Construction of the Hybrid Package: Evolution of Product Concepts and Production Concepts Through Experiments with Artefacts

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Abstract

This dissertation examines the innovation process of a hybrid package for food products as a bundle of practices, which engage both human and non-human actors. Despite the acknowledgement of the significance of integrated product and process development to innovation, the understanding of the interdependency between the development of products and production remains limited. To explore the intertwined trajectories of the product, production technology and production practices over time, the study draws on a practice-based approach to innovation. The study develops a relational approach to the analysis of the role of artefacts in collaboration and proposes using boundary object as an umbrella term for artefacts that mediate collaborative work. The study suggests that artefacts perform as boundary objects through mediating functions, which artefacts acquire as part of a practice.

The study follows the development of the hybrid package and its production practices by analysing qualitative data that cover a period of eight years. The data originate from a research collaboration with a recently founded business unit of a paper company and they include interviews, observations and workshops.

The study produces three main findings. First, boundary objects shaped the innovation process of the hybrid package in four ways. They attracted partners to join the collaboration, facilitated the development of the product's properties through collaborative and autonomous work, enabled the transfer of work tasks without direct communication between people and transformed the course of action through resistance. Second, the study identifies 11 mediating functions of boundary objects, which evolved from the mediation of communication to the mediation of experimentation practices over the course of a product development process. Third, the study demonstrates the intertwined evolution of the properties of the product and its production practices over time.

The study provides new insight into the interaction between product development and production in the innovation process. The study demonstrates how engagements of humans and artefacts produced the properties of the hybrid package and created its manufacturing technology, organised the development process and resulted in the establishment of a business unit. The study bridges the innovation and the operations management literature by illustrating interdependencies of the trajectories of product concepts and production concepts. The study contributes to the literature on the roles of artefacts in collaboration demonstrating the multifunctional and transformative nature of boundary objects.

Tiivistelmä

Tämä väitöskirja tarkastelee elintarvikkeille tarkoitetun hybridipakkauksen innovaatioprosessia joukkona käytäntöjä, joihin osallistuu sekä inhimillisiä että ei-inhimillisiä toimijoita. Huolimatta integroidun tuote- ja prosessikehityksen merkityksen tunnustamisesta innovaatiotoiminnassa ymmärryksemme tuoteinnovaatioiden ja tuotannon kehittämisen vuorovaikutuksesta on rajoittunutta. Tutkimus hyödyntää käytäntöperustaista lähestymistapaa innovaatioiden tutkimiseen tehdäkseen näkyväksi tuotteen, tuotantoteknologian ja tuotantokäytäntöjen toisistaan riippuvaisia kehityskulkuja. Tutkimus kehittää relationaalisen lähestymistavan artefaktien tehtävien tutkimiseen yhteistyötilanteissa ja ehdottaa rajakohteen käsitteen käyttöä sateenvarjoterminä yhteistoimintaa välittäville artefakteille. Tutkimus esittää artefaktien toimivan rajakohteina osana käytäntöä saamiensa välittämisfunktioiden kautta.

Tutkimus seuraa hybridipakkauksen ominaisuuksien ja sen tuotantokäytäntöjen kehittymistä analysoimalla laadullista aineistoa, joka kattaa kahdeksan vuoden ajanjakson. Aineisto perustuu tutkimusyhteistyöhön paperiyhtiön vastikään perustetun liiketoimintayksikön kanssa ja siihen kuuluu haastatteluja, havainnointia ja työpajoja.

Tutkimus tuottaa kolme päätulosta. Ensinnäkin, rajakohteet vaikuttivat hybridipakkauksen innovaatioprosessiin neljällä tavalla. Rajakohteet houkuttelivat kumppaneita liittymään yhteistyöhön, tukivat tuotteen ominaisuuksien kehittämistä välittämällä yhteistoiminnallista ja itsenäistä työskentelyä, mahdollistivat työtehtävien siirtymisen ilman suoraa ihmisten välistä vuorovaikutusta ja muuttivat vastustamalla toiminnan suuntaa. Toiseksi, tutkimus tunnistaa 11 rajakohteiden välittämisfunktiota, jotka kehittyivät vuorovaikutuksen välittämisestä kokeellisten käytäntöjen välittämiseen tuotekehitysprosessin aikana. Kolmanneksi, tutkimus osoittaa tuotteen ominaisuuksien ja tuotantokäytäntöjen kehittymisen yhteen kietoutumisen.

Väitöskirja tarjoaa uutta tietoa tuotekehityksen ja tuotannon vuorovaikutuksesta innovaatioprosessissa. Tutkimus osoittaa, miten ihmisten ja artefaktien yhteistyö tuotti hybridipakkauksen ominaisuudet ja tuotantoteknologian, organisoi kehittämisprosessin ja johti liiketoimintayksikön perustamiseen. Tutkimus yhdistää innovaatioiden ja tuotannon johtamisen kirjallisuutta esittämällä tuotekonseptien ja tuotantokonseptien kehityskulkujen keskinäisen riippuvuuden. Lisäksi tutkimus tuo uutta artefaktien rooleja koskevaan kirjallisuuteen osoittamalla rajakohteiden olevan monitoiminnallisia ja muuntuvia.

Acknowledgements

This research stems from an interest in the work of people in the development and production of products. I first got a glimpse of this world during a factory tour at a Finnish cranes producer when starting to work for the research project in which I completed my master's thesis. Since then, I have worked with many manufacturing companies in research collaboration. It is from the encounters with practitioners that the inspiration to study practices of producing products originates. Another inspiration stems from the discovery of practice theories during my postgraduate studies, which take the activities of people (and things) as the starting point of scientific exploration.

During my research journey, which has taken many turns, I have had the privilege of learning from and working with many scholars. The endeavours whose outcome this dissertation is have thoroughly benefitted from the contributions of many colleagues, which I would like to acknowledge here.

First, I thank my supervisors, Matti Vartiainen and Hannele Kerosuo, for their guidance during the thesis work. Matti has taken care of the coherence of my research design, analysis and argumentation. He has kept asking for solid definitions and justifications, thus requiring me to provide explicit accounts of my reasoning. The enthusiasm Matti has shown for my work has encouraged me to continue on the selected path despite the moments of doubt. I am also grateful for his care to secure the funding of my work. Hannele has supported my work through her broad reading and extensive experience of fieldwork and intervention methods. She has always studied my writing carefully, not only finding areas of improvement but also coming up with concrete suggestions. Furthermore, I am grateful for her skill of providing encouragement just in the moment when I needed it the most.

Despite not having a formal role in the dissertation process, Anneli Pulkkis is the person to whom my research owes the most. She has introduced me to the research practice and I have learnt enormously from working with her during the past decade. I am grateful for her treating me as a peer since the beginning, when I was taking the first steps in the academic world. Doing research and teaching with her have taught me a great deal about action research and university–industry collaboration. Moreover, I deeply respect Anneli's generosity and humanism: She shows her appreciation of people's work and is not afraid of displaying her values.

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1. Introduction

Societal development and technical development proceed hand in hand. The formation of new institutional practices often calls for the creation of technical aids, while the adoption and adaptation of technological innovations may change the conventional ways in which an activity has previously been carried out. However, many technical innovations never reach widespread use, while important societal problems lack technological aids. Many technological innovations that require great amounts of work aim to provide novel solutions to practical needs, but their introduction goes rather unnoticed among the members of a society. The object of this study, a novel package for food products, is an example of an innovation that looks like a simple and easy-to-make product but whose development required many years of development efforts. It is the hybrid nature of the product that makes its development and production complicated. First, the package is hybrid in the sense that its material form depends on the combination of two different kinds of materials – fibre and plastic. Second, the package is hybrid because it is both an industrial product, developed to meet the needs of food companies, and a consumer product, whose end users are citizens who buy the product covered with the package from a supermarket. Due to these characteristics of this product, I call it a "hybrid package."

What makes this mundane product an innovation? Innovation research distinguishes between an invention and innovation. Invention refers to the development of a new solution to a problem, while innovation requires that the solution be introduced to a market in which potential users evaluate its usefulness (Akrich, Callon, & Latour, 2002a; Schumpeter, 1934). Furthermore, the literature suggests that an innovation needs to be new to the producer and to the market (OECD, 2005). The hybrid package combines fibre and plastic with a method that makes the package air-tight and thus usable for packing food products with gas, such as ready-made meals. The hybrid package was one of the first fibre-based packages providing such functionality. Furthermore, the developers of the hybrid package adapted a manufacturing method from plastics manufacture – injection moulding – into the production of fibre packages.

The innovation process that generated the hybrid package also included the development of the manufacturing method and resulted in the establishment of a new organisational unit. The development process engaged a large number of people working in different organisations. The development process did not end with the launch of the first product to the market; rather, the development of

the package's properties continued and proceeded hand in hand with the refinement of the components of the manufacturing technology.

This contradiction between the mundane appearance of the hybrid package and the complexity of its production intrigued me to investigate the connections between the development of the product, production technology and production practices. Since my first encounters with the hybrid package and its developers, I was fascinated by the multitude of human actors and artefacts that seemed to play a part in the development process. Therefore, I set out to study the product development practices of the hybrid package, which brought these heterogeneous actors together.

1.1   Innovation from a practice perspective

To understand how the hybrid package, its production technology and the organisation that became responsible for the production and further development of the package emerged, this study draws on a practice-based approach to the study of the innovation process and its outcomes. Thus, I approach innovation as work that is involved in its creation and direct my research efforts to explore the actions that make the innovation happen and the conditions under which the actions are carried out (cf. Nicolini, Gherardi, & Yanow, 2003). Dougherty's (2008) definition of product innovation suits the study of actions in the innovation process: A product innovation "concerns bringing new products and services into customers' use, and encompasses the whole process of conceptualizing, developing, designing, manufacturing, marketing, and distributing new products" (p. 418). Furthermore, to address the outcomes of the innovation process, the study attends both to the business goals the product is to achieve, which are determined by the company, and to the value of the product, which the customers and consumers perceive (Simula, 2012).

The practice-based approach aims to provide a more nuanced understanding of innovations and their generation processes. Thus far, most organisational innovation research has focused on innovation as a source of competitive advantage for the company and the success of the products; this emphasis on innovation as an outcome has left the innovation process that produces them under-researched to a large extent (Crossan & Apaydin, 2010). The practice-based approach thus has the potential to bridge the process and outcomes perspectives to innovation. Furthermore, the success factors and process models identified by the innovation literature tend to be very general (e.g. Brown & Eisenhardt 1995; Henard & Szymanski 2001), with little consideration given to the nature of the product or the efforts required to produce it profitably. In addition to the distinction between product and process innovations, the literature distinguishes between radical and incremental innovations (e.g. Ahuja & Lampert, 2001; OECD, 2005). However, other characteristics of the product are mostly ignored in analyses, which often span several companies and even industrial sectors. For example, Simula's (2012) study illustrates that industrial, business-to-business products have received little attention in the innovation literature compared to consumer products. Furthermore, innovation research focuses on

the organising of the product development process (Ravasi & Stigliani, 2012), often ignoring the efforts required to produce the final product to introduce it to the market.

According to a practice-based understanding of the innovation process and its outcomes, the work that creates innovations consists of a bundle of practices, which engage both human and non-human actors. Practices are sociomaterial activities which have historical roots and which are reproduced – faithfully or unfaithfully – by the performances of humans and artefacts (Gherardi, 2015; Schatzki, 2012; Shove, Pantzar, & Watson, 2012). *Practices are "socially recognized forms of activity, done on the basis of what members learn from others, and capable of being done well or badly, correctly or incorrectly"* (Barnes, 2001, p. 27).

The adoption of a practice-based approach to the study of innovation requires theoretical resources for the analysis of the emergence and evolution of practices as well as of the formation and use of artefacts as part of these practices. Therefore, my practice approach draws on research traditions that emphasise the centrality of artefacts in the performance of practices. These research streams include cultural–historical activity theory, posthumanist theories of scientific practice and a postphenomenological theory of human–world relations.

1.2   The significance of artefacts in organising

The role of objects in organisational processes has attracted increasing attention among scholars of organisation, following a 'material turn' in social sciences (Hicks & Beaudry, 2010; Kallinikos, Leonardi, & Nardi, 2012; Preda 1999). This interest in the material aspects of organising has been part of practice theories in the social sciences (Schatzki, Knorr Cetina, & von Savigny, 2001), seeking to overcome the subject–object dualism (Feldman & Orlikowski, 2011; Nicolini et al., 2003; Miettinen, Samra-Fredericks, & Yanow, 2009). In recent years, research on the role of materiality in organisations has gathered under the notion of 'sociomateriality.' Orlikowski (2007) introduced this concept to organisation studies to describe a view of organisational practices according to which materiality is integral to organising: "[T]he social and the material are *constitutively entangled* in everyday life" (p. 1437, emphasis in original).

In the present study, I have chosen to use the term 'artefact' instead of 'object' to avoid problems with the vague use of the notion of object in organisation studies. Furthermore, the term object has a special meaning as the societal purpose of an activity in the literature of cultural–historical activity theory, whereas the term artefact is more general and can be used to refer to the object of activity as well (Engeström & Escalante, 1996). The notion of artefact refers to particular kind of objects that participate in activity in particular ways: *Artefacts are human-made, simultaneously conceptual and material constructions, which serve specific purposes* (Cole, 1996; Kallinikos 2012). An artefact can be an object as found in nature, when it is given specific meaning in a practice, but most of the artefacts present in organisational activities have been transformed by

humans in some way. Artefacts also include abstract constructions, such as concepts and models, which represent an action by symbolic means and therefore enable the transmission of skills (Cole, 1996; Wartofsky, 1979).

Until recently, material artefacts have mainly been studied as a means of collaboration in organisation studies. Studies of artefacts in collaboration have relied on the notion of boundary object, introduced by Star and Griesemer (1989) in science and technology studies. Boundary objects are artefacts – such as prototypes, models or methods – which are at the same time (1) flexible enough so that each professional group or community can give specific meaning to them and (2) sufficiently robust to maintain a common identity across groups (Star, 1989). In recent years, organisational scholars have borrowed other notions from neighbouring research fields to explore the different characteristics that make artefacts useful in different kinds of collaborative practices. These scholars have called for more nuanced research on the role of artefacts in collaborative work beyond the notion of boundary object (Ewenstein & Whyte, 2009; Nicolini, Mengis, & Swan, 2012). They also criticise the tendency of many studies to discern the intrinsic characteristics of artefacts to evaluate their usefulness for collaboration, arguing that boundary objects emerge as the outcome of situated interaction (Ewenstein & Whyte, 2009; Nicolini et al., 2012; Zeiss & Groenewegen, 2009).

This study seeks to answer these calls by developing a dynamic understanding of the role of artefacts in innovation practices, especially when they include collaboration. Following the situated understanding of practice theories of how work is carried out, I propose *a relational approach to the study of the role of artefacts in collaboration*. The relational approach draws on psychological, sociological and philosophical understandings of *mediation* as a way to understand the interactions of human and non-human actors in the performance of practices. The mediation of activity is a foundational aspect of cultural–historical activity theory (CHAT): Human activity is oriented towards shared objects and is conducted by performing actions that rely on the use of conceptual and material artefacts (Cole, 1996; Engeström & Escalante, 1996; Miettinen & Virkkunen, 2005). However, the CHAT analysis of mediation by artefacts tend to focus on changes of mediational means, such as the introduction of novel artefacts, rather than on the ways in which artefacts take part in the carrying out of practices. To study the situated roles that artefacts play in innovation practices, I therefore complement CHAT insights with a postphenomenological understanding of the mediating artefacts of Verbeek (2005), who has developed a 'relativistic philosophy' of human–world relations mediated by artefacts. This postphenomenological approach to the study of artefacts is informed by the philosophy of technology and the sociology of translation, actor–network theory.

The relational approach presumes that the mediating ability of an artefact is not an inherent property but rather depends on the kinds of relations in which the artefact is involved (Verbeek, 2005). Following this approach, I propose the notion of *boundary object to be used as an umbrella term for various kinds of artefacts that mediate activity between communities*. Thus, a boundary object is understood as an emergent and more or less temporary function which an

artefact may acquire in a specific situation as part of a practice. A *function* refers to the purpose(s) an artefact fulfils in a situation, either by deliberate design or coincidental use (Kallinikos, 2012). The relational approach enables the study of the *mediating functions* that boundary objects perform in different situations. Based on this approach, I develop *a typology of mediating functions of boundary objects*, which I employ in the empirical analysis of innovation practices.

1.3 Following artefacts to trace trajectories of products and their production practices

In the research on innovation processes, the study of sociomaterial practices with a focus on the functions of artefacts is one way to bring together the different phases of the process, moving from ideation until the delivery of a new product. Depending on the scope of the study, following artefacts may transcend the boundaries of a company and investigate the efforts of different kinds of partners or the use of the product by consumers. Some artefacts travel throughout the innovation process, while others are used only for a short time. Often, the efforts of people working in different parts of an organisation or in different organisations are connected through artefacts. Early designs depicting a new product are later refined; the designs are translated into models and lists of components, which are materialised in prototypes; the testing of prototypes may require modifications of the designs; and the delivery of the final product is accompanied by artefacts promoting financial transactions and documenting instructions for its use. The outcome of the innovation process, the new product, is a manifestation of efforts involving a multitude of people and artefacts.

The organisational research on collaboration often focuses on the coordination of interdependent tasks and boundary objects as a coordination mechanism (Okhuysen & Bechky, 2009; Scarbrough, Panourgias, & Nandhakumar, 2015). The present study goes beyond coordination in the analysis of the mediating functions of boundary objects in innovation practices. It examines how an idea about a new product becomes entwined with the construction of the manufacturing technology for its production and how the development efforts to create the product and its production infrastructure shape each other. The boundary objects enrol a network of collaborators, whose participants and the organisation of development efforts evolve along the process. Once the new product is introduced to the market, the innovation process continues as consecutive product development projects that influence both the conception of the product's properties and the adopted ways to carry out production practices.

This study examines the intertwined development of a product and its production practices that took place through the collaborative efforts of a manufacturing company, their customers, subcontractors, suppliers and universities. To investigate how the trajectories of the product and the production practices interacted, I develop practice-based definitions of product concept and production concept, which enable the analysis of their intertwined evolution. A *product concept* defines the properties of products that embody a comparable use for

customers. A *production concept* refers to the principles of organising the activities of producing products; such a logic is manifested in the division of work, the relationships with partners, the production technology and the management tools. The study integrates the development of a product's properties with the development of its production practices by analysing the evolution of product concepts and production concepts over time. Following a practice-based understanding, *the innovation process is viewed as a bundle of sociomaterial practices, which are oriented by the logic of product concepts and production concepts*.

1.4 Aims of the research

The aims of this study originate from the theoretical considerations and empirical observations described above. First, the study seeks to increase our understanding of the engagements of human actors and artefacts in collaborative development efforts and the ways they shape the innovation process. The adoption of the practice-based approach to the study of the innovation process enables the analysis of the various ways in which artefacts as boundary objects participate in the shaping of the process. Furthermore, boundary objects are examined through mediating functions and their use is analysed throughout the process to illustrate their transformative nature. Second, the study aims to develop the understanding of interdependencies between product development and production in the innovation process by analysing the intertwined evolution of a product's properties and its production practices. The practice-based approach studies the innovation process as a bundle of situated sociomaterial practices organised to create a new product, including the efforts to create the practices for producing the product. Moreover, tracing the trajectories of product concepts and production concepts allows the analysis of their interdependencies.

These aspirations, together with my engagements with theoretical discussions and empirical analyses, have led to the formulation of three research questions. Thus I examine an innovation process through the following questions:

1. How do boundary objects shape the unfolding of an innovation process and its outcomes?
2. How do boundary objects transform during a product development process?
3. How do product concepts and production concepts evolve through the development of the product's properties and its production practices?

In addition to answering these theoretical questions, this research seeks to produce an understanding of the possibilities to organise the continuous development of both the product and the production. The research outlines concepts and methods that may aid practitioners in the development of innovation practices. These insights are based on a collaborative research process, which included researcher-led interventions for the identification of product concepts and production concepts.

1.5 Package development as an empirical setting

The present study examines the innovation process that generated the hybrid package and introduced the injection moulding method to the production of fibre-based packages. The development of the hybrid package involved an R&D project team from a paper company that collaborated with university and company partners to create the package and its manufacturing technology. It took approximately four years of development efforts to produce a commercial package. After the launch of the first product to the market, the innovation process continued in the form of several product development projects, which contributed to the development of the package's properties and the construction of a highly automated production infrastructure. During the innovation process, the R&D project team transformed into a new business unit of the paper company; I will refer to this business unit as Fipak. The unit established a production network composed of suppliers, subcontractors and other partners to which the university collaborators no longer belonged. Customers were also an important part of the network.

Figure 1 provides an example of the hybrid package. The hybrid nature of the product differentiates it from conventional fibre-based packages: It is air-tight and therefore suitable for food products protected by gas (modified atmosphere packaging). The combination of paperboard and plastic materials in an indistinguishable way is realised with an integrated manufacturing process. The addition of a plastic rim to the paperboard package provides the air-tightness; the package can be sealed with a plastic film. The paperboard makes the package recyclable (in the Finnish recycling system); the hybrid package is marketed as an ecological alternative. The paperboard enables printing directly on the package without extra sleeves etc. The package is suitable for heating in microwave or oven as well as for freezing; it competes with conventional plastic and aluminium packages.

Figure 1. The first commercial hybrid package (later "the Pilot package").

This study grew out of a collaborative research project that involved three universities and two companies. We entered the field when Fipak's first commercial product had just been launched. Our research collaboration allowed us access to the current partners of the unit in addition to the development team that

made up the unit's personnel. Through interviews concerning the past product development project resulting in the product launch, we got an understanding of the earlier phases of the innovation process. By following a product development project from the beginning, we were able to understand the collaborative practices that belonged to the different project phases. Later on, we used these data to analyse Fipak's products and production practices in workshops together with the development team to identify the unit's product concepts and production concepts. Based on these and additional data produced by the Fipak team members themselves, our research group and the team members outlined a project model for product development projects, including tools for coordinating the tasks between phases and for combining data from different projects for product development purposes. After the research collaboration ended, I returned to the field twice to complement the data with insights that helped me answer the research questions. These visits also enabled me to follow the evolution of Fipak's product concepts and production concepts.

The data that I investigate in this dissertation cover a period of eight years from 2005 to 2012. During this period, the paper industry underwent a heavy restructuring of operations. Northern European paper companies, whose operations often cover the whole production process from wood preparation to different kinds of paper products, have closed down factories in Europe while investing in production facilities in Asia and Southern America. Due to the overproduction of newspaper and fine paper, paper companies have sought new markets and re-profiled their operations. One of the growing market opportunities has been packaging; the global demand for paperboard products is expected to continue its growth (Järvinen, Lamberg, Nokelainen, & Tikkanen, 2012). The development of the hybrid package reflects the industry's efforts to develop novel products for the changing markets and to re-allocate resources to promising new business areas.

1.6 Research approach and methodology

The production of scientific knowledge is a constructivist process during which a researcher engages in different kinds of research practices that become entangled with the practices of the studied field. This process is shaped by the ontological, epistemological and methodological commitments of the researcher, which influence the selection of the research phenomenon, the theoretical-methodological framework, the empirical setting etc. (cf. Maxwell, 2005). The adoption of the practice approach does not bring with it clear answers to ontological and epistemological questions. No unified practice approach exists (Schatzki, 2001), but theories of practice stem from different disciplinary traditions. However, the practice theories share a set of family resemblances despite disagreeing on other assumptions (Nicolini, 2013). Therefore it is possible to talk about practice-based studies as an umbrella concept covering the different traditions (Gherardi, 2011, 2012).

As outlined above, the main theoretical traditions that my work draws on are cultural–historical activity theory, posthumanist approaches to science and the

postphenomenological approach to technology. While I acknowledge the differences between these intellectual traditions in terms of some of their assumptions, I have tried to construct my theory–method package (Nicolini, 2013) in a way which allows the combination of these theories. Below, I summarise the foundational assumptions of practice theories that all these approaches share.

First, important features of human life are understood as forms of human activity (Schatzki, 2012), rooted in practices that are "embodied, materially mediated arrays of human activity centrally organized around shared practical understanding" (Schatzki, 2001, p. 2). Second, practice theories are united by 'relational thinking,' according to which individuals, artefacts and organisations derive their significance from the relations that link them (Østerlund & Carlile, 2005). This relational thinking departs from a 'substantialist view' treating the qualities attached to individuals or artefacts as forces detached from their social and historical context (Østerlund & Carlile, 2005). The relational understanding offers a way to overcome many of the long-debated dualisms in the social sciences, such as actor/system, social/material or body/mind (Nicolini, 2013) as well as the problem with different levels (micro/meso/macro) (Miettinen et al., 2009). Third, practice theories emphasise the embodied and material nature of activities. The body is seen as a meeting point "both of mind and activity and of individual activity and social manifold" (Schatzki, 2001, p. 8). Practices rely on an array of material resources, which participate in their accomplishment and make this accomplishment durable over time (Nicolini, 2013). Fourth, meanings, language and normativity are tied to practices, not individuals; the generation, maintenance and transformation of these phenomena take place through the performance of practices (Schatzki, 2001). While human beings engage in the practices, they rely on their skills and the resources around them; the performance of practices thus includes the possibility of their transformation (Miettinen, Paavola, & Pohjola, 2012; Shove et al., 2012).

The practice ontology is characterised by relationality, constructivism, heterogeneity and situatedness (Nicolini et al., 2003). The world as we perceive it is an ongoing accomplishment: It is "relationally constituted, a seamless web of heterogeneous elements kept together and perpetuated by active processes of ordering and sense making" (Nicolini et al., 2003, p. 27). Our view of the world depends on the practices in which we participate, because these entail situated, normative understandings of the meanings of phenomena (Gherardi, 2011) and thus influence the way we see and judge them. Even though the members of a practice share knowing and valuations within the realm of practice, their understandings are not uniform.

Furthermore, the relational epistemology of practice theories assumes that knowing and practicing are ontologically inseparable: They are "performed in the course of specific material-discursive practices" (Gherardi, 2011, p. 51). This study does not aim to produce objective knowledge of innovation practices but rather a situated understanding of such practices, which may inform further research and practice development. When a researcher is studying activities in a field of practice, such as the development of products, she becomes a part of this web of elements and relations, contributing to their reproduction. Entering into

the field of practice is always an intervention: The presence of the researcher in the field and the questions she raises may direct the interpretations the members of the practice make of their experiences. This means that the knowledge for the research is co-produced by the members and the researcher – the latter interpreting this knowledge through the chosen theoretical lenses. Furthermore, the researcher's understanding of the field of practice depends on the kinds of engagements she happens to have during the study; the produced knowledge is thus necessarily partial.

Methodologically, practice approaches tend to promote immersive methods that enable the researcher to engage in the field of practice. This can be accomplished with ethnographic and ethnomethodological methods by observing situated actions and attaining an insider's view (Miettinen et al., 2009; Nicolini, 2013). Moreover, Nicolini (2013) suggests that practices be studied relationally to understand how interconnected practices influence each other. This calls for multi-sited ethnography (Marcus, 1995) or following the elements of the practice (Nicolini, 2013; Shove et al., 2012). Besides, Gherardi (2012) encourages scholars of practice to adapt and invent the methods of inquiry.

This study employs various qualitative methods to provide a holistic picture of the innovation practices and the participants' understandings. The research group traced the generation of the hybrid package backwards with retrospective interviews and forward by following a product development project. Our observations followed the construction of the product through the production of various artefacts engaging several actors from different companies. Thus, the fieldwork took the form of focused, multi-sited ethnography (Knoblauch, 2005; Marcus, 1995). Because the research project aimed at the generation of relevant knowledge that could inform the development of practices in addition to the production of scientific insights, the research group discussed the produced data with the research participants in several phases of the research collaboration. Furthermore, we arranged a series of workshops aimed to identify Fipak's product and production concepts, based on the discussion of the accumulated research data. Hence, our research approach combined applied ethnography (Chambers, 2000) with participative action research (Greenwood & Levin, 2007). This research ethos stemmed not only from ethical considerations to engage the participants in decisions about the research process but also from the conviction that they are capable of reflecting on and analysing their practices, thus contributing to the production of scientific knowledge (Islam, 2015). Our engagements with the members of Fipak's development team contributed to the development of analytical concepts and further to the theorisations of their practices.

1.7   Structure of the dissertation

This dissertation is structured in eight chapters. After this introductory chapter, the next two chapters are devoted to the development of my theoretical approach to studying the innovation process from a practice-based perspective with a focus on boundary objects as mediators of collaborative work. Chapter 2

begins with an introduction of the practice-based approach, after which it explores the understandings of innovation in innovation management and science and technology studies. Further on, I review the literature on production concepts and product concepts and propose that the organisation of production (the production concept) is related to the characteristics of the product (the product concept). The chapter ends with the outline of an artefact-centred practice-based approach to the study of the innovation process.

Chapter 3 begins with reviewing the literature of boundary objects and other artefacts, which have been identified to play a role in collaborative work. The literature review suggests that the characteristics and uses of artefacts in collaboration do not distinguish between the situated roles that artefacts play within and across practices. Therefore, I suggest a relational approach to the study of the role of artefacts in collaboration based on the notion of mediation in cultural–historical activity theory and postphenomenology. Hence I propose the use of the notion of boundary object as an umbrella term for various kinds of artefacts that mediate activity between communities. The relational approach analyses the role of artefacts as different mediating functions, which artefacts may acquire depending on the situation and the relationships between the actors and the artefacts. Moreover, I develop a typology of the possible mediating functions that boundary objects may perform in collaborative work. The chapter ends with a proposal to study the trajectories of boundary objects to identify temporal shifts in the mediating functions that artefacts perform in the innovation process.

Chapter 4 describes the methodological choices I have made in this study. It begins with a description of the research project and the research collaboration with Fipak. Further on, I describe in detail how my research process evolved, how the data were produced and how I analysed them. The chapter ends with the description of the writing process of the dissertation.

Chapters 5, 6 and 7 present the empirical findings of my study. In Chapter 5, the analysis of the development process of the hybrid package illustrates the use of the relational approach to identify boundary objects and their influence in collaborative development efforts. The analysis explores the first research question: How do boundary objects shape the unfolding of the innovation process and its outcomes? The findings are based on retrospective interviews with participants of the development process that resulted in the launch of the first commercial hybrid package. The findings show that boundary objects shaped the development of the hybrid package by attracting partners to join the collaboration, facilitating the development of the product's properties through collaborative and autonomous work, enabling the transfer of work tasks without direct communication and transforming the course of action through resistance.

In Chapter 6, I analyse the development process of one of Fipak's new products by examining the second research question: How do boundary objects transform during the product development process? During the empirical analysis, I refined the literature-based typology of the mediating functions of boundary objects developed in Chapter 3; I suggest a modified typology and identify 11 mediating functions. The analysis is based on observation data derived from

following product development projects through events that represent the different phases of Fipak's product development process. The transformation of boundary objects is explored by identifying the mediating functions that boundary objects performed in the collaborative practices and by following shifts in the mediating functions during the product development process. The findings illustrate the evolution of mediating functions from the conceptual to the material mediation of actions, which reflected central concerns of the actors in each development phase.

In Chapter 7, I analyse the encounters between members of the Fipak team and the research group by exploring the third research question: How do product concepts and production concepts evolve during the innovation process? I distinguish between three phases of concept development that took place during the research collaboration. To identify changes along the trajectories of the concepts, I examine what characteristics the product concepts and the production concepts had in different phases of the concept development process. The findings illustrate the intertwined evolution of a product's properties and its production practices.

Chapter 8 discusses my findings in relation to previous research to identify the contributions of the study. The chapter begins with a summary of the central findings and answers to the research questions. Then I discuss the contributions and implications of the study. The study makes theoretical contributions to research on the role of artefacts in collaborative work and to research on innovation, product development and operations management. The study develops a relational approach to the role of artefacts in collaboration and proposes the use of boundary object as an umbrella term for artefacts that mediate collaborative work. The study suggests that artefacts perform as boundary objects through mediating functions, which artefacts acquire as part of a practice. Moreover, the typology of mediating functions developed in the study demonstrates that boundary objects are multifunctional and transformative because they can perform various mediating functions in different situations. The study bridges innovation and operations management literature by demonstrating interdependencies of the trajectories of the product, production technology and production practices. In addition, I evaluate the validity and limitations of the study as well as reflect on the practice-based methodology of the study. I conclude the thesis with suggestions for future research.

2. Studying innovation from a practice-based perspective

This study adopts a practice-based approach to the study of the innovation process and its outcomes to explore the interactions of the trajectories of a product, production technology and production practices over time. This chapter introduces the practice-based approach that aims to open up the activities of the innovation process, which have remained a black box in conventional innovation research. The practice-based approach draws on science and technology studies to address the intertwinement of technological, social and economic aspects of the innovation process. Furthermore, the approach bridges innovation and operations management literatures by suggesting that product concepts and production concepts evolve in an interrelated way. The approach proposes that innovation process may be studied as a bundle of sociomaterial practices, which contribute to the development of the product and production practices through engagements of human actors and artefacts.

2.1   The practice-based approach

This research studies innovation as work that is involved in its creation. With the adoption of a practice-based approach to the study of innovation processes and their outcomes, research efforts are directed to understanding the actions that make the innovation happen and the conditions under which the actions are carried out (Nicolini et al., 2003). The practice approach recognises the situational and provisional nature of collective human activity: Practices exist only to the extent that they are enacted, while every performance of a practice carries with itself a possibility of change (Miettinen et al., 2012; Nicolini, 2013; Nicolini et al., 2003, Shove et al., 2012). Thus, the approach invites the researcher to pay attention not only to the world as it is but also to how it could be (or has been) different (Nicolini et al., 2003). When studying an innovation process, this means that the account does not content itself with the outcome of the process but rather depicts through what lines of action, whose participation and what resources the process came about.

Practices are constituted of interconnected elements, including bodily and mental activities, artefacts, skills and understandings, as well as emotional states (Reckwitz, 2002). Practice is "a collective knowledgeable doing which is

socially sustained" (Gherardi, 2011, p. 57). Thus, practices are, by definition, social: They always entail a normative character, which can only be sustained at a collective level (Gherardi, 2012; Nicolini, 2013). This sociality also includes different kinds of artefacts, which play an active role in the shaping and performance of practices (Nicolini et al., 2003) by affording certain possibilities for action (Leonardi, 2012). The materiality of a practice supports the stabilisation of particular ways of carrying out actions, because the ways of acting can be inscribed in the artefacts (Gherardi, 2011). Thus, practices are sociomaterial activities that are reproduced – faithfully or unfaithfully – by the performances of humans and artefacts (Shove et al., 2012).

The 'practice ontology' assumes that the production and reproduction of social relations take place in the realm of practice (Gherardi, 2011). This means that practices are prioritised over individuals as sources of meaning and order: "the forms of individual activity depend on the practices in which people participate" (Schatzki, 2001, p. 11). Practices have shapes that precede particular actors' actions in a given practice; it is the practices that carry social meanings and connect humans to one another (Kemmis, 2011; Schatzki, 2001, 2012). Practices thus invite participants to perform in the particular ways appropriate for that practice by organising their thoughts and actions as well as their relationships with the others involved (Kemmis, 2011). From this perspective, people act as carriers of a practice when participating in its enactment (Reckwitz, 2002); that is, practices recruit people (Shove et al., 2012). Thus, it is the practice which defines the community of practitioners, sometimes called a community of practice (Wenger, 1999), participating in the carrying-out of the given practice. The participation in a practice shapes the participants' understanding of themselves as practitioners and becomes part of their identity (Wenger, 1999). At the same time, the participants enact the practice in their own personal ways by bringing in their experience-based knowing, which shapes their understanding of the practice (Kemmis, 2011). Practicing is understood as knowledgeable doing "sustained by social norms appreciative of the doing of things well, beautifully, usefully, etc." (Gherardi, 2011, p. 49): Knowing is produced through learning that takes place when performing a practice.

Thus, the practice-based approach emphasises the situatedness of actions and the engagements of human actors and artefacts in the performance of practices. Furthermore, the approach involves an understanding of the inseparability of knowing and practicing. Next, I explore how these insights may complement the innovation literature. First I explore the understanding of innovation in the innovation management studies. Then I turn to science and technology studies to open up the activities that make innovations happen.

2.2 Innovation management studies: Innovations as outcomes of coordinated processes

The innovation management research has focused on innovation as a source of competitive advantage for the company and on the success of the products as

outcomes of the innovation process (Crossan & Apaydin, 2010). The introduction of technological inventions as novel products to the market is considered as an important driver of economic success and company survival (Ardito, Messeni Petruzelli, & Albino, 2015). Since innovation studies emerged as a research field some 50 years ago, most scholars have focused on the study of the management of innovation in organisations on one hand and on the economic and social changes triggered by technological innovation on the other (Fagerberg, Fosaas, & Sapprasert, 2012). Despite the increasing scholarly interest in "how innovation takes place and what the important explanatory factors and economic and social consequences are" (Fagerberg et al., 2012, p. 1132), recent reviews display innovation research as fragmented (Ardito et al., 2015) with weak theoretical grounds (Crossan & Apaydin, 2010).

Crossan and Apaydin (2010) distinguish two views of innovation in the innovation literature: Innovation as an outcome and innovation as a process. This differentiation should not be confused with the separation of product innovation from process innovation, where the former refers to the introduction of new products to the market and the latter to the adoption of new production methods (OECD, 2005). Both definitions view innovation from the outcome perspective. Crossan and Apaydin (2010) argue that, due to the major focus on the outcome perspective, the theorising of the innovation process remains under-developed. Moreover, when the innovation literature addresses the innovation process, it is often viewed from a linear perspective, moving forward through a series of manageable sequential events that are directed towards the fulfilment of market needs identified a priori (Christiansen & Varnes, 2007).

The focus on innovation outcomes is demonstrated by the importance given to new product development (NPD) in the organisational research on innovations. This literature emphasises the role of NPD as a potential source of competitive advantage and develops models, processes and practices for making effective and successful products (Brown & Eisenhardt, 1995). NPD research views product development as "the transformation of a market opportunity and a set of assumptions about product technology into a product available for sale" (Wind & Mahajan, 1997, p. 1). The NPD literature focuses on the management of product development projects and strives to develop models describing how organisations may structure their product development projects to be successful in the market in which they operate (cf. Brown & Eisenhardt, 1995). NPD studies often entail a normative stance on the management of NPD projects, suggesting that the factors predicting successful outcomes of projects can be identified and used by managers to find an appropriate fit to obtain effective new product performance (Brown & Eisenhardt, 1995; Henard & Szymanski, 2001; Krishnan & Ulrich, 2001; Wind & Mahajan, 1997). However, a recent meta-analysis of empirical NPD studies conducted between 1999 and 2011 undermines some of these normative expectations (Evanschitzky, Eisend, Calantone, & Jiang, 2012). According to this analysis, nowadays it is more difficult to identify the common success factors that would explain why certain NPD projects succeed and others fail. Evanschitzky and colleagues (2012) call for new and more comprehensive theoretical approaches to capture the underlying nature of the

success factors affecting the results of NPD projects, assuming that the research has failed to identify some factors affecting the performance of NPD projects.

Most research on organising innovation processes focuses on a single organisation and its short-term performance (Dougherty & Dunne, 2011). Innovation scholars have acknowledged the meaning of inter-organisational networks in creating new knowledge and innovations (Powell, Koput, & Smith-Doerr, 1996). The engagement of actors from different organisations in the development of a new product or service is often discussed in terms of coordination of efforts (Deken & Lauche, 2014). However, most research on the coordination of collaborative work centres on a single organisation (see Okhuysen & Bechky, 2009). The organisation of the innovation process is marked by uncertainty; the outcomes of development processes – especially in the case of complex products – emerge only after many years of work (Dougherty & Dunne, 2011). Innovation scholars expect the greatest levels of uncertainty during the early process phases and propose information acquisition as a means to reduce it (Christiansen & Varnes, 2007). Innovation management research has striven to harness the uncertainty by developing management processes and tools that structure the innovation process into stages, whose unfolding is controlled through managerial checkpoints (e.g. Cooper, 2008). Whereas a major concern of innovation scholars is the identification of innovations' success factors (Henard & Szymanski, 2001), few studies are able to identify links between the innovation process and its long-term outcomes (for an example, see Deken & Lauche, 2014).

To develop more grounded theories of innovation, Crossan and Apaydin (2010) call for innovation research combining the outcome perspective with the process perspective as well as bringing together the individual, organisational and societal levels of analysis. Dougherty and Dunne (2011) advocate more research on the ways of organising the collaborative development of complex products and services among several organisations. Moreover, Crossan and Apaydin (2010) propose the practice-based view as a uniting "meso-level theory" for innovation research, which could combine the activities of organisational actors at the micro level with consequences for innovation outcomes at the macro level as well as the interaction between these levels. The present study addresses these concerns by complementing conventional innovation research with insights from science and technology studies.

2.3 Science and technology studies: Intertwinement of technological, social and economic elements in the innovation process

Science and technology studies (STS) display scientific and technological innovations as outcomes of generation processes, in which various social, technological and economic elements interact. STS analyse innovation from a sociological perspective, linking the development of innovations to broader societal developments and contextualising them in time and space (Pinch & Bijker, 1992). Such studies may trace the unfolding of the innovation process beyond the introduction of the innovation and analyse how the innovation – often a techno-

logical artefact – the practices of development and use, and the identities of developers and users are co-produced in the process. This means that both the development of an innovation and its diffusion among users are included in the innovation process (Harty, 2010). Hence, STS regard the innovation process from a constructivist standpoint that highlights the messiness and serendipity involved in the development of technologies. STS demonstrate how the success of an innovation not only depends on the intrinsic characteristics of a product and their correspondence with the value expectations of the market but rather on a network of human actors and artefacts that promote its existence (Akrich, Callon, & Latour, 2002b).

The sociology of translation or actor–network theory (ANT) is one of the STS research traditions studying innovations from a constructivist perspective. ANT analyses "everything in the social and natural worlds as a continuously generated effect of the webs of relations within which they are located" (Law, 2009, p. 141). In particular, ANT scholars are interested in processes of translation, which displace and transform the actors' identities and goals (Callon, 2007). Furthermore, the construction of a network of both human and non-human actors may create obligatory points of passage: An innovation becomes an obligatory passage point when potential users want to acquire it (Law & Callon, 1992). In addition, on its way to the market, a potential innovation undergoes between different trials of strength: The "in vitro" trials take place during the development process of a product, while the "in vivo" trials take place once the product has entered the market (Reijonen & Tryggestad, 2012). The in vitro trials include decisions about granting resources to the development of the product, while the in vivo trials occur in the encounters between the product and the potential users. Moreover, the qualities of the product may transform in the course of these trials (Reijonen & Tryggestad, 2012).

STS suggest that innovations emerge from the often serendipitous interactions of heterogeneous actors, including people and artefacts. Because the innovation process unfolds through the engagements of various actors with potentially conflicting interests, innovations become "uncertain, fluid and open to translation and transformation through both development and use" (Harty, 2010, p. 301). However, the associations between the actors involved in the innovation process also promote the existence of the innovation; the configurations among the participating actors either succeed or fail in ensuring the durability of the innovation (Akrich et al., 2002a, 2002b; Latour, 2005; Law, 2009). Furthermore, non-human actors are indispensable stabilisers of social relations because human actors can delegate complicated series of actions to them by inscribing them into artefacts (Akrich & Latour, 1992; Latour, 1994). STS have also demonstrated the interaction between scientific ideas and material technologies, showing how innovations emerge from experiments conducted with instruments in laboratories.

STS-informed studies of innovations refrain from defining a priori the significant stakeholders on whose actions the research should focus. Instead, Latour (2005) advises the researcher to "follow the actors themselves" (p. 12) to study

how a heterogeneous socio-technical network is constructed. Such thinking insists that the stability of social phenomena is accomplished through continuous efforts (Latour, 2005). The study of the innovation process may trace the attempts of various actors to align the actions of the other actors according to particular interests (Harty, 2010). Similarly, scholars of practice argue that the emergence, evolution and disappearance of a practice can be traced by following the elements that compose it (Nicolini, 2013; Shove et al., 2012).

Science and technology studies thus broaden the view of innovations to cover various kinds of actors involved in their creation and use. They provide insight into studying the innovation process as a co-construction of the product and the network promoting it existence as well as into analysing the reception of the product among potential users. However, because STS focus on the entwinement of societal and technological development, they rarely address the development of innovation activities in organisations. To develop a comprehensive understanding of the relationship between product development and production activities in organisations, I turn to literature on product concepts and production concepts.

2.4 Product concepts and production concepts: Exploring the relationship between product development and production in the innovation process

This research assumes that the mutual development of products and their production practices may be essential to create innovations. However, these are separated into different disciplines in academic research and functions in industrial organisations. The separation of product development and production reflects the legacy of mass production and scientific management, drawing a clear distinction between planning and execution tasks (Duguay, Landry, & Pasin, 1997). Even though both researchers and practitioners acknowledge the need for interdisciplinary collaboration to create innovations, studies of innovation typically adopt a singular functional perspective (Tatikonda & Montoya-Weiss, 2001). In the academic literature, studies of product development and innovation management focus on the characteristics of successful products and the organisation of the product development process (Crossan & Apaydin, 2010; Ravasi & Stigliani, 2012), without considering the production of the final product. Operations management literature focuses on the optimisation of the production process and resources used (Gunasekaran & Ngai, 2012), barely addressing the role of products in this optimisation. Even though scholars have called for the integration of these literatures to explore the intimate connections between product design and manufacture (Ettlie, 1995; Spring & Dalrymple, 2000; Tatikonda & Montoya-Weiss, 2001), attempts to establish a comprehensive understanding of innovation activities have remained rare.

To investigate the interaction of the hybrid package and its production practices along the development process, I develop a practice-based understanding of product concepts, which guide the development of product properties, and of production concepts, which guide the development and organisation of production practices.

The role of concepts and models in human activities has been investigated under different disciplines. Studies of scientific and engineering practice have explored the meaning of scientific concepts, models and experimental systems. Management studies have analysed the creation and use of business models in organisations, while CHAT researchers have developed the notion of activity concepts to analyse changes in the logic of activity.

The research on scientific practice shows that the development of scientific concepts and theories proceeds in parallel with the development of experimental instruments and methods (e.g. Rheinberger, 1997). Modelling practices are central to scientific problem solving: Scientists build models to investigate their phenomena of interest, while their experiments with models drive the development of concepts to explain the empirical observations (Nersessian 2012). The generation of new phenomena relies on the co-production of already existing ones to provide a basis for comparison (Rheinberger, 1997). The combination of loosely defined concepts and standardised experimental methods has led to the emergence of new disciplines (Fujimura, 1992; Löwy, 1992).

In management studies, the study of business models has proliferated in recent years. Business models capture "the logic of the firm, the way it operates and how it creates value for its stakeholders" (Casadesus-Masanell & Ricart, 2010, p. 197). Business models suggest an organisation of the elements of the company's activity with a set of rules to follow that promise a particular kind of outcome (Baden-Fuller & Morgan, 2010). The business model is understood as choices about the set of activities performed, how these activities are linked and who performs them (Zott & Amit, 2010). The research on business models suggests that while all companies have a business model, an articulated business model can be used as a conceptual tool for analysing and developing business activity (Günzel & Holm, 2013).

Within the realm of cultural–historical activity theory, Virkkunen (2006a, 2007) has discussed the significance of concepts in guiding the activity. He has developed the notion of the 'activity concept' for describing the logic of collective activity and for analysing transformations of activity. An activity concept "manifests itself in the specific character of its generalized object/outcome, the principle of dealing with the object and reaching the outcome, and the corresponding relative compatibility of the elements of the [activity] system" (Virkkunen, 2006a, p. 45). Even though the notions of activity concept and business model bare resemblance to each other (see Virkkunen & Ristimäki, 2012), they diverge in terms of the understanding of actors and actions. Whereas management literature considers the construction of a business model as a design issue accomplished by managers (Zott & Amit, 2010), CHAT emphasises the engagement of different organisational actors in the collective effort of analysing and developing an activity concept (Virkkunen, 2006a). Furthermore, the actions that aim to construct an activity concept go beyond decision making and include questioning, analysis, modelling, experimenting and reflecting (Virkkunen, 2006a, 2007; cf. Virkkunen & Ristimäki, 2012).

2.4.1 Product concepts

The product development literature states that coherent product concepts are critical to the success of the final product in the market. The product concept relates to the market and the target customers, defining "the character of the product from a customer's perspective" (Clark & Fujimoto, 1990, p. 109). It is to serve as a representation of the goals for the product development process (Seidel, 2007), which bring together recognised market needs and the capabilities of the developing organisation (Brown & Eisenhardt, 1995; Orihata & Watanabe, 2000). A product concept can be perceived from four perspectives: what the product does, what the product is, whom the product serves and what the product means to customers; the most powerful product concepts contain all these (Clark & Fujimoto, 1990). A product concept serves to integrate the different technologies inside a product and to establish the fit between product performance and user expectations (Orihata & Watanabe, 2000). Hence, a clear product concept functions as a framework for making decisions during the product development process (Clark & Fujimoto, 1990).

  According to the literature, product innovations begin with the development of a product concept, which defines the performance expectations of the new product that need to be translated into technical requirements (Orihata & Watanabe, 2000). Concept development is included as one of the first phases of the product development process (Burchill & Fine, 1997). Traditional approaches to product development expect that specifying a product concept is preceded by collecting customer requirements, considering competitors' products and establishing criteria for product properties (Seidel & Mahoney, 2014). This generation process is supposed to result in a single guiding concept that remains fixed throughout the development process (Burchill & Fine, 1997); if the created concept becomes problematic during the next stages, the product development team is expected to return to the earlier stage to reconsider the concept (Seidel, 2007). This assumption of a fixed product concept has recently been questioned. For example, Seidel (2007) suggests that the ability to elaborate the product concept during the product development process may in fact be important in radical product development, whose outcomes are new both to the company and to the market.

  More recent research has studied product concept development in terms of creation and change of concept representations (Seidel, 2007; Seidel & Mahoney, 2014). This kind of analysis breaks the product concept into three components or representations: verbal stories, verbal metaphors and physical prototypes (Seidel, 2007). These representations are used for different purposes: Typically, stories explain customer needs and metaphors articulate product functions, while prototypes define a product's form (Seidel & Mahoney, 2014). During the product development process, the product concept may change when a concept representation is found not to fit with the identified market needs or the developed technological solution (Seidel, 2007). Such shifting of the product concept may cause coordination problems among the participants of product development, and the concept may lose coherence; Seidel and Mahoney (2014) have identified practices that enable product development teams

to keep up a coherent repertoire of concept representations. These studies still maintain a view of the product concept as a representation of a single product; the actual product as the outcome of the development process is understood to embody the defined product concept (Seidel, 2007).

Despite studies on the evolution of the product concept and its representations during the product development process, previous literature tends to ignore the evolution of the properties of the product in the process. My interest is to examine how a product gains its properties through the product development process and how these properties are translated between the product concept and its material instantiations. Therefore, I adopt insights from constructivist market studies about the processes of product qualification where "product qualities are constructed and attain significance enabling the comparison and qualification of a product" (Reijonen & Tryggestad, 2012, p. 213).

In this study, I adopt a practice-based and processual approach to the study of the evolution of a product concept during the innovation process and beyond it. I assume that the product concept is related to the production concept: For example, a mass production concept requires a fixed, predictable product concept which is competitive in commodity markets. However, a co-construction concept presumes that the product concept can be refined according to feedback from the customer and thus evolves during its lifecycle. Furthermore, the previous literature considers one product concept to represent one single product, but I propose that *a product concept defines the qualities of a range of products that embody a comparable use for customers* (Jalonen, Ristimäki, Toiviainen, Pulkkis, & Lohtander, 2016). The product concept thus reflects the principles guiding the development of both single products and the product offering of the company as a whole. When the development of the product concept is studied across the development processes of various products, it is possible to trace its evolution over time.

This understanding of the product concept emphasises the compatibility of the product with the preferences of the customers and the characteristics of the production practices on one hand and the emergent character of the product's properties on the other. First, the purpose of the product concept is to reconcile the requirements of customers with the expertise of designers and producers as well as with the capacities and limitations of the production. A product concept thus defines the boundaries of producing the products' profitably. Second, even though the product development process seeks to determine the properties of the product early on, different product qualities become emphasised in the different phases of the development process – and even in the use of the product. The properties of the product are gradually adjusted while the product under development is examined and evaluated by various actors, such as marketers, designers, producers, potential customers and users (Reijonen & Tryggestad, 2012).

From this perspective, the products which are produced are material manifestations of the product concept but do not necessarily embody all the properties that the concept embraces. An organisation may have several different product

concepts to identify the common properties of groups of products serving different kinds of customers or uses.

2.4.2   Production concepts

I have chosen to analyse the principles guiding the organisation of work practices to produce products with the notion of the production concept. In the literature, qualitative characterisations of production logics have been discussed as production concepts (e.g. Duguay et al., 1997), production models (e.g. Bartezzaghi, 1999) and manufacturing strategy (e.g. Spring & Dalrymple, 2000). Whereas the notion of the business model emphasises the creation of economic value and profit (e.g. Teece, 2010; Zott, Amit, & Massa, 2011), the notion of the production concept focuses on the organisation of the production process according to some guiding principle, such as flexibility (Duguay et al., 1997) or efficiency (Moyano-Fuentes & Sacristán-Díaz, 2012). The profitability of production activity is an inherent goal of any production concept, but the principles of the concept identified by the literature tend to emphasise activities within the company or the supply chain rather than orient towards the customer. My understanding of production concepts also embraces the customer perspective but does not include an analysis of the economic outcomes of the production activity in terms of performance.

The literature characterising different production concepts, such as lean production, discusses them as management concepts or models that "guarantee" the competitiveness of a company (Moyano-Fuentes & Sacristán-Díaz, 2012; Pettersen, 2009). This literature tends to raise one production concept at a time as universally applicable (cf. De Toni & Tonchia, 2002). Recent production concepts have challenged the mass production concept, addressing its shortcomings in the era of globalising markets (Duguay et al., 1997; De Toni & Tonchia, 2002; Moyano-Fuentes & Sacristán-Díaz, 2012). Even though new generations of management theories have surpassed scientific management (Barley & Kunda, 1992), the mass production concept that is built on its premises still continues to exist, at least as a common reference point.

The adoption of a production concept is commonly understood as the implementation of new production management instruments (Da Silveira, Borenstein, & Fogliatto, 2001; Moyano-Fuentes & Sacristán-Díaz 2012). The production concept is often described as a set of principles and corresponding management and information systems to translate the principles into operations (Pettersen, 2009; Moyano-Fuentes & Sacristán-Díaz, 2012). However, the literature does not define a coherent set of dimensions of production that a production concept is composed of; even among scholars studying the same concept, differences in emphasis prevail (Pettersen, 2009). Table 1 provides exemplary dimensions that the literature has associated with different production concepts; many of these distinguish characteristics between two concepts, such as mass production and lean production (e.g. De Toni & Tonchia, 2002).

Table 1. Examples of dimensions associated with production concepts identified in the literature.

Dimension of production concept	Source
Primary objective (low cost / quality / customer value)	Duguay et al. (1997); Moyano-Fuentes and Sacristán-Díaz (2012)
Product variety (low – high)	De Toni and Tonchia (2002)
Market push / pull	De Toni and Tonchia (2002)
Basis of quality (standards / continuous improvement)	De Toni and Tonchia (2002); Pettersen (2009)
Role of workforce (single task – process improvement)	Duguay et al. (1997); Moyano-Fuentes and Sacristán-Díaz (2012); Pettersen (2009)
Organisation structure (mechanistic – organic)	Duguay et al. (1997)
Relationship with suppliers (exchange – partners)	Duguay et al. (1997); Moyano-Fuentes and Sacristán-Díaz (2012); Pettersen (2009)

Victor and Boynton (1998) have created a distinctive framework which analyses different kinds of production concepts in terms of capabilities. According to this view, each production concept is based on a distinctive kind of knowledge, associated with a typical type of work and organisation, which can produce a specific kind of market value. Thus, the type of production work is associated with the certain type of products it can deliver. The framework distinguishes between five production concepts: craft, mass production, process enhancement, mass customisation and co-configuration. Victor and Boynton analyse transformations between these production concepts as a series of developmental steps, proceeding from craft to co-configuration. The framework explains the transformation as an accumulation of learning within the previous production concept to be capitalised on when markets create new kinds of opportunities.

Victor and Boynton (1998) define each production concept in terms of four "key alignment elements" (p. 76) required to create market value, characteristic of the concept. The most important element is the kind of knowledge that workers create through learning in their daily tasks; for example, craft relies of tacit knowledge, while mass production requires the development of 'articulated knowledge' (cf. 'explicit knowledge' in Nonaka, 1994). The rest of the elements are not defined with the same precision but rather rely on the characterisations of the organisation (organisational structure, roles of managers and workers), process flow (division of work) and information technology. Process management tools and procedures are also considered but mainly as a means of transformation from the previous production concept to the next one.

The general production concepts identified by Victor and Boynton (1998) resemble the concepts analysed in the operations management literature. I briefly describe each of these and draw parallels with other streams of literature to illustrate how production concepts have been understood. Victor and Boynton

describe production concepts as subsequent modes of work that have historically followed each other, while other scholars have discussed similar historical sequences using different labels (e.g. Baden-Fuller & Morgan, 2010).

Craft is based on workers' tacit knowledge and individual skills, which are learnt through participation in a community of practice (Victor & Boynton, 1998). Craftmanship is about "the desire to do a job well for its own sake" (Sennett, 2008, p. 9): It includes the development of skill through practice and imagination with serious engagement and commitment to the quality of one's work. Craft produces high-priced novel products with the worker's handprint of unique quality; it relies on the autonomous work of individuals and groups (Victor & Boynton, 1998). Some product customisation strategies and the organisation of work to tailor products according to customer preferences may be analysed as craft work (cf. Spring & Dalrymple, 2000).

Mass production relies on explicit, articulated knowledge about the best practices of carrying out production tasks; standard procedures or automation instils discipline into the work process (Victor & Boynton, 1998). To reduce all sources of change causing additional costs, work under mass production is systematically organised, which creates a distinction between planning and execution tasks (Duguay et al., 1997). Through elimination of variations in quality, mass production generates standard, low-price commodities (Victor & Boynton, 1998). However, the focus on the reduction of costs with high-volume production exposes companies to trade-offs between product quality, production time and costs (Duguay et al., 1997).

Process enhancement is based on an understanding of work processes and their interconnections that enables the identification of weaknesses and their improvement (Victor & Boynton, 1998). This kind of knowledge has been analysed as 'work process knowledge' in industrial settings (Fischer & Boreham, 2004). The workers seek improvements by constantly experimenting with process parameters and evaluating their outcomes (Victor & Boynton, 1998); production tasks are reintegrated through teamwork, and decision making is decentralised (Virkkunen, 2007). Process enhancement produces high-quality products (Victor & Boynton, 1998).

Production concepts based on the continuous improvement of processes, including total quality management (TQM) and lean production, have stemmed from studies of the Japanese car industry. Among these concepts, lean production has attracted the most attention, and it is maybe the best-known production concept today. Lean production aims to manage the production process as an integrated manufacturing system with a focus on efficiency and flexibility; it seeks to create value by eliminating "waste" from the process (Moyano-Fuentes & Sacristán-Díaz, 2012). Lean production departs from other process improvement concepts, such as TQM, in its attempt to "eliminate the human factor from the system" (Pettersen, 2009, p. 135). Recently, the scope of lean production has expanded to embrace supply networks to ensure that suppliers act according to the principles of the concept (Moyano-Fuentes & Sacristán-Díaz, 2012).

Mass customisation (MC) relies on an understanding of the ways of combining activities to create a reconfigurable production process (Victor & Boynton,

1998). MC involves "the ability to provide customized products or services through flexible processes in high volumes and at reasonably low costs" (Da Silveira et al., 2001, p. 1). Thus MC combines the efficiency demands of mass production with the customisation ability of craft; it generates tailored products that correspond to customers' unique needs (Victor & Boynton, 1998). MC may range from the adaptation of products by customers themselves during use up to the total customisation of the production process (Da Silveira et al., 2001). However, MC is a demanding production concept because the customisation of products "involves an intimate connection between product design and manufacture" (Spring & Dalrymple, 2000, p. 445). Victor and Boynton (1998) maintain that MC requires the development of both modular products and a modularised production process, which makes the implementation costs of the concept high.

Co-configuration is only vaguely characterised by Victor and Boynton (1998), who argue that it is based on a systemic understanding of "the dynamic interactions between the product, the customer, and the firm" (p. 14). They suggest that continuous collaboration between these elements may produce "customer-intelligent" products that adapt to the customers' needs over time. The development of a co-configuration concept thus requires both the development of technologies tracing a customer's experiences with the product and collaborative relationships between the producer and the customer. Virkkunen (2006b) provides an example of co-configuration involving a software package for the optimisation of customers' production processes. His illustration exhibits the process of developing a co-construction concept as complex and tension-laden, requiring constant negotiations about the objective of collaboration and division of labour both between and within the producer and the customer company. Only recently has collaboration with customers been emphasised in the operations management literature; servitisation is one of the labels addressing this issue. Servitisation refers to the idea of manufacturing companies offering integrated product–service systems – tailored solutions – to their customers (Baines, Lightfoot, Benedettini, & Kay, 2009). However, servitisation is not a comprehensive production concept, because it does not address how this kind of production could be organised.

This overview of the literature on production concepts demonstrates that the understanding of their meaning in the organisation of companies' production activities is ambiguous. The literature does not agree on the dimensions of which a production concept is composed. Furthermore, evidence from the translation of the principles of production concepts into everyday operations as well as the achievement of expected results is contradictory (Moyano-Fuentes & Sacristán-Díaz, 2012). This calls for an exploration of the connections of the principles and their implementation.

In this research, I employ a practice-based approach to production concepts. The approach includes a distinctive understanding of production, which does not confine itself to a single phase of a production process. Production is understood as a collection of practices to create a product, spanning from the articu-

lation of the product requirements to the delivery of the product to the customer. Hence, the study of production focuses on the interconnected, situated actions of knowledgeable actors giving the product its form (cf. Nicolini et al., 2003).

Here, *a production concept refers to the principles of organising the activities of producing products; it represents the logic of the production activity* (Jalonen et al., 2016). The guiding principles, such as uniqueness, quality or optimisation of costs, are translated into work practices by embedding them in the organisation of work and the artefacts used. The logic is manifested in the division of work within the company and between the company's partners, the kinds of relationships among the partners and the chosen production technology as well as the tools for the management of the production activity. The organisation of tasks typically expands beyond a company's boundaries to include the outsourcing of work to suppliers or subcontractors as well as the collaborative work with them or with customers. Collaboration with partners involves different kinds of expectations and interests, which are projected on the collaboration. The production concept binds together the work of diverse actors, providing them a shared orientation to the activity (Virkkunen, 2006a).

The definition of the production concept used in this research is a local and situated one: It addresses the practices of the whole production process and seeks to characterise their logic. The assumption is that each organisation has one or more production concepts, either as defined models of operations or intuitively followed ways of working. Even though the production concept follows a general model known in the industry, it is always adapted to the situation of the organisation; there are many ways of carrying out mass production, for example. Pettersen (2009) acknowledges the locality of production concepts by proposing an adaptational approach to the implementation of production concepts, which takes into account "the contextual factors and previous production practices that exist within the organization" (p. 137).

2.4.3   Interdependence of product concepts and production concepts

My assumption is that production concepts and product concepts evolve in an intertwined way. Especially in the case of new products, companies need to transform or create the production process and possibly the manufacturing technology. Therefore, the relationships between production and product concepts need to be studied to determine how the principles inherent in the concepts orient actions. For example, in craft, experimentation and the analysis of failures are important sources of learning. The product is developed iteratively in the form of improved prototypes, which means that the product concept evolves as a result of learning. Mass production, in contrast, aims to produce products cost-effectively and to eliminate flaws in the production process through the standardisation of work methods. Thus, the product concept is also standardised to produce a high volume of products of optimised quality with low costs. The interdependencies between the production concept and the product concept suggest that inconsistencies between them may lead to serious problems in the production process and possibly to failures in the market.

This understanding of concepts acknowledges both their conceptual and operational character in human activity. In the conceptual sense, a concept has a representational meaning: It expresses the aspired logic of the activity and integrates understandings about the activity by giving it a name (Virkkunen, 2006a). Commonly known production concepts such as mass production or lean production represent the general principles of a mode of production. In the operational sense, the concept guides actions coherently towards mutually set objectives; it provides "internal coherence embedded in the structures and daily practices of the activity" (Virkkunen, 2006a, p. 46). Often the logic of the production concept guides the actions of participants through the use of information systems that require the performance of a pre-defined set of operations. My understanding of product concepts and production concepts views them as "concepts in practice" (Hutchins, 2012), covering both the conceptual and the operational dimensions.

2.5   Innovation work as a bundle of sociomaterial practices

The adoption of a practice-based approach to the innovation process requires analytical tools for the analysis of the emergence and evolution of practices as well as the artefacts created and used in these practices. Furthermore, the analysis needs to account for connections between the innovation process and the product concepts and production concepts of the studied organisation. Therefore the approach that this study draws on emphasises the centrality of artefacts in the performance of practices.

2.5.1   Artefacts and agency

My study examines the interactions between human actors and artefacts in innovation practices. This connects with the ongoing discussion about the sociomaterial nature of organising among scholars of organisation studies. This discussion centres on the possibility of drawing a distinction between what is social and what is material on one hand and between social agency and material agency on the other (Kautz & Jensen, 2013; Leonardi, 2013; Mutch, 2013; Scott & Orlikowski, 2013). While studies using sociomateriality as a lens to theorise organisational phenomena have proliferated, the approach has attracted critique regarding the tendency of its promoters to define their perspective in vague terms, hindering its fruitful use in empirical studies (Kautz & Jensen, 2013). Therefore I explore different research traditions that theorise the participation of artefacts in the performance of practices.

The first tradition draws on the notion of affordance by Gibson (1979). From this perspectice, artefacts in our environment afford us with different possibilities of action (Faraj & Azad, 2012). Kallinikos (2012) identifies three dimensions that define the materiality and "instrumental identity" of artefacts: matter, form and function. Artefacts can be material or immaterial – concrete or abstract; the uses of an artefact may extract specific qualities from its matter that fit the situational purpose. In the case of the hybrid package, the matter is a combination

of paperboard and plastic. Form refers to the mould that the matter enters; artefacts are often designed for a particular use. The hybrid package is formed in a particular shape and has geometric dimensions that define its volume. Function is the purpose that the artefact is to fulfil; in the advanced manipulation of artefacts, these may serve several functions. The hybrid package is designed to protect the food product between production and use, to communicate the qualities of the product and to serve as a dish in the heating and the consumption of food. Through the often sophisticated combination of matter, function and form, an artefact offers possibilities for human action – the purposes it supports are manifested in the functions and forms that the materiality of the artefact is able to sustain. However, if affordance is equated with the function of an artefact, it delimits the agency of the artefact and ascribes a fixed intention to the person who uses it (Jarzabkowski & Pinch, 2013).

The second tradition, actor–network theory considers artefacts as actors that carry out programmes of action, which may interfere in the actions that other actors are performing (Latour, 1994). In ANT terms, "any thing that does modify a state of affairs by making a difference is an actor" (Latour, 2005, p. 71). Furthermore, ANT draws a distinction between two ways in which artefacts participate in activities. Latour (2005) defines an intermediary as something that "transports meaning or force without transformation" (p. 39); such an artefact is a neutral representation of the state of affairs. Mediators act in the opposite way: They "transform, translate, distort, and modify the meaning or the elements they are supposed to carry" (Latour, 2005, p. 39) and make other actors do unexpected things. This difference in the behaviour of artefacts is not related to their nature but their position in the activity that is taking place. In the course of action, mediators may become intermediaries and vice versa (Latour, 2005). Furthermore, an actor is never the sole source of an action, since there are always multiple actors present in a situation.

The notion of inscription in ANT literature resembles the notion of affordance. Designers make decisions about the delegation of responsibilities in the use of the artefact they are designing and inscribe this vision in the artefact, thus producing a script of the possible use of the artefact (Akrich, 1992). The actors (either human or non-human) engaging with the artefacts in their activity subscribe to the inscripted purposes through their reactions to the scripts that the artefacts encompass. However, the actors may also de-inscript the action possibilities provided by the artefact and modify the sequence of actions (Akrich & Latour, 1992). ANT studies demonstrate how the relationships between human actors change following the adoption of the new artefact. Some artefacts fail as innovations because they do not allow the actors to manipulate them to make them usable for their activities (Akrich, 1992). Other artefacts manage to persuade actors to play the roles proposed to them, and, consequently, the established network of human actors and artefacts begins to redefine their relationship with the society at large. The breakdown of an artefact's script is a test of the stability of the network composed of human actors and artefacts; the rapidity with which a solution to the breakdown is found is a measure of its stability (Akrich, 1992). However, ANT has been criticised for not addressing the creative

and social nature of human action adequately (Jarzabkowksi & Pinch, 2013; Miettinen, 1999).

The third tradition, cultural–historical activity theory, views artefacts as simultaneously conceptual and material – "an aspect of the material world that has been modified over the history of its incorporation into goal-directed human action" (Cole, 1996, p. 117). Hence, artefacts do not only include material things but also concepts, symbols and other forms of language. CHAT emphasises the connection between artefacts and human culture: All artefacts in the sphere of human culture are infused with human purposes (Cole & Gajdamashko, 2009). Wartofsky (1979) sees the creation of artefacts for the means of existence as the distinctive feature of human activity. Hence, the use of artefacts makes cultural transmission possible: "[T]he artifact is to cultural evolution what the gene is to biological evolution" (Wartofsky, 1979, p. 205).

CHAT scholars differentiate between two fundamentally different roles in which an artefact may appear in human activity: It can be either an object of activity or a mediational means (Engeström & Escalante, 1996). The object of activity expresses the purpose of the activity in society, while the mediational means are cultural resources that humans use when working to accomplish the object. The characteristics of the artefact do not decide the role it assumes in a given activity; the activity is a systemic whole in which the status of the artefact depends on the relationships between the elements. Furthermore, over the course of the activity, artefacts may transform from an object of activity into its means and vice versa (Miettinen, 1998).

CHAT takes as its unit of analysis the collective and object-oriented activity. The activity is oriented towards the accomplishment of the object of activity through actions carried out by individuals or groups, which obtain their meaning only as part of the activity (Engeström, 1987). These actions are composed of local operations performed by humans or machines. The activity is typically understood as an activity system whose elements are defined by their relationships with each other (Engeström, 1987). The activity is performed by a collective subject who acts towards the object by means of material-conceptual tools and signs. The participants of the activity form a community whose actions are organised according to shared rules and a division of labour. An activity is thus a locus within which the coevolution of the cognitive, material and social aspects of human practice takes place as a system of interrelated elements (Miettinen, 1999).

These three research traditions have a different stance on the agency of artefacts. ANT lays its foundation on the ontological symmetry of human and non-human actors, arguing that both gain and exercise agency through their engagements in the heterogeneous networks that the society is composed of (Latour, 2005). The affordance approach and CHAT assert an asymmetrical agency between humans and artefacts. The distinction between three different modes of agency that different (human and non-human) actors may exhibit proposed by Kaptelinin and Nardi (2006) illustrates the stance of CHAT on the issue. The first mode of agency is 'conditional agency,' which does not require intentions or can result in unexpected action; this kind of agency belongs to all kinds of

actors because they can produce effects (Kaptelinin & Nardi, 2006). The second mode is 'need-based agency,' which refers to forming intentions to meet one's biological or cultural needs; this kind of agency belongs only to living things, including "higher" animals, humans or social entities. The third mode, 'delegated agency,' refers to realising the intentions of (other) human beings; this kind of agency may be performed by humans and social entities as well as living beings and artefacts within human cultural influence. Whereas non-human entities may delegate responsibilities to humans in ANT, delegation flows from humans to all other kinds of actors in CHAT: Artefacts cannot create meaningful activities or form intentions (Kaptelinin & Nardi, 2006).

In this study, I stand somewhere in the middle ground between these stances. On one hand, I follow the ANT understanding of agency as an ability that emerges through enactments of humans and artefacts. On the other, I distinguish between human intentions and non-human programmes of action, following the asymmetrical understanding of agency. Artefacts gain agency in relation to humans in terms of how their behaviour corresponds to the expectations of human actors (Pickering, 1993). However, artefacts may enable certain ways of human acting while making other ways of acting impossible. In any practice, human and material agency are mutually shaped (Pickering, 1993); the activity transforms both human actors and (the material form and meaning of) artefacts (cf. Miettinen, 1999).

2.5.2 Innovation process, sociomaterial practices and product and production concepts

To study the innovation process with the practice-based approach, I draw on CHAT and other traditions of practice theory that emphasise the centrality of artefacts in the performance of practices. Next, I outline my understanding of the innovation process as a bundle of sociomaterial practices and connect it to the development of product and production concepts.

As the basis of my understanding, I draw on CHAT and the 'elemental' practice framework of Shove and colleagues (2012), who maintain that practices consist of elements that become integrated when practices are enacted. These elements include materials – the different kinds of artefacts and the human body; competencies – the knowledgeability of the actors; and meaning – the significance of participation to the actors (Shove et al., 2012). The material elements resemble the mediational means in CHAT theorising, except that CHAT does not discuss the role of the body in activity; I presume it belongs to the subject. The competences in the form of understanding and skills pertain to the human subject in CHAT, the norms that govern the way actions are carried out are labelled as rules and the knowledgeability of the organising of the actions belongs to the division of labour. Furthermore, these competences can be preserved and transmitted by embedding them in artefacts (Miettinen, 1998; Miettinen et al., 2012). The meaning of the activity in CHAT is related to its object and is embedded in the tools. In Schatzki's (2012) terms, the meaning element can be understood as a teleoaffective structure, which includes the ends that participants are to realise and the emotions that they are expected to express when carrying out a

practice. The meaning can also be viewed as general understandings, which are senses of the worth that are infused in the participants' actions (Schatzki 2012).

Thus, this practice approach assumes that practices are defined by the interdependent relations between the composing elements. Furthermore, the approach enables tracing the constitution and change of practices. Shove and colleagues (2012) distinguish between two analytical but integrated views of practice: practice-as-entities and practice-as-performances, whose temporal unfolding can be studied as trajectories. According to their framework, elements of a practice become integrated when the practice is enacted. In the performance of the practice, actors simultaneously reproduce the actions and the elements of which the practice is made. However, through these enactments, the constitutive elements of the practice may also be transformed and their relations reconfigured. Practices emerge as links between their defining elements are made and they change as a result of the new configurations of the elements. Thus, the stability of a practice is provisional and is only maintained when the elements are consistently integrated through repeatedly similar performances (Shove et al., 2012). Over the course of time, practises may also disappear once the relations between the constitutive elements are no longer enacted. However, the elements may continue their existence in some form as parts of another practice, as elements circulate within and between many different practices. Several related practices thus constitute complex sociomaterial arrangements, through which social life unfolds (Schatzki, 2006, 2012)

Figure 2 depicts my practice-based understanding of the innovation process and its outcomes. This perspective views the innovation process as a bundle of sociomaterial practices that contribute to the development of a product, which eventually meets the requirements of both customers and effective manufacturing. These practices engage participants who use their competencies in making use of artefacts, such as concepts, models and prototypes, in the development efforts. The practices may span functional and organisational boundaries (the figure contains only examples of practices identified in the innovation literature) and they are linked by the performances of the human actors and the artefacts. The existing product concepts and production concepts of the company direct the innovation process, influencing the ways in which the properties of the product under development are evaluated, the organisation of the development efforts etc. The innovation process eventually produces a product whose innovativeness is put to the test when it reaches the market. Moreover, the process may produce a novel product concept and production concept or change the existing ones. The logic of the concepts orient the production and further development of the product: Their logic is embedded in the practices.
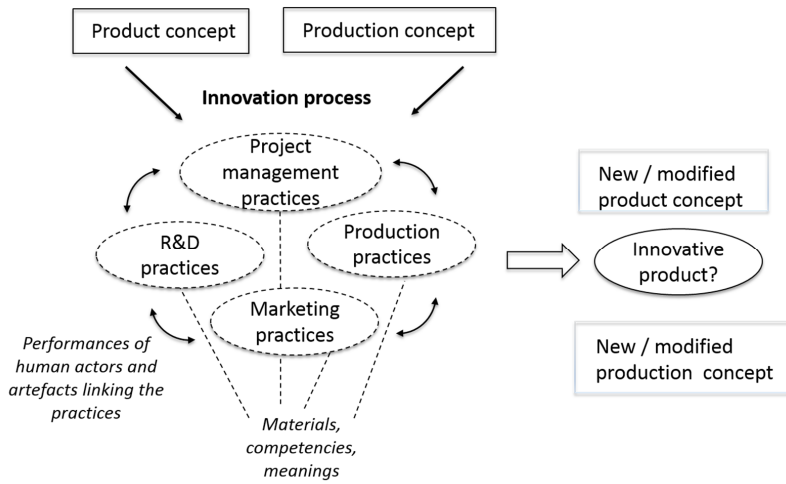
Figure 2. A practice-based understanding of the innovation process and its outcomes.

In the empirical analysis, I will explore the innovation practices in the development process of the hybrid package as well as the links between the innovation process and the product and production concepts. Next I delve more thoroughly into the role of artefacts in collaborative practices, which are important to the development of innovations.

3. A dynamic perspective of boundary objects as mediating artefacts

In product innovation, artefacts are of particular significance: The product to be designed and produced transforms through the formation and manipulation of a series of artefacts from a more or less vague idea to a manufactured material product (or an immaterial product such as an information system). Studies of engineering design and architecture have acknowledged the significance of different kinds of representations created during a product development process and have identified the roles they play (e.g. Henderson, 1991; Ewenstein & Whyte, 2009; Vinck, & Jeantet, 1995). Scholars of organisation and management have studied the role of artefacts as facilitators of communication and coordination at the boundary between designers and manufacturers (e.g. Bechky, 2003; Carlile, 2002, 2004). However, some researchers have shown that artefacts may also impede collaboration between different communities in distributed projects (Sapsed & Salter, 2004). Organisation studies have moreover examined the consequences of the adoption of new artefacts by users in their practices (e.g. Orlikowski, 1992, 2000). Although the product is designed to be used in a certain way, it often allows for different kinds of uses not anticipated by the designers (Akrich, 1992).

Previously, organisation studies have identified several roles that artefacts can play in interdisciplinary collaboration. Until the recent rise of the discussion on sociomateriality in organising, the role of artefacts has mostly been analysed by drawing on the notion of boundary objects, introduced by Star and Griesemer in 1989. In recent years, many scholars have problematized the widespread use of boundary objects in the organisation and management literature. They have argued that the notion of boundary objects should be used in reference to artefacts only when these artefacts are relatively stable and mediate the collaborative work between communities (Ewenstein & Whyte, 2009), and they suggested that other roles of artefacts should be studied with other labels (Nicolini et al., 2012).

First, I review the literature of boundary objects and other artefacts which have been identified to play a role in collaborative work. The literature review suggests that the characteristics and uses of the artefacts in collaboration do not distinguish between the situated roles that artefacts play within and across practices. Therefore, I propose a relational approach to the study of the role of artefacts in collaboration based on the notion of mediation in cultural–historical

activity theory and postphenomenology. The approach analyses the role of arte-facts as different mediating functions. Moreover, I develop a typology of the pos-sible mediating functions that boundary objects may perform in collaborative work. The chapter ends with a proposal to study the trajectories of boundary objects to identify temporal shifts in the mediating functions that artefacts per-form in the innovation process.

3.1   Boundary objects: Artefacts mediating collaborative work be-tween communities

The notion of boundary objects arose from the problematic of the heterogene-ous nature of scientific work: How diverse groups of actors conducting scientific work can collaborate without consensus. In their seminal study, Star and Griesemer (1989) analysed the practices of coordination in the scientific enter-prise of establishing a natural history research museum and ensuring the quality of the scientific work conducted in the museum. Both of these objectives de-pended on the development of practices to manage the work at the intersection of heterogeneous groups of actors, including amateur collectors, researchers, animals, administrators etc. Successful scientific work in the museum was con-tingent on the contributions of diverse other actors whose primary concerns only partly coincided with those of the scientists. According to the analysis by Star and Griesemer, the establishment of coherence of information among the different actors required the development of methods of standardisation and boundary objects. The former meant enforcing a clear set of methods to acquire the necessary information from the non-scientists providing the museum with specimens. The latter demanded the generation of a series of artefacts which would maximise both the autonomy and communication between the different groups of actors.

Star and Griesemer (1989) characterised boundary objects as both inhabiting several intersecting professional communities and satisfying the information requirements of each of them. Collaboration is based on the dynamic nature of boundary objects: The object is weakly structured in common use between groups but becomes strongly structured when worked on by local groups (Star & Griesemer, 1989). Therefore, boundary objects enable actors in different com-munities both to communicate about their work across the community bound-aries and gain autonomy to continue their work within the specialised (discipli-nary, professional or organisational) domain.

Star (1989) argued that the characteristics of the heterogeneous information combined by the participants to create such partially shared artefacts lead to different types of artefacts to fulfil the information needs. Star and Griesemer (1989) and Star (1989) outlined a tentative typology that covered four types of boundary objects, as given below.

Ideal types or platonic objects are fairly vague, abstracted artefacts, which serve as means of symbolic communication (Star & Griesemer, 1989). Their vagueness makes them adaptable to local needs, and they help in overcoming

differences in degrees of abstraction between communities (Star, 1989); a scientific concept is an example of ideal types.

Coincident boundaries are common artefacts having the same boundaries but different contents; for example, a map of a territory can serve as such a boundary object (Star & Griesemer 1989). Coincident boundaries enable collaborating communities to conduct autonomous work by serving as a common referent and bridging between different goals and means of aggregating data (Star, 1989).

Repositories are sets of artefacts indexed in a standardised fashion in order to overcome differences in unit of analysis between communities (Star, 1989). Repositories provide modularity of information; people from different communities "can use or borrow from the 'pile' for their own purposes without having directly to negotiate differences in purpose" (Star & Griesemer, 1989, p. 410); a library is such a repository.

Forms and labels serve as methods of communication across dispersed work groups, thus creating standardised indexes that can be transferred over distances without changing information (Star, 1989). Standardised forms – used, for example, for documenting a specimen – delete local uncertainties (Star & Griesemer, 1989); they may or may not become part of larger repositories (Star, 1989).

This preliminary categorisation of boundary objects was developed based on the analysis of the establishment of the museum and the practices of collecting and categorising specimens. Whereas this typology includes both material and conceptual artefacts, most organisational studies on boundary objects have tended to emphasise the meaning of material, tangible artefacts such as design drawings and product prototypes (e.g. Bechky, 2003; Carlile, 2002, 2004) and have neglected the conceptual dimensions of boundary objects present in the seminal study. Trompette and Vinck (2009) remind that boundary objects are multiple and malleable in the sense that they act as a partial and temporary bridge between communities: While they have different meanings in these communities, "those meanings are sufficiently structured to be recognised by the other" (p. e). Star (2010) herself observed that boundary objects are "temporal, based in action, subject to reflection and local tailoring, and distributed throughout all of these dimensions" (p. 603).

The notion of boundary objects has highlighted the existence of boundaries between different groups within and between organisations. Researchers have interpreted boundary objects as vehicles for boundary crossing, as interface mechanisms between actors (Trompette & Vinck, 2009). In organisation studies, boundaries are often viewed in terms of differences between the knowledge of expert communities and the dependence between their tasks, calling for coordination of work efforts (Carlile, 2002, 2004; Scarbrough et al., 2015). Akkerman and Bakker (2011) have developed a more general definition of a boundary: "[A] sociocultural difference leading to discontinuity in action or interaction" (p. 133). Boundaries are ambiguous in nature: They belong to both one world and another, while at the same time they belong to neither one nor the other world (Akkerman & Bakker, 2011). Individuals and artefacts that cross bound-

aries both act as a bridge between communities and represent the division between them (Akkerman & Bakker, 2011). Therefore, encounters at boundaries may lead to their renewal and reconstruction (Kerosuo, 2001). Whereas most research on boundary objects analyses the crossing of knowledge boundaries with the help of artefacts, Lee (2007) argues that artefacts are also needed in the establishment of boundaries to divide work tasks between individuals and communities.

The tendency to focus the analysis of boundary objects on the sharing of knowledge and coordination of tasks through tangible artefacts may compromise the nuances of interaction between human actors and artefacts. Trompette and Vinck (2009, p. g) maintain that "[the] complexity of interactions between social worlds is often forgotten to the benefit of simplified modelisation of the articulation between two worlds via a boundary object." In her reflection on the notion of boundary objects, Star (2010) reminded that, in essence, boundary objects are arrangements that allow different groups to work together without consensus.

Recently, the extensive use of boundary objects has gained increasing critique. Whyte and Harty (2012) argue that during the expansion of the use of the concept, some of the original intention and the tentative nature of Star and Griesemer's analysis has been lost. Trompette and Vinck (2009) note that the popularity of the concept has led to a situation where it is sometimes used merely in an anecdotal manner. Nicolini and colleagues (2012) urge scholars to study artefacts from different theoretical perspectives, arguing that if the notion of the boundary object is stretched to all objects, then the explanatory power of the theory is undermined.

Furthermore, many scholars have problematised the tendency in organisation studies to discern the intrinsic characteristics of boundary objects to evaluate their effectiveness in mediating cross-boundary collaboration. They maintain that an artefact becomes a boundary object as the outcome of situated interaction, not due to the artefact's qualities (Ewenstein & Whyte, 2009; Nicolini et al., 2012; Zeiss & Groenewegen, 2009). Trompette and Vinck (2009) argue that when the notion is equalled with any artefact that is at the boundary of two communities, it loses its original analytical momentum, namely that "certain objects or configurations – or even organisations – materialise and transport an invisible infrastructure made up of standards, categories, classifications and conventions that are specific to one or more social worlds" (p. l). This line of reasoning suggests that the use of boundary objects should be limited, and therefore other roles of artefacts should be studied in terms of other labels (Nicolini et al., 2012).

I review the literature on the roles of artefacts that are used in collaborative work between and within communities. These studies have suggested alternatives to boundary objects to specify the ways in which artefacts participate in collaborative work. I explore these parallel and alternative notions to see how they expand and specify Star and Griesemer's (1989) typology.

3.2 Siblings of boundary objects: Different labels for collaboration artefacts

After the introduction of the notion of boundary objects, many scholars have explored the different roles that artefacts perform in cross-boundary work. These scholars have sought to specify the ways in which artefacts shape collaborative work by labelling them as representing a certain type of artefact. Some of this work has emerged partly as a response to the concept of boundary object, and some stems from different research traditions that operate with different a kind of vocabulary.

Table 2 summarises the types of artefacts used for collaboration across boundaries identified in previous research. I include artefact notions that have been conceptually and empirically compared with the notion of boundary objects, either by the creators of these alternative notions and/or their subsequent users. I have identified streams of literature that develop new conceptualisations of the use of artefacts in collaborative settings. In addition to the seminal studies, I use empirical studies that have sought to further theorise the concept to provide examples of the artefacts and their use in cross-boundary collaboration, which I employ to identify the functionalities and characteristics of these artefacts. I have also included empirical studies that compare the use of different kinds of artefacts by employing the several labels proposed in this literature. I include boundary objects in this examination to compare their use and characteristics with those of other types of artefacts in order to identify to what extent these characteristics are relative. For the comparison, I identify the studied contexts in which the artefacts are used and discern some empirical examples of the artefacts the study analyses. Following Kallinikos (2012), I seek to identify the matter, form and function of the studied artefacts in the following summaries – to the extent that the reviewed studies articulate these dimensions.

Table 2 is organised according to the closeness of the alternative notions to the notion of boundary objects. The first concepts (boundary concept, boundary negotiating artefact) are directly derived from the notion of boundary objects; these new labels were developed to define the significance of some type of boundary object more specifically or to address an identified shortcoming. The next concepts (conscription device, intermediate object) have been introduced with some inspiration from boundary objects to specify new functionalities. The last group of concepts (epistemic object, technical object, infrastructure and object of activity) are notions whose emergence does not connect with boundary objects but which have been compared to boundary objects in organisation and management studies.

Boundary object. Boundary objects enable actors in different communities both to communicate about their work across the community boundaries and to work autonomously within the specialised community (Star & Griesemer, 1989). The flexible nature of boundary objects is essential to collaboration: They are weakly structured in common use between groups while strongly structured when worked on by local groups. Star (1989) proposed that cross-boundary collaboration is enabled by the development of a system of boundary objects; the

type of boundary object needed depends on "the characteristics of the heterogeneous information being joined to create them" (pp. 46–47). The tentative typology of boundary objects identified by Star and Griesemer covered both abstract and concrete artefacts as well as both deliberately designed and emerging uses. Empirical examples include the concept of the species, the map of California and standardised forms for the collection of specimens. In organisation studies, the notion of boundary objects became popular through the influential studies of Carlile (2002, 2004), who elaborated the typology by Star and Griesemer (1989) to identify the most efficient boundary objects for overcoming particular kinds of boundaries. Carlile (2004) analysed visual assembly drawings and physical prototypes of valves as boundary objects to transfer, translate and transform domain-specific knowledge. Ewenstein and Whyte (2009) identified digital drawings as boundary objects in architectural design, while Nicolini et al. (2012) analysed a bioreactor as a boundary object among scientists.

Boundary concept. Based on a study on the construction of interdisciplinary alliances in science, Löwy (1992) observed the significance of loose and imprecise concepts for the process. She named such concepts boundary concepts, which corresponds to the 'ideal type' boundary object in the typology of Star and Griesemer (1989). Löwy distinguished boundary concepts from boundary objects: The former are loosely defined concepts adaptable to local sites that can facilitate communication and cooperation between distinct professional groups. The latter are composed of a "hard core," the zone of agreement between interacting professional groups, and of a "fuzzy periphery" different for each of the groups. Löwy claimed that both boundary objects and boundary concepts facilitate heterogeneous interactions between professional groups as negotiable entities by simultaneously delimiting and linking domains of professional expertise. In Löwy's empirical study of the development of immunology, the construction of a boundary concept coincided with the development of new experimental methods, which were available for distinct professional communities united by the boundary concept. The interdisciplinary interactions thus contributed to the redefinition of immunology as a discipline and the integration of specific techniques into a shared set of laboratory practices (Löwy, 1992). Even though some scholars have employed the notion of boundary concept in their empirical research (e.g. Allen, 2009), they have not further theorised the concept.

Boundary negotiating artefact. Lee (2007) developed the concept of boundary negotiating artefact to describe material artefacts that mediate work at community boundaries in non-routine work processes; such artefacts facilitate both the crossing of boundaries in transferring information and the establishing of boundaries in dividing labour. Lee claims that the notion of boundary objects relies heavily on standardised structure; therefore, another concept is needed to explain how groups who lack such structures are able to collaborate. In Lee's reading, to satisfy the information requirements of each community boundary, artefacts described by Star and Griesemer (1989) need to pass "from one community of practice to another with little or no explanation" (Lee, 2007, pp. 312–313). In her study of a design process of a new exhibition in a museum, Lee (2007) identified five types of boundary negotiating artefacts, which all were

visual in nature. 'Self-explanation artefacts' were created and used mostly when working in privacy. Such autonomously created artefacts were developed into 'inclusion artefacts,' which were used to propose new ideas to members of another community; sometimes these were used to create alliances. 'Compilation artefacts' were used to develop a shared understanding of a problem between different communities. 'Structuring artefacts' were used to coordinate and direct the activity of others; sometimes the artefacts created by different members competed with each other and were used to negotiate boundaries. 'Borrowed artefacts' were taken from one community and used in unanticipated ways by another community. In conclusion, Lee (2007) suggests that boundary objects may be found primarily in fairly routine or simple work contexts, whereas boundary negotiating artefacts may be more prevalent in fairly non-routine and complex contexts.

Pennington (2010) picked up Lee's concept of boundary negotiating artefacts to propose a typology of boundary objects – 'boundary specifying object' and 'boundary negotiating object' – in order to develop a dynamic account of the role of different kinds of artefacts in different phases of collaborative work. According to Pennington (2010), the characteristics and functions of boundary objects are related with the temporal stage of the collaboration process: Boundary negotiation needs to lead to boundary specification in order for the participants to align their work. In her study of an interdisciplinary research team, Pennington followed the emergence of boundary negotiating concepts, new conceptualisations and terms and new artefacts that represented these conceptualisations and terms. She suggests that the artefacts produced by a group will take on the characteristics of the processes that produced them; boundary objects (even boundary specifying objects) are continually modified and reused, and thus the complexity of the work being carried out determines the need for flexible boundary objects.

Conscription device. Henderson (1991) developed the concept of conscription devices based on her study of the work practices of design engineers and the essential role of visual representations. She argued that engineers' visual representations, such as sketches and drawings, are not only boundary objects – being flexible for various uses and facilitating differential readings – but are additionally conscription devices, which socially organise the work of engineers by enlisting participation. This enlisting concerns not only engineers themselves but also the users of the artefacts who need to take part in their creation and modification to make the design serve its intended function. Such artefacts are essential when design engineers communicate with each other; "[t]he conscriptive quality of these visual representations is so strong that participants find it difficult to communicate about the design at all without them" (Henderson, 1991, p. 456).

The study by Karsten, Lyytinen, Hurskainen and Koskelainen (2001) on the use of artefacts in a paper machine delivery project is an example of the research comparing the notions of conscription device and boundary object. Karsten and colleagues maintain that boundary objects are physical artefacts that allow di-

versity in interpretation when used to facilitate collaboration, whereas conscription devices are physical artefacts facilitating the sharing of information within a community and providing means for participating in the construction of this information. Karsten et al. (2001) argue that boundary objects have an immutable quality, whereas conscription devices need to be mutable to allow mutual manipulation of the artefact.

Intermediary object. Vinck and Jeantet (1995) developed the concept of intermediary object to reconceptualise the design process and to emphasise the active role of non-humans that may transform the intention behind their design. Intermediary objects lie in-between several elements, several actors or successive stages of a work process; they "mark the transition from one stage to another, circulate from one group to another or around which various actors and instruments revolve" (Vinck & Jeantet, 1995; p. 118). Vinck and Jeantet created a typology of intermediary objects by distinguishing between two types and two dimensions of intermediary objects. 'Commissioning objects' are temporary materialisations of a previous state of human interaction, which represent the intentions of their creators. 'Mediating objects' translate information and meanings between actors; they result from previous interactions, are mobilised as new resources in negotiations and shape future developments. An intermediary object may be either "closed," imposing on its user a way of interpreting or acting on it, or "open," allowing some extent of freedom in its use. However, the typology does not describe the intrinsic characteristics of objects; artefacts acquire these properties and abilities in certain situations resulting from interactions between people and artefacts (Vinck & Jeantet, 1995).

Further research on intermediary objects has studied their emergence and uses in design processes; identified examples include CAD models and sketches (Boujut & Blanco, 2003) and partnership contracts (Hussenot & Missonier, 2010). Boujut and Blanco (2003) see intermediary objects as intermediate states of the product to be designed and produced; the artefacts are both traces and outputs of the process. Hussenot and Missonier (2010) note that often such artefacts are initially abstract ideas or concepts, which are later materialised into physical artefacts, such as plans and drafts. Intermediary objects are mediators manifesting and creating change in social relations, translators of agreements between things and people and representations of the human and non-human actors involved in their shaping (Vinck, 2012). While intermediary objects enable following actions in the process, they also create some irreversibility: Once articulated and materialised, the features of the product represented by the artefact, such as a sketch, become "a reference for the participants that implicitly orient the future choices" (Boujut & Blanco, 2003, p. 215). Thus, intermediary objects can prevent the exploration of alternative solutions once an acceptable design has been found. At the same time, they offer anchoring points, new points of departure and future perspectives (Brassac, Fixmer, Mondada, & Vinck, 2008).

Epistemic object. Knorr Cetina (1997, 2001) followed Rheinberger's (1997) analysis of the centrality of scientific objects as targets of experimental inquiry to discuss the significance of artefacts in epistemic work practices. She called

these epistemic objects, which are characterised by openness and incompleteness. Epistemic objects can never be fully attained, as they continually acquire new properties while being worked on (Knorr Cetina, 2001); they acquire their significance from their unpredictable future (Rheinberger, 1997). The open-ended nature of epistemic objects makes them work as a source of motivation and form an emotional affiliation that binds a community to work together (Nicolini et al., 2012). Furthermore, epistemic objects can be only partly expressed in material instantiations: They require concrete material artefacts through which they can be manipulated and developed (Rheinberger, 1997; Ewenstein & Whyte, 2009). Knorr Cetina (2001) discussed a protein as an example of an epistemic object, while transfer RNA and messenger RNA are examples of epistemic things in the historical study by Rheinberger (1997). The building to be designed was analysed as an epistemic object of architects by Ewenstein and Whyte (2009), whereas Nicolini and colleagues (2012) analysed the bioreactor as an epistemic object among researchers. Miettinen and Virkkunen (2005) examined the change of safety inspection activity as an epistemic object.

Technical object. Rheinberger (1997) calls material artefacts, through which epistemic objects can be articulated, technical objects. Technical objects embed the epistemic objects in the material conditions of the experimental system: They "determine the realm of possible representations of an epistemic thing" (Rheinberger, 1997, p. 29). Hence, technical objects establish the conditions under which epistemic objects may be manipulated and the grounds for evaluating the outcomes of experiments. Technical objects are complete and unproblematic material artefacts, which are characterised by closeness (Ewenstein & Whyte, 2009). However, the properties of the artefact do not decide whether it works as an epistemic or a technical object but rather the function of the artefact depends on its position in the setting of use (Rheinberger, 1997). In essence, the production of differential events that "may induce major shifts in perspective within or beyond their confines" (Rheinberger, 1997, p. 36) depends on the transformation of epistemic objects into technical objects and vice versa. Empirical examples of technical objects include radioactive amino acids in Rheinberger's (1997) study and a top floor plan in the study by Ewenstein and Whyte (2009).

Infrastructure. The notion of infrastructure gained momentum as researchers studied the dynamics of the development of information systems and organisational practices arising from Internet technologies used by people separated by geographical distances. Today, information infrastructures are "the digital equivalents of the canonical infrastructures of telephony, electricity, and the rail network" (Edwards, Bowker, Jackson, & Williams, 2009). Star and Ruhleder (1996) developed an understanding of infrastructure as a relational property: Any artefact can potentially become infrastructure when it becomes taken for granted and embedded in material and social arrangements of organised practices. When an artefact is part of infrastructure, it is transparent to use, because local variations are standardised and acquire an unambiguous meaning (Star & Ruhleder, 1996). Furthermore, this transparency makes the infrastructure invisible when it supports the carrying out of the practice; it becomes visible only

upon breakdown (Star & Ruhleder, 1996). Empirical examples of infrastructures include software for geographically dispersed collaborative scientific work, whose failure Star and Ruhleder (1996) analysed. In their study, Nicolini et al. (2012) considered an email system and a meeting room to be infrastructure for collaborative scientific practice. Bowker and Star (1999) have brought together the notions of boundary objects and infrastructure by suggesting an understanding of boundary infrastructures that serve several communities of practice by establishing stable regimes of boundary objects which operate as standards across the communities.

Object of activity. The notion of object of activity stems from the sociocultural theories of Soviet psychologists, whose work CHAT scholars have expanded. An object of activity is "an enduring, constantly-reproduced purpose of a collective activity system that motivates and defines the horizon of possible goals and actions" (Engeström, 1999a, p. 170). The object of activity is realised in the construction of products and services that constitute the outcome of the activity (Miettinen & Virkkunen, 2005). The object is simultaneously material and conceptual: It is both materially and socially constructed (Foot, 2002). Furthermore, the object of activity is projective and transitory in nature (Engeström, 1999a): The object escapes once an intermediary goal is achieved (Engeström, 1999b), but through the re-conceptualisation of the object, the community may "embrace a radically wider horizon of possibilities" (Engeström, 2001, p. 137). Hence, the object of activity undergoes temporal trajectories of development, during which it can take different kinds of forms and functions (Miettinen, 2005); a typical trajectory is the transformation of an object into the mediating means of the activity and vice versa (e.g. Miettinen, 1998). The activity is thus structured by its object, which organises the actions of participants. Nicolini and colleagues (2012) conclude that the object of activity provides "the direction, motivation, and meaning for the activity" (p. 620). They note that as motivation for human activity, the notion resembles an epistemic object. However, the emergent, fragmented and expanding nature of the object of activity as well as its action as a trigger of contradictions and negotiation distinguish it from epistemic object (Nicolini et al., 2012). Typically, empirical analyses of the object of activity focus on the emergence or developmental changes of an object, as exemplified by the studies by Miettinen (1998) on the production of ethanol from wood and by Foot (2002) on the formation of a network of conflict monitors. In the study by Nicolini et al., (2012) the bioreactor is the object of collective scientific activity. Even though the notions of object of activity and boundary object have been developed in different disciplines, scholars from both disciplines have discussed their connections. Bowker and Star (1999) note that pragmatism and CHAT both acknowledge that artefacts mediate action, while Miettinen (2005) suggests boundary objects as a possible way of understanding the object of activity.

Table 2. Different types of artefacts mediating collaborative work identified in previous empirical studies.

Type of artefact	Definition	Studied context of use	Empirical examples of the studied artefacts
Boundary object	"both inhabit several intersecting social worlds (…) and satisfy the informational requirements of each of them" (Star & Griesmer, 1989, p. 393)	Star & Griesmer (1989): collecting and documenting museum specimens Henderson (1991): engineering design Carlile (2002): development of a new valve for automobile fuel systems Ewenstein & Whyte (2009): architectural design of an extension of a herbarium Nicolini et al. (2012): development of a bioreactor for growing cells	Star & Griesmer (1989): scientific concepts, maps, a library Henderson (1991): fixed drawings Carlile (2002): assembly drawings, physical prototypes Ewenstein & Whyte (2009): digital multi-layered drawings Nicolini et al. (2012): Power Point slides, the bioreactor and its components
Boundary concept	"loosely defined concepts which (…) are adaptable to local sites and may facilitate communication and cooperation" (Löwy, 1992, pp. 374–375)	Löwy (1992): development of immunology as a scientific field	Löwy (1992): the immunological concept of the self
Boundary negotiating artefact	"[f]acilitate the crossing of boundaries [and] the pushing and establishing of boundaries" (Lee, 2007, p. 333)	Lee (2007): design of a museum exhibition Pennington (2010): collaboration between scientists and computer scientists	Lee (2007): technical sketches, exhibition concept map etc. Pennington (2010): empirical examples not specified
Conscription device	"enlist group participation and are receptacles for knowledge created and adjusted through group interaction aimed toward a common goal" (Henderson, 1991, p. 456)	Henderson (1991): engineering design of an engine package Karsten et al. (2001): a paper machine delivery project	Henderson (1991): engineering sketches and drawings Karsten et al. (2001): technical specification as a failing conscription device
Intermediary object	"mark the transition from one stage to another, circulate from one group to another or around which various actors and instruments revolve" (Vinck & Jeantet, 1995, p. 118)	Vinck & Jeantet (1995): engineering design Boujut & Blanco (2003): engineering design of an axle Hussenot & Missonier (2010): design of a virtual learning environment	Vinck & Jeantet (1995): empirical examples not specified Boujut & Blanco (2003): CAD models, sketches Hussenot & Missonier (2010): a partnership contract

A dynamic perspective of boundary objects as mediating artefacts

Type of artefact	Definition	Studied context of use	Empirical examples of the studied artefacts
Epistemic object	"are always in the process of being materially defined, they continually acquire new properties and change the ones they have" (Knorr Cetina, 2001, p. 190)	Rheinberger (1997): molecular biology Knorr Cetina (2001): molecular biology Miettinen & Virkkunen (2005): safety inspection Ewenstein & Whyte (2009): architectural design of an extension of a herbarium Nicolini et al. (2012): development of a bioreactor for growing cells	Rheinberger (1997): e.g. transfer RNA, messenger RNA Knorr Cetina (2001): a protein Miettinen & Virkkunen (2005): changing the activity of safety inspection Ewenstein & Whyte (2009): a design sketch, the building Nicolini et al. (2012): a new sensor, the bioreactor
Technical object	"ready-to-hand and unproblematic instruments" (Ewenstein & Whyte, 2009, p. 12)	Rheinberger (1997): molecular biology Ewenstein & Whyte (2009): architecture	Rheinberger (1997): radioactive amino acids Ewenstein & Whyte (2009): a top floor plan
Infrastructure	"occurs when local practices are afforded by a larger-scale technology, which can then be used in a natural, ready-to-hand fashion" (Star & Ruhleder, 1996, p. 114)	Star & Ruhleder (1996): development of software for geographically dispersed collaborative scientific work Nicolini et al. (2012): development of a bioreactor for growing cells	Star & Ruhleder (1996): the Worm Community System as failed infrastructure Nicolini et al. (2012): an email system, a meeting room
Object of activity	"an enduring, constantly-reproduced purpose of a collective activity system that motivates and defines the horizon of possible goals and actions" (Engeström, 1999a, p. 170)	Miettinen (1998): research on cellulose-degrading enzymes Foot (2002): formation of a network of conflict monitors Nicolini et al. (2012): development of a bioreactor for growing cells	Miettinen (1998): production of ethanol from wood by enzymatic degradation Foot (2002): interlinked processes of ethnological monitoring and the building of an epistemic community Nicolini et al. (2012): the bioreactor

To further compare the types of artefacts that previous studies have identified as facilitators of collaborative work, I identify the characteristics and the situational uses of these artefacts, as summarised in Table 3. I categorise their characteristics and uses in terms of form, manipulability and function. Here, "form" refers to the materiality of the artefact, such as physical, visual and conceptual; "manipulability" refers to the flexibility of the use of the artefact, such as open or closed; and "function" refers to the purpose that the artefact serves (Kallinikos, 2012). The table follows the terminology used by the authors of the studies, but if they have not provided the characteristics explicitly, I use general characterisations (marked with italics).

Table 3 is ordered from the most open types of artefacts to the most closed types. Epistemic objects, objects of activity and boundary concepts are loosely defined and conceptual in nature. Conscription devices, boundary objects, boundary negotiating artefacts and intermediary objects stand in the middle ground, appearing in both abstract and concrete forms and being more open or closed depending on the situation of use. Technical objects and infrastructure are material artefacts that are closed, not allowing manipulation. However, the functions that the artefacts serve in collaboration do not follow the characteristics of the artefacts: For example, motivation has been identified as a function of epistemic objects and objects of activity as well as conscription devices. Furthermore, most of the artefact types are associated with several functions.

The comparison of the characteristics and the uses of the artefact types suggests that various kinds of artefacts may serve similar collaborative purposes. Even though the authors characterise the artefacts under study using different terms, we can see that artefacts may be both conceptual (abstract) and material (concrete, physical); the visuality of conscription devices receives special emphasis. Furthermore, most of the artefacts are flexible to a certain extent, while the openness of epistemic objects and closeness of technical objects can be taken to be extreme cases in this dimension. *The most distinctive dimension distinguishing the artefacts appears to be their use or function in collaborative work, ranging from communication to organisation and standardisation.* In addition to illustrating that previous studies have identified several functions for almost all the artefact types, the comparison of the functions shows that these functions overlap across the artefact types. Hence, this comparison demonstrates that the labels associated with the different roles that artefacts may play do not provide sufficient explanatory power to prove that an artefact with particular characteristics will serve a specific purpose in a collaborative practice.

Based on this comparison, I propose that the different dimensions of artefacts may fruitfully be examined in terms of situated functions instead of using different labels for different roles that artefacts play. Labelling artefacts as different kinds of objects according to their situational role entails the danger of a substantialist approach, which associates the role with the intrinsic characteristics of the artefact (cf. Østerlund & Carlile, 2005). To enable the practice-based study of the roles that artefacts play in different kinds of situations and of the possible changes in these roles according to the participants and circumstances of each situation (Nicolini et al., 2012), a dynamic understanding of artefacts'

participation in collaboration is needed. Therefore, I suggest that the role of artefacts in collaborative work be understood as emergent and more or less temporary functions that an artefact may acquire in a specific situation as part of a practice.

Table 3. Characteristics and functions of the collaboration artefacts identified in the literature.

Type of artefact	Form	Manipulability	Function
Epistemic object	*Conceptual-material*	Open Incomplete	Motivation
Object of activity	Conceptual-material	Emergent Fragmented Projective	Motivation Transformation
Boundary concept	Conceptual	Loose Imprecise	Communication Cooperation Negotiation
Conscription device	Visual	Manipulable	Motivation Organisation Communication
Boundary object	Abstract Concrete	Flexible Loosely / strongly structured	Communication Transfer Translation Transformation
Boundary negotiating artefact	Material	Flexible Modifiable Reusable	Negotiation Representation Transfer Establishment of boundaries
Intermediary object	Abstract Physical	Open Closed	Mediation Representation Translation *Standardisation*
Technical object	Material	Closed Complete Unproblematic	Representation *Standardisation*
Infrastructure	*Physical*	Standardised Transparent Invisible	Standardisation

To further explore the situated functions that artefacts perform in collaborative practices, I will take the notion of *boundary object as an umbrella label for various kinds of artefacts that mediate activity between communities*. This mediation occurs as the collaborating groups tack between the ill-structured form of the artefact while doing cross-disciplinary work and the tailored, local forms of the artefact in disciplinary work (Star, 2010). To develop an analytical framework for identifying the different functions that artefacts perform in innovation practices as well as for exploring possible shifts in the functions, I draw on the

concept of mediation in cultural–historical activity theory and the postphenom-
enological philosophy of technology.

3.3   Mediation by artefacts – towards a relational understanding

To develop a relational understanding of the functions performed by artefacts
in collaborative work, I explore the phenomenon of artefact mediation. Cul-
tural–historical activity theory views mediation as one of the foundations of hu-
man activity and its development. The postphenomenological theory of the role
of artefacts in human-world relations views mediation as the ways in which ar-
tefacts influence human perception and shape human actions.

3.3.1   CHAT: Mediation of activity by artefacts

Cultural–historical activity theory views artefacts as simultaneously conceptual
and material (Cole, 1996). It is this dual character from which the mediating
ability of artefacts derives: They carry norms and modes of action (Miettinen,
1998). CHAT scholars analyse artefacts either as objects of activity or media-
tional means (Engeström & Escalante, 1996). However, the characteristics of
the artefact do not decide the role it assumes in a given activity but the role de-
pends on its relationships with the other elements of the activity system
(Engeström & Escalante, 1996). Furthermore, CHAT scholars maintain that
transitions from an object of activity into its means and vice versa may occur in
the activity (Miettinen, 1998).

   Whereas CHAT views objects of activity as fundamentally powerful artefacts
that motivate, organise and transform the activity, meditational means are un-
derstood as more passive artefacts that people create and use. Many CHAT
scholars rely on Vygotsky's distinction of mediating artefacts between tools and
signs. Engeström (1987) conceptualises this distinction as a hierarchical one: A
tool serves as a means in the mediation of external activity to transform the ob-
ject of activity, while a psychological tool – which is a combination of tool and
sign – mediates the behavioural processes of the actors. To emphasise this dis-
tinction, Engeström (1987) calls the psychological tools 'instruments.'

   Furthermore, to draw clearer distinctions between different kinds of mediat-
ing artefacts beyond tools and signs, Engeström (1987) and other CHAT schol-
ars have drawn on the hierarchy of artefacts outlined by Wartofsky (1979).
Wartofsky classifies cultural artefacts, which are invested with cognitive and af-
fective content, into three categories: primary, secondary and tertiary. *Primary
artefacts*, such as tools and the technical skills needed in their use, are directly
used in human activities; Cole (1996) adds words, writing instruments and ICT
networks into this category of artefacts. *Secondary artefacts* represent an action
by symbolic means; such representations are created to preserve and transmit
skills for the production and use of primary artefacts. Engeström (1987) draws
a parallel between a secondary artefact and Vygotsky's psychological tool.
Wartofsky (1979) emphasises that representations are not mental entities in the
mind but are rather actual physical and perceptual embodiments of a mode of

practice: These representations change corresponding to the evolution of different forms of practice. *Tertiary artefacts* play a crucial role in the creation of alternative ways of acting: They are imaginative artefacts – perceptual hypotheses which transcend the perceived world and provide alternatives for conceivable change in the current mode of practice (Wartofsky 1979). Tertiary artefacts resemble the notion of epistemic objects or even objects of activity: Miettinen (1998) suggests that they function by orienting the participants to the future and motivating their activity.

CHAT scholars understand the mediation of activity to occur through the formation and use of artefacts. The mediating artefacts function as means of transformation in the pursuit of the object of activity. When a human actor is carrying out a practice, he or she situationally interprets – and possibly elaborates and transforms – the norms and ways of acting while using the mediating artefacts (Miettinen, 1998). However, an artefact gains its mediating ability only through the actors' actions, while interaction with the artefact may change these actions and the meaning given to them (Béguin & Rabardel, 2000). Mediation takes place through the internalisation and externalisation of the meanings and skills embedded in the artefacts. Internalisation occurs when an individual participates in actions with other humans and artefacts (Miettinen & Virkkunen, 2005), while externalisation occurs when modes of action are inscribed in cultural artefacts (Miettinen, 2006). This makes artefacts an essential means to transfer human culture: CHAT scholars see that "[t]he embodiment of forms of human activity within artefacts is the primary means of learning and transmitting human achievement" (Miettinen et al., 2012, p. 354). Consequently, CHAT discusses re-mediation or 're-tooling' – the collective creation of artefacts and their use as means for reflecting and changing practices – as a key to transforming activity (Miettinen & Virkkunen, 2005).

The notion of mediation in CHAT stems from Vygotsky's psychological analysis of the development of children's psychological capabilities, and the use of language signs was at the centre of his studies (Lektorsky, 2009). Mediation was brought from the psychological sphere of the individual's learning to the social-psychological sphere of human activity by Leontjev, who conceptualised collective activity as object-oriented through the orchestration of individual actions (Engeström, 2001). In the collective efforts to transform the object of activity, artefacts mediate the activity together with the division of labour within the community of practitioners and the norms governing their actions (Engeström, 1999b). CHAT relies on this psychological tradition and was introduced to education and organisation studies through the concepts of activity system and expansive learning developed by Engeström (1987).

Even though mediation remains a key concept in the CHAT literature, the analysis of the phenomenon tends to focus on changes of mediational means in the collective activity rather than on the ways in which the artefacts participate in the carrying-out of practices. Because CHAT scholars are primarily interested in the development of activity, empirical studies focus on the incoherencies between the elements of an activity system, which are interpreted as traces of contradictions that may trigger change in the activity (Engeström, 1987). When the

object of activity is changing or new elements are introduced to the activity system, the existing mediational means do not support the carrying out of actions appropriately. Problems with mediation also occur when a new tool enters the activity system and is controversial in relation to the object, the rules, the division of labour, etc. Due to the emphasised interconnectedness of the tools and the object of activity, CHAT interventions often centre on the development of new tools to align the new conceptualisation of the object with the mediational means of the activity (Miettinen & Virkkunen, 2005). Another characteristic way of analysing the re-mediation of activity is the study of object–means transformation. For example, Miettinen (1998) has studied how an emerging object organises the collective efforts of a community of researchers and how this object becomes a mediational means as the community directs its activity towards a new object of industrial production.

Despite the centrality of artefact mediation in CHAT, the object of the activity seems to have dominated the research interests of scholars, leaving more detailed analyses of the workings of mediating artefacts underdeveloped. Even though activity theorists have suggested different types of mediation, such as epistemic and pragmatic mediation (Rabardel & Bourmaud, 2003), they barely discuss the ways in which artefacts perform mediation. Only recently have calls for revisiting the characteristics of mediational means arisen in CHAT (e.g. Kerosuo, Miettinen, Paavola, & Korpela, 2015; Paavola & Miettinen, 2013; Rückriem, 2009).

Hence, CHAT offers limited analytical resources for the situational analysis of the ways in which artefacts mediate collaborative practices. Therefore, I complement the activity-theoretical understanding of artefact mediation with insights from the postphenomenological interpretation of the role of artefacts in human existence. Verbeek (2005) has developed this approach which focuses on the mediating role that artefacts play in the relations between human beings and the world.

3.3.2 Postphenomenology: A relational view of the role of artefacts

The "postphenomenological turn toward things" developed by Verbeek (2005) stems from his critique of the phenomenological understandings of the role of technical artefacts in human life. His philosophical analysis of the relations between human beings and material artefacts draws on theorisations by Don Ihde, Albert Borgmann and Bruno Latour. Verbeek (2005) claims that the classical philosophy of technology, exemplified by Martin Heidegger and Karl Jarpers, tends to approach technology in terms of what technology requires or presupposes and thus to neglect the treatment of technological artefacts themselves. Verbeek adopts the term "postphenomenology" from Ihde and takes it as his starting point to develop an understanding of "the role of artefacts in the practices and experience of human beings; the ways in which human beings can be present to their world, and the ways in which the world can be present to them" (Verbeek, 2005, p. 11).

The basic assumption of Verbeek's philosophy of technology is that artefacts "mediate the intentional relation between humans and world in which each is constituted" (Verbeek, 2005, p. 116). Verbeek follows Ihde by claiming that artefacts have a certain directionality that shapes the ways in which they are used; artefacts thus promote or evoke certain ways of use. However, artefacts receive an identity only within a concrete context of use, which is determined by both the artefact in question and the way in which it becomes interpreted. By maintaining that the mediating ability is not an intrinsic property of the artefact itself, Verbeek promotes *a relational view of the role of artefacts* in human existence.

Verbeek (2005) investigates the ways in which artefacts mediate both human experience – how humans perceive and interpret reality – and human existence – how artefacts co-shape human actions. In terms of experience, artefacts mediate perception and the context of interpretation by strengthening specific aspects of the perceived reality while weakening others. In terms of existence, artefacts mediate action and the context of existence by inviting particular actions while discouraging others. This transformational nature of artefact mediation means that artefacts are not merely neutral intermediaries which transport meaning faithfully but are rather active mediators which transform the meaning they are supposed to carry (Latour, 2005).

Due to my interest in the ways that artefacts mediate collaboration in innovation practices, I do not discuss Verbeek's investigation into the mediating roles of artefacts in terms of perception and interpretation. Instead, I use his analysis of the ways in which artefacts shape human action to distinguish between different kinds of mediating roles. *The mediating roles of artefacts* "depend in part on the kinds of relations in which they are involved" (Verbeek, 2005, p. 170). This means that the same artefact may have different meanings in different situations and that different artefacts can contribute to the pursuit of the same goal. Like CHAT scholars, Verbeek (2005) argues that artefact mediation co-shapes both subjectivity and objectivity – how humans are present in their world and how their world is present for them.

Verbeek (2005) draws on Latour's (1994) typology of mediation of action by artefacts, based on which he develops his own versions of translation and delegation, the most relevant types of mediation for his postphenomenological analysis. With *translation* of action by artefact, Verbeek (2005) refers to relations in which artefacts shape the way humans use them and deal with their world: Artefacts invite particular actions while discouraging others. With *delegation* of action, Verbeek refers to both delegation *by artefacts to humans* and *by humans to artefacts*; he sees as primary the former, which takes place when artefacts make humans involved in their programmes of action. Verbeek claims that the latter is only interesting for the study of human–artefact–world relations, when humans try to inscribe forms of mediation in artefacts in product design, for example. However, I see both kinds of delegation relevant for the analysis of collaborative practices engaging humans and non-humans: In both cases (when humans delegate actions to artefacts and vice versa), the division of labour between humans as well as between humans and non-humans is affected.

Furthermore, Verbeek (2005) distinguishes between various kinds of involvement with the artefacts humans use: actions directed to the artefact itself, to the environment of artefacts or to the product that the artefact makes available. He observes that in the use of an artefact, shifts between the different kinds of relations that humans have with the artefact occur: Attention moves between the artefact and its products. The artefact can also sink into the background of human action; it can be present and absent at the same time, because it goes unnoticed until it stops functioning, thus comparing with infrastructure (see Star & Ruhleder, 1996).

However, Verbeek (2005) examines the artefact–human–world-relations from an individual point of view, analysing the relations of a single person with a single artefact that mutually shape the relations with the world. To use the different kinds of mediation identified by Verbeek for the analysis of relations between communities and artefacts, they need to be extended to the collective sphere of social practices. Furthermore, the mediating roles Verbeek identifies need to be brought to the sphere of empirical analysis to serve as analytical tools.

3.4   A relational approach to the study of artefacts in collaborative work

This study suggests that the role of artefacts in human activity can be analysed as different forms of mediation carried out by artefacts depending on the situation and the relationships between the actors and artefacts. Such *a relational approach to the study of artefacts*, which draws on insights from CHAT and Verbeek's postphenomenology, entails a dynamic understanding of the role of artefacts: Artefacts may perform different roles in different kinds of situations, and hence these roles change according to the participants and circumstances of each situation (Nicolini et al., 2012). Thus, *the roles of artefacts are viewed as emergent and more or less temporary functions that an artefact may acquire in a specific situation as part of a practice.*

Due to my interest in innovation practices and the significance of collaboration, I direct my analysis to the functions of artefacts in collaborative work. Therefore, I use the notion of boundary objects as an umbrella label for the various kinds of artefacts that mediate activity between different communities. In a different kind of a setting, another label for the artefacts could be used, but boundary object is a customary concept in studies of collaborative work. The use of a single label for the different artefacts also enables an exploration of the boundaries of the concept; thus, the present study is also a test.

The relational approach directs the analysis to the performance of artefacts rather than to their characteristics. I call these performances *mediating functions*: Artefacts mediate the actions in certain situations by encouraging some operations or discouraging others (Verbeek, 2005). The artefacts fulfil particular purposes or programmes of action (Latour, 1994) in the situation, and different human actors may interpret these purposes in different ways. The function of an artefact emerges in situated interaction between the human actors and the artefact, either by deliberate design or coincidental use (Kallinikos,

2012). The analysis of the situated mediating functions enables the study of the emergence of the mediating ability of artefacts as well as of the shifts between the functions that artefacts perform in different situations.

3.4.1 A typology of mediating functions of boundary objects

I use the preceding characterisations of the types of artefacts that play a role in collaboration to formulate a tentative typology of the mediating functions that artefacts may perform in collaborative work. As my working definition of boundary objects suggests, artefacts always perform some mediating function when they participate in collaborative practices. However, this function may be of a different nature: Artefacts can enlist participants in collaboration, organise collaboration between participants, translate interest among participants, represent certain meanings etc.

   In order to identify the possible mediating functions that artefacts perform when they are used as boundary objects, I explore the situated uses of the types of collaboration artefacts found in the literature review. Table 4 presents the preliminary typology of mediating functions and relates each function to the type of artefact that has been previously associated with the function in question. The table also summarises the characteristics of the artefacts that I identified in the empirical descriptions of previous studies (see Table 3).

   Table 4 is ordered according to the typicality of the mediating functions in the reviewed literature: Communication (sometimes called transfer) has been associated with four types of collaboration artefacts, while cooperation has been associated with only one type of artefact. The typology presented in the Table 4 also includes the function of delegation, which has not been identified in the literature about collaboration artefacts. I have added this function to the typology due to the emphasis on delegation in actor–network theory (Latour, 1994) and postphenomenology (Verbeek, 2005). I discuss the performance of artefacts related to each mediating function based on the literature. I also give reasons for discarding two mediating functions – representation and cooperation – from the typology.

   Communication (Transfer / Mediation). Conceptual, visual and material artefacts – boundary concepts, conscription devices, boundary objects, boundary negotiation artefacts or intermediary objects in the literature – communicate something about the state of affairs or the problem at hand between communities. Many scholars of organisation and management studying boundary objects have analysed the function as knowledge 'transfer' between communities (e.g. Carlile, 2002, 2004). In the case of intermediary objects, scholars have named this function 'mediation' (e.g. Vinck, 2012). When mediating communication, boundary objects are used to point out and concretise concerns that representatives of different communities would otherwise hardly understand. In the case of boundary objects, the interpretations of the meaning of the artefact in question differ between communities but are close enough to enable collaboration; they are more open to different interpretations in interdisciplinary use and take on a more closed meaning in disciplinary use (Star & Griesemer, 1989).

Table 4. A preliminary typology of the mediating functions of artefacts in collaborative work.

Mediating function	Form	Manipulability	Artefact notion
Communication Transfer Mediation	Conceptual Visual Abstract / concrete Material Abstract / physical	Loose, imprecise Manipulable Loosely / strongly structured, flexible Flexible, modifiable, reusable Open / closed	Boundary concept Conscription device Boundary object Boundary negotiation artefact Intermediary object
Representation[1]	Material Abstract / physical Material	Flexible, modifiable, reusable Open / closed Closed, complete, unproblematic	Boundary negotiation artefact Intermediary object Technical object
Motivation	*Conceptual-material* Conceptual-material Visual	Open, incomplete Emergent, fragmented, projective Manipulable	Epistemic object Object of activity Conscription device
Translation	Abstract / concrete Abstract / physical	Loosely / strongly structured, flexible Open / closed	Boundary object Intermediary object
Transformation	Conceptual-material Abstract / concrete	Emergent, fragmented, projective Loosely / strongly structured, flexible	Object of activity Boundary object
Negotiation	Material Conceptual	Flexible, modifiable, reusable Loose, imprecise	Boundary negotiation artefact Boundary concept
Organisation	Visual Conceptual-material	Manipulable Emergent, fragmented, projective	Conscription device Object of activity
Cooperation[2]	Conceptual	Loose, imprecise	Boundary concept
Standardisation	*Physical* Abstract / physical Material	Standardised, transparent, invisible Open / closed Closed, complete, unproblematic	Infrastructure *Intermediary object* *Technical object*
Delegation[3]	*N.A.*	*N.A.*	*N.A.*

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[1] Representation will not be part of the typology although previous literature on collaboration artefacts has discussed it, see below.

[2] Cooperation will not be part of the typology although previous literature has discussed it, see below.

[3] Delegation will be part of the typology although previous literature on collaboration artefacts has not discussed it, see below.

Representation. Abstract and physical artefacts – boundary negotiation arte-facts, intermediary objects or technical objects in the literature – represent is-sues that are under examination in collaboration. However, the representation and communication functions appear very similar: Some authors use them in parallel (e.g. Carlile, 2004, Rehm & Goel, 2015). According to Wartofsky (1979, p. 202), any artefact which is "capable of preserving and transmitting a mode of action, thus 'representing' it, serves that function." This suggests that *all bound-ary objects necessarily play a representation function but are used for differ-ent purposes and therefore I discard representation from the typology of me-diating functions.*

Motivation. Conceptual–material artefacts – epistemic objects or objects of activity in the literature – serve as the goals of actions and thus provide motiva-tion. They are open and transient and can be only partially represented through other artefacts. Moreover, visual artefacts used as conscription devices motivate participants to engage in the process of designing something new (Henderson, 1991). Artefacts in this mediating role thus invite actors to participate in their development.

Translation. Abstract and concrete artefacts – intermediary objects or bound-ary objects in the literature – may translate concerns across boundaries. The concerns can be embedded in the artefacts that make other actors take these concerns into account or even see them as corresponding to their own concerns. However, different authors understand the meaning of translation in very dif-ferent ways. For example, Carlile's (2004) conception resembles the ordinary meaning of the word as translation between two languages: He refers to the translation of domain-specific knowledge into shared meanings across commu-nities. Boujut and Blanco (2003) refer to translation in terms of transforming a product from one state into another. Verbeek (2005) argues that artefacts act in the translation function when they invite particular ways of acting or discourage certain other ways; when functioning in this way, the artefacts are manipulable only in a predetermined way. ANT scholars understand translation as a trans-formed programme of action due to interaction between humans and artefacts; translation means "displacement, drift, invention, mediation, the creation of a link that did not exist before and that to some degree modifies two elements or agents" (Latour, 1994, p. 32). I will specify my use of this function in the analyt-ical framework in section 6.2.

Transformation. Conceptual–material artefacts – objects of activity – may lead actors to transform the way they act and think about their activity; this transformation is a process marking the historical development of the activity (Miettinen, 2005). In the realm of boundary objects, Carlile (2004) has sug-gested that the use of material artefacts enables the transformation of existing knowledge and interests to share knowledge and establish common interests. This exemplifies a more limited understanding of transformation, whereas the transformation of activity may imply changes to participants' identities, norms governing the actions etc. in addition to changes in the use of artefacts.

Negotiation. Conceptual and material artefacts – boundary concepts or boundary objects in the literature – may require negotiation about the identity of these artefacts and the contributions of different participants (cf. Lee, 2007). Negotiation requires that the artefacts be open and modifiable to the suggestions and concerns of different actors.

Organisation. Visual artefacts – conscription devices – organise work around them (Henderson, 1991). Conceptual–material artefacts – objects of activity – organise the actions carried out by a community to pursue their objectives (Nicolini et al., 2012). Artefacts in this mediating role thus shape the division of work between the participants of the practice.

Cooperation. Conceptual artefacts – boundary concepts – facilitate cooperation between communities due to their negotiable character (Löwy, 1992). However, the ways in which artefacts perform the cooperation function remain implicit. *Because my focus is on the mediation of collaborative practices and I use boundary object as an umbrella term for all collaboration artefacts, I discard cooperation from the typology of mediating functions.*

Standardisation. Physical, standardised artefacts can sink into the background of human action in a way that makes them part of an almost invisible infrastructure. Such artefacts are not objects of human attention but rather make other artefacts available and thus support actions; they become visible and receive attention only upon breakdown (Star & Ruhleder, 1996; Verbeek, 2005). They are not under human adjustment directly. Furthermore, other types of artefacts may also acquire functions that make them transparent. For example, Star (2010) proposed that boundary objects may become standardised to an extent which makes them part of the infrastructure. Also Rheinberger's (1997) characterisations of technical objects resemble the standardisation functions as does the irreversibility brought into the design process by intermediary objects (Boujut & Blanco, 2003).

Delegation. The mediating function of delegation was not mentioned in the reviewed studies, but my own interpretation of the empirical analyses suggests that some artefacts may serve this purpose. On one hand, material artefacts can be delegated actions by inscribing programmes of action in them (Latour, 1994); artefacts can also manipulate other artefacts on behalf of human actors. On the other hand, artefacts can also delegate actions to human actors by determining how they need to carry them out (Verbeek, 2005).

Some of the functions that the previous literature has associated with collaboration artefacts remain rather indicative, because empirical descriptions focus on the characteristics of the artefacts rather than on the way in which they shape the observed practices. Therefore, I will use the mediating functions described above as a starting point for my empirical analysis, during which I will elaborate them to construct an analytical framework. Nevertheless, this preliminary typology of the mediating functions of artefacts suggests that a particular artefact used as a boundary object may perform some of these functions in different situations, depending on both its characteristics and the way it is used. Therefore,

I believe that the typology will help me to identify the mediating functions artefacts perform in different situations and to trace how artefacts shift between different functions during the innovation process.

3.4.2 Trajectories of boundary objects

Scholars calling for more nuanced studies of the role of artefacts in organising have raised the question of the temporality of these roles. For example, Nicolini and colleagues (2012) suggest that researchers study how artefacts transition in terms of their role and the impact that these transitions have on collaboration. They propose that we ask when artefacts acquire certain roles and what the meanings of certain artefacts are for different actors. Further, Ewenstein and Whyte (2009) have suggested studies about when and why different types of artefacts become boundary objects and what other roles artefacts play.

Previous studies have observed shifts between the different roles that artefacts take on in different situations. Ewenstein and Whyte (2009) studied artefacts in three roles: as epistemic objects, technical objects and boundary objects. Following Rheinberger (1997), they claimed that epistemic objects can become technical objects once they are no longer changed through epistemic work. An artefact can also be at the same time a boundary object and a technical object, or a boundary object and an epistemic object (Ewenstein & Whyte, 2009).

The temporality of intermediary objects has also received attention. Hussenot and Missonier (2010) discuss the evolution of a certain artefact, a partnership contract, through its changing roles in a software development process. According to their study, any physical or abstract artefact can become an intermediary object. Hussenot and Missonier (2010) call for empirical studies that follow the evolution of multiple artefacts to identify different intermediary objects. Vinck (2012) states that following intermediary objects is an ethnographic method, which allows the study of dynamic activities across organisational boarders. With such a method, one can also study the biography of artefacts to understand their changes in terms of status and forms. Identifying and following intermediary objects enables the mapping and qualifying of relations between actors and documenting their practices (Vinck, 2012).

The shifting situational role of an intermediary object described by Vinck (2009, 2012) resembles the shifts between boundary objects and infrastructure suggested by Star (2010). Vinck (2009) argues that an artefact gains or loses its status as an intermediary object depending on the interactions in a situation: It can be picked up from the environment as a focus of attention to be soon forgotten. In a similar way, artefacts can be passed from the private sphere of single actors to the public sphere of interaction. Star (2010) states that boundary objects are not stable, because people try to make equivalent the ill-structured and well-structured forms of the object. This kind of standardisation of the movement between the ill-structured form and the structured form of a boundary object may bring it into infrastructure, making it transparent to use (Star & Ruhleder, 1996).

The current study joins Nicolini and colleagues (2012), who argue that artefacts used in collaboration follow a trajectory; they perform certain functions

and tend to move back and forth between roles. The notion of trajectory stems from the research of Strauss (1993): It refers to "a course of action but also embraces the interaction of multiple actors and contingencies that may be unanticipated and not entirely manageable" (p. 53). The concept was created in healthcare settings, but trajectory also fits the organisation of other kinds of work which involve a sequence of expected tasks that are sometimes routinized but sometimes subject to unexpected contingencies (Strauss, Fagerhaugh, Suczek, & Wieener, 1997).

In my research setting, I study *the process of developing the hybrid package through the analysis of the trajectories of the artefacts that were necessary for the emergence of the package*. All these trajectories included their specific tasks, their organisation of work and other resources (Strauss et al., 1997), while the interaction of these trajectories with each other shaped the development process of the package.

4. Methodological choices and the research process

This study is based on a collaborative research project conducted with two manufacturing companies. The data that I analyse in this dissertation were produced during the research project and concern the innovation process of the hybrid package. The research collaboration with the recently founded business unit of the paper company, Fipak, lasted about 18 months. The qualitative data were produced with ethnographic and intervention methods. The data selected for analysis include interviews, observations and workshop discussions.

The data that I examine in this study cover a period of eight years, from 2005 to 2012. The data were produced during the research project, from 2009 to 2012. However, the accounts of the research participants cover the whole development process of the hybrid package from the initial ideas until the launch of the first commercial product, while the observations of the researchers cover the first years of Fipak's business activity.

To answer to the three research questions, I divided the data into three sets according to the research object. The first data set includes 18 interviews that account for the development process of the hybrid package from the initial ideas until the launch of the first commercial product, from 2005 to 2009. The interviewees include the members of the Fipak development team as well as representatives of the pilot customer, for whom the first commercial package was developed, and six subcontractors. The second data set includes observations of product development practices in Fipak's product development projects. The observations focused on seven key events that each represent a phase in the development process of a new product. Most of the events engaged only Fipak team members; two events also involved representatives of Fipak's subcontractors. The third data set includes encounters between members of the Fipak team and the research group during the research collaboration. In these encounters, the characteristics of Fipak's product concepts and production concepts were discussed.

The research collaboration relied on the combination of action research and ethnographic methods. The research approach may be labelled as applied ethnography (Chambers, 2000): By employing different qualitative methods we aimed to produce data about work practices to serve as a basis for the development of those practices. Following the action research tradition, the research collaboration was continuously negotiated between the representatives of Fipak

and the research group (Neumann, 1997). Furthermore, we conducted deliberate interventions to develop Fipak's activity: These interventions drew on dialogic action research (Lehtonen & Kalliola, 2008) and developmental work research (Virkkunen & Newnham, 2013).

In this chapter, I first describe the research project from which the data originate and then the development of my own research design. Then I report the production of the research data and the process of data analysis. I conclude the chapter by describing the writing process of the thesis and the choices pertained to it.

4.1   Research process

The research process of this dissertation began with the Learning Production Concepts project, which produced the data. In addition to the aims of the project, the research setting has influenced my choice of the research focus. I began the thesis work only after the research project ended by formulating the research questions.

4.1.1   The Learning Production Concepts project

The research project that enabled the production of data for this thesis resulted from the work of many people. The project received funding from the "Concepts of Operations" funding programme of Tekes – the Finnish Funding Agency for Innovation – in spring 2009 after many rounds of applications. The research project began in autumn 2009, and the project lasted until spring 2012; I worked in the project both as a researcher and project manager.

The research project "Learning Production Concepts – Tools for the Management of Networked Activity" (LPC) aimed at developing work practices in manufacturing companies operating in networks, particularly those at boundaries, where the collaboration between different work communities is required. The objectives of the LPC project were aligned with those of the Concepts of Operations funding programme, which aimed to develop competitive production concepts for the Finnish manufacturing industry. The project strived to encourage companies to develop sustainable business in networks beyond the contemporary focus on subcontracting. The project plan suggested that companies could take advantage of the competence and material resources of the distributed design and production of products by developing a common understanding of the goals of collaboration and by forming different kinds of relationships with partners in a production network. We aimed to support companies through our research and development activity to create a learning orientation towards working in the network. The development of such 'learning production concepts' would include the whole production process of products in networked production.

The LPC project was a joint effort between researchers from three Finnish universities: Aalto University (Aalto), University of Helsinki (UH) and Lappeenranta University of Technology (LUT). The research and development ac-

tivity was carried out with two manufacturing companies in Finland; one business unit from each took part in the project. Additionally, we worked with researchers from Tallinn University of Technology, who carried out a similar study in one Estonian company. Our research group consisted of five core members: Anneli Pulkkis and myself from Aalto, Hanna Toiviainen and Päivi Ristimäki from UH and Mika Lohtander from LUT. Taru Havas from LUT worked in our project first while completing her master's thesis and then as a project researcher. Additionally, two students from UH wrote their master's theses based on the project but worked only for a certain time period with our research group while taking part in data collection.

The LPC project took approximately two and half years, while the research collaboration with the companies lasted 18 months and took place in two main phases, as depicted in Figure 3. We started with a data collection phase in autumn 2009, which ended in a feedback workshop and a development plan in summer 2010. We entered into a development phase in autumn 2010, which ended with an evaluation workshop between the companies, after which we delivered a research report to both companies in spring 2011. When the research collaboration with the companies ended, we focused on the dissemination of the research results by writing a guidebook for practitioners about the development of production concepts.

| Data collection: studying activities in product development projects | Feedback workshop & development plan | Development of concepts and tools: workshops and preparation tasks | Evaluation: meeting of the companies, company reports | Dissemination: writing a practical guidebook |

| Autumn 2009 | Spring 2010 | Autumn 2010 | Spring 2011 | Autumn 2011 – Spring 2012 |
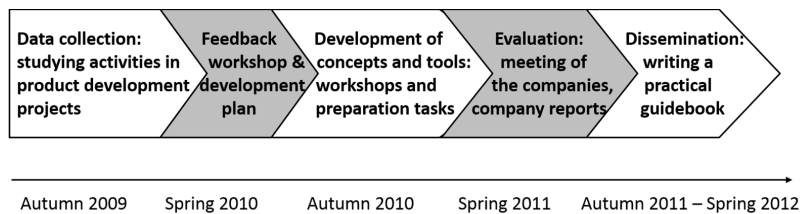
Figure 3. Research process of the Learning Production Concepts project.

After the conclusion of the research collaboration in spring 2011, we were in contact with the representatives of the case companies mainly in the meetings of the steering group of the LPC project. Each case company had one representative in the steering group, which held meetings two to three times a year during the project from autumn 2009 until spring 2012. After the project ended in spring 2012, our research group dissolved and focused on other projects. We have worked together to elaborate the theoretical framework modelled during the project in the form of a writing project, but otherwise I have been the only one continuing to analyse the data produced during the project.

4.1.2   Research setting: How Fipak became the site of my research

The LPC project needed company partners as research sites as well as partial funders due to Tekes' regulations.[4] In the application phase, we contacted SMEs in the manufacturing field, because we thought that they were struggling with networked production processes due to their weaker position compared with larger companies. We believed they could benefit from research collaboration with universities; at that time, most of university–industry research projects were conducted with large companies in Finland. Furthermore, we sought companies with subsidiaries in the Baltic countries, because SMEs seemed to have a lower threshold to start their international operations in the neighbouring countries and they looked for partners to lower their production costs. Our aim was to extend the collaboration between the network partners beyond a subcontracting relationship focused on reducing costs; we believed that by developing collaboration practices and learning from each other, the network partners could gain broader benefits. After contacting several companies, we succeeded in attracting potential partners. However, when our application finally proceeded to the next round in Tekes, which required financial commitment from the partners, the companies withdrew. [5]

Despite this drawback, we continued the effort and rewrote the research proposal once again. A lucky coincidence intervened, providing us the critical company participation: Another funding application in which one of our university partners was involved failed to obtain funding from another funding programme, and thus two committed companies were left without a research project. These companies agreed to participate in the LPC project on condition that the technical studies, which had been planned as part of the other research project, would be included in this one.

In autumn 2009 we were finally ready to start the research collaboration with the two manufacturing companies. Because neither was an SME, we had planned a dissemination phase of the lessons learnt from the research collaboration as a separate phase of the project. One of the companies was a paper company, and the other one a manufacturer of renewable energy applications. We first met their representatives in the initial meeting of the project's steering group. Negotiations about the practices of research collaboration began during the first visits to the companies.

Our research partner within the paper company was a recently founded business unit created to commercialise an innovative package. I have named this package manufacturer with the pseudonym Fipak. When we started the research collaboration, Fipak had only recently launched its first commercial product, and the employees were working on the development of several products for new customers. The design and production process of Fipak's product, the hybrid package, involved partners supplying materials, components and

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[4] Tekes requires research projects to involve company partners that participate in the funding of the project work. Due to the difficult economic situation, Tekes reduced this portion of funding from 15% to 10% of the total budget of funded research projects in 2009; the participating universities needed to fill this gap because Tekes' portion remained at 60%.

[5] The negotiations took place in 2008, during which Finnish companies faced the global financial crisis.

technologies as well as customers whose requirements determined the properties of the package to a great extent. The first customers purchasing the hybrid package were from the food industry.

The development process of the hybrid package had begun four years earlier. During the process, a novel manufacturing method for the package was developed and Fipak was established as a business unit to continue the commercial development and production of the new package. At the beginning of our research collaboration, Fipak operated as a small development team and carried out product development projects with their partners. The team comprised a business manager, a technical manager, a sales manager and a salesperson, two product designers, two production engineers and three operators (workers running the production). In a sense, Fipak operated like an SME within a multinational company of almost 30,000 employees: All development team members were involved in all projects and took responsibility for several tasks. However, Fipak was supported from the resources directed from the company's R&D budget and faced pressure to generate profitable business.

The starting point of the negotiations on the research collaboration was ambiguous: On one hand, people at Fipak were eager to get help from researchers to organise their work, but on the other, they had only a vague idea of what the research collaboration would be like and what its outcomes could be. During the development process of the hybrid package, the members of the development team had worked with university researchers on the technical development of the package innovation and of its manufacturing technology. Many students from these universities and some other schools had written their theses based on the development project. Thus the development team's experience in research collaboration was collaborative R&D work. Our approach was different: We came with an initial idea of how to develop collaboration with network partners, but the actual development targets were to be decided after the data collection phase. We were promising some practical tools which Fipak could implement in their activity, but those tools were supposed to be developed over the course of the project together with Fipak.

Fipak's business manager had made the decision for the unit's participation in the project, but she had delegated the practical responsibilities to the development team. After having told her expectations for the project in our first visit to the unit, the manager participated only in the steering group meetings. Fipak's technical manager became our contact person in the unit, and gradually we familiarised ourselves with other members of the development team. Following action research methodology, we proposed that Fipak would form a 'development group' to act as our negotiation partner on issues concerning the research collaboration.[6] During the project, Fipak's development group extended to eventually covering almost the entire development team. With the development group, we agreed on data collection methods and research participants. In this way, we sought to create a shared understanding about the aims and practical execution of the research project.

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[6] The development group follows the idea of 'development organisation' whose task is to take care of the organisation of development tasks alongside with operational tasks (Pålshaugen, 2001).

We proposed to the development group that the data collection would study work practices in Fipak and their network by investigating certain product development projects. The members of the development group selected these projects together with us and identified the key persons who had been involved in the projects – who were thus selected as research participants. Because the commercial packages were all tailored according to a certain customer's needs, we proposed to also include representatives of the customers as research participants. At the beginning, the members of the development group were unsure whether it would be possible to involve customers in the research, but the participation of subcontractors was not a problem for them. When we had refined the data collection plan and discussed with them the possible projects to be studied, the team members allowed us to interview representatives of their first customer, with whom they had an established collaboration relationship. Eventually, our data from the first product development project (based on retrospective interviews) covered Fipak's network most extensively; the data of the other projects focused more on the practices of the development team. The development phase was conducted solely with the Fipak development team, even though collaboration with partners was discussed in the workshops.

4.1.3 Constructing the research design of the thesis

While I was involved in planning and conducting the LPC project as a researcher and project manager, my research interests played a part in the decisions about the focus and methods of data collection. However, the research questions of my dissertation emerged while the data collection in the project was ongoing, and they became clear when I was analysing the data during the thesis process. I began outlining a research plan for the thesis in 2010 while the development phase of the project was ongoing; because we were analysing the collected data for the workshops in the research group, I had a general understanding of what the data were about. I was especially interested in the relationship between the different products whose development processes we had been studying and the product concept which we sought to characterise with representatives of Fipak. I started to explore this idea in a paper in 2011, discussing the evolution of Fipak's product concept throughout the product development process. In this first analysis, I started thinking about the product concept as a boundary object and analysing how it evolved during the process. This work contributed to the formulation of the first and second research questions of my dissertation and served as a basis for their further analytical examination.

During 2012, I gradually began to work on the thesis itself, while I was still involved in other research projects. Together with Anneli Pulkkis from the LPC research group I wrote a paper that examined the development of the model of learning production concepts through the research collaboration with Fipak. This second analysis contributed to the formulation of the third research question of my dissertation. The year 2012 marked an important divide in my research process, during which I started to think about myself as a thesis worker. Two essential enablers have supported my work since then: I began working with my supervisors, Matti Vartiainen and Hannele Kerosuo, on a regular basis,

producing some text for my thesis for each meeting, and I received my first scholarship, which enabled me to work part-time on my own research. During 2012, I reviewed literature to outline the theoretical background of the study and began a systematic analysis of the data, whose initial analysis I had presented in the paper in 2011. Additionally, I participated in an international PhD course on cultural–historical activity theory. During this first year of thesis work, I elaborated my research questions, which helped to focus the literature reviews as well as the initial analysis.

In 2013, I was finally able to concentrate on the thesis almost full time, even though I still continued to collect and analyse data for another research project. I continued with the re-analysis of the emergence of the hybrid package in the innovation process, which addressed the first research question. I presented this analysis in a paper and used it as a basis for the first analysis chapter, Chapter 5. My visit to the Copenhagen Business School (CBS) in autumn 2013 supported a more focused work on the thesis. I also attended two intensive courses, which caused me to elaborate and even rethink my research approach. I participated in a course on practice-based studies and started to work on my own take on practice research. I also took part in a course on actor–network methodology, which helped me to look at my research from a different perspective and to see alternative interpretations. During my visit to CBS, I continued working on the theoretical framework and started analysing a second data set, which I examined with both the first and second research questions.

In the research plan of the thesis, I had aimed to analyse the data sets of both partner companies of the LPC project. However, when I had refined the research questions in relation to the analyses I had already conducted with the Fipak data, I decided to leave out the data from the other company for good. I concluded that the research questions had become bounded to the Fipak data.

At the beginning of 2014, I finally received funding that covered my thesis work up to its conclusion. I continued working on the second analysis of the mediating functions of boundary objects in product development practices. For this I needed new analytical tools, which led to further reading and re-writing of the theoretical part of the thesis. I presented a first version of this analysis in seminars and received useful feedback, which encouraged me to elaborate the analytical tools; this analysis served as a basis for the second analysis chapter, Chapter 6. I also started to write about the methodological framework of my research, which led me to explore how I had come up with this approach and the research questions. The elaboration of the theoretical framework led me back to the analysis of the first research question and the rewriting of Chapter 5 in autumn 2014. The iteration between theoretical elaboration and analysis made me return to the second analysis; I rewrote Chapter 6 in winter 2015. In spring 2015 I began analysing the last data set to examine the third research question, presented in Chapter 7. I elaborated this analysis in parallel with a literature review on product and production concepts during summer 2015. Then I was able to outline the conclusions of the thesis, and during autumn 2015 I iteratively rewrote each part of the dissertation to finalise the manuscript for examination.

4.2   Producing the research data

Due to the emergent research design described above and the intimate relationship between the LPC project and my dissertation study, the data I analyse in this thesis were originally produced for the purposes of the LPC project and the contemporary research interests of our research group. Therefore, I first discuss the process of generating the research data based on the rationales of the LPC project before proceeding to the methodological choices I have made during my dissertation study. I focus my discussion on the data that I have chosen for my own analysis from among all the research data produced during the research process with Fipak. I will explain the rationale of these choices in the next section describing my process of analysing the data.

In the LPC project, the production of the research data was organised into two phases (see Figure 3). In the data collection phase, we studied work practices in different phases of product development projects, involving employees both from Fipak and their network partners. In the development phase, we used the collected data to examine Fipak's product and production concepts together with members of the development team as well as to develop work practices and tools to better master the product development projects. In this dissertation, I analyse a major portion of these data produced during the research collaboration with Fipak to answer to the research questions. For the purposes of my own research, I divide the data production into two phases in a way slightly different than that in the LPC project.

The first phase of data production, the study of product development projects, began with an introductory visit, where we familiarised ourselves with Fipak's product as well as its production process and discussed the research collaboration with Fipak's representatives. After the visit, we studied three different product development projects, each with a different kind of method, which can therefore be thought of as sub-studies. To move from the first phase to the second, we organised a feedback workshop, where we discussed the preliminary findings with Fipak's development team to identify development targets. The research collaboration then proceeded to *the second phase, the identification of product and production concepts and development of tools*. We organised workshops for the collective analysis of the concepts and their evolution. Later we arranged further workshops for the definition of tasks and tools in the product development projects,[7] but these are excluded from my analysis because they did not provide new insights in terms of my research questions. The research collaboration ended with an evaluation workshop that engaged participants from both case companies to reflect on their experiences of the research collaboration. These data are also beyond the scope of my analysis, which is limited to the analysis of data from Fipak.

Table 5 summarises the sub-sets of research data that I analyse in my dissertation, the methods that we used in their production and the research participants. Because of the collective way of working in the research group, different

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[7] The development of tools, which would embody the logic of the production concepts, was part of our process to develop learning production concepts. This followed the CHAT understanding of tool-mediated activity.

researchers took responsibility for the sub-studies during the LPC project. During the first months of the project, I was working for another research project and was able to participate in the data production only on a limited basis. Since the beginning of 2010, Päivi Ristimäki and I were intensively engaged with the production of data and the organisation of the interventions, which took place in both participating companies at the same time until spring 2011, while other members of our group concentrated on other projects. During the entire research process, our research group met regularly to analyse the produced data and to prepare the next phases of the project.

Table 5. Production of data during the phases of the research process.

Object of the study	Methods and responsible researchers	Data and participants
1. Study of product development projects (October 2009–August 2010)		
Fipak's product and production process	Discussion Meri Jalonen, Mika Lohtander, Anneli Pulkkis, Hanna Toiviainen	Transcription of *an introductory visit* with 3 representatives of Fipak
Practices in different phases of a product development process (*"Customer" project*)	Collective interview Meri Jalonen, Mika Lohtander, Anneli Pulkkis	Transcriptions of *2 "process workshops"* with 6 members of Fipak
Development process of the first commercial package (*"Pilot" project*)	Individual interviews Hanna Toiviainen Meri Jalonen, Päivi Ristimäki	Transcriptions of *18 interviews*:[8] 8 members of Fipak's development team 2 representatives of the pilot customer 7 representatives of subcontracting companies
Development practices in product development projects (*"Module," "Customer," "Food" project*)	Observation Individual interview Meri Jalonen, Anneli Pulkkis, Päivi Ristimäki	Field notes and transcriptions of *the observation of key events* of the projects Transcription of *an interview* with a member of Fipak

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[8] Two of these interviews were conducted later to complement the data set: one at the end of 2010 and one at the beginning of 2012.

Object of the study	Methods and responsible researchers	Data and participants
2. Identification of product and production concepts and development of tools (May 2010–March 2011)		
Projects as illustrators of the product and its development practices	Mirror data Researcher-led discussion Group work Meri Jalonen, Anneli Pulkkis, Päivi Ristimäki	Transcription of *a "feedback workshop"* with 8 members of Fipak
Product concept and production concept	Mirror data Researcher-led discussion Pre-assignments Meri Jalonen, Päivi Ristimäki	Transcriptions of *3 "concept workshops"* with 7 members of Fipak Transcription of *a seminar presentation* by Fipak's representative Transcriptions of *3 factory visits* in Fipak Transcriptions of *2 interviews*[9]

4.2.1   Study of product development projects

The data collection phase, which began in autumn 2009, aimed to gain an understanding of the work practices in Fipak and their network. All Fipak's products were tailored according to customers' needs. Fipak had only one product on the market, and the production of each product meant a new product development project, which included tailoring the production equipment. The work of the development team centred on the development of these products, including collaboration with the customers and supplier partners participating in the development process. Following the activity-theoretical idea that collective activity is organised to pursue a shared object (Engeström, 1987), we sought to gain an understanding of the work practices in Fipak and their network by studying different product development projects. Thus, we assumed that the product under development was the object of the network that formed to produce it: The data produced was always related to a particular project in which the participants of the study had been involved. We assumed that by discussing a particular project with the research participants, we could gain insights into their situated work practices rather than receive mere generic descriptions of how the work was usually carried out. In the data production, we thus followed an 'an object-oriented' approach to networks, as proposed by Miettinen Toikka, Tuunainen, Lehenkari and Freeman (2006), according to which following concrete projects enables the researcher to study the development of the product and the evolution of the associated network in each project as well as the learning that emerges in the development process.

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[9] These interviews were part of the data set of 18 interviews.

The study of these product development projects each formed a data set produced via different methods, which I describe in chronological order. The projects reflected the collaboration practices with different customers and other partners; they also represented different phases in the development of Fipak's activity – we selected a past, an ongoing and a beginning project to follow (see Figure 4).
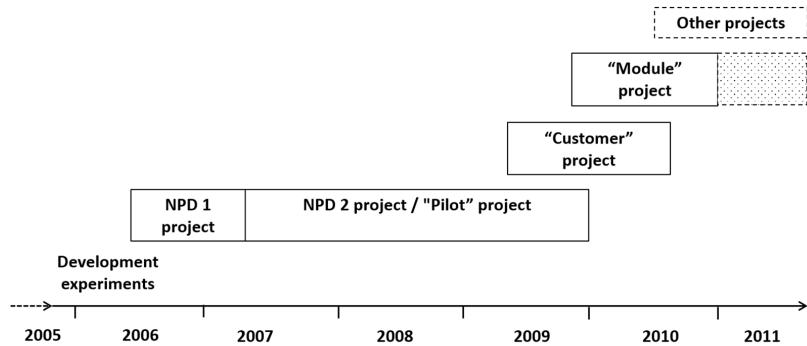
Figure 4. The development process of the hybrid package and the location of the studied product development projects on its trajectory.

The introductory visit to Fipak in October 2009 proceeded as a discussion between our research group and three members of the unit: the technical manager, the business manager and the product designer in charge of tool design. Fipak representatives told us about the hybrid package and its design and production process. We also discussed their expectations of the research collaboration and our ideas on how to conduct the research project, which we subsequently formulated into a data collection plan. The discussion was audio recorded and transcribed. After the meeting, the technical manager and the tool designer took our research group on a factory visit and presented the production facilities to us.

The process workshops discussed an ongoing product development project for a customer; I call it the *Customer project*, because the development team referred to it with the customer's name. The project was Fipak's second commercial project following the launch of the first commercial package. The first session of the workshop dealt with the design phases of the development process and the second session with the trial runs in which the product was produced in a testing environment. The participants included Fipak's salespersons, product designers, technical manager and production engineer (see Figure 5). They described how they had worked in the project and what kinds of issues had raised problems during the process. Anneli Pulkkis, Mika Lohtander and I arranged the two workshops: We guided the discussion based on prepared themes and documented the issues that participants raised with post-it notes on the wall; this documentation was photographed at the end of each session (see Figure 6). This simultaneous documentation was done to facilitate the development of a

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shared understanding and to help the participants' memorising; I have not uti-
lised the documentation in my analysis. The workshops were both audio and
video recorded, and they were transcribed according to the audio recordings.

Figure 5. A video snapshot from the second process workshop.

Figure 6. Part of the documentation of the process workshops depicting the tasks, partic-
ipants, artefacts and issues that needed to be taken into account in phases of the Cus-
tomer project.

The interviews covered the activities during the product development project
that resulted in Fipak's first product launch; I call it the *Pilot project* to demar-
cate its significance as the product development project which resulted in the
commercialisation of the hybrid package. The pilot customer became Fipak's
first customer when the unit was established, and their collaboration continued
with the development of new packages. The interviews began with Fipak's de-
velopment team and expanded to cover the network partners whom the team
members suggested to be interviewees. The interviewees included eight mem-

bers of Fipak's development team (excluding two operators who had been recently employed and who thus did not have experience of the studied product's development process) and altogether nine representatives of the pilot customer and six subcontractors. When we analysed the interviews, we realised that the interviewees had been referring to the history of the product development process before it gained a more commercial focus with the joining of the Pilot Customer; the product development project had actually been called the *NPD 2 project* (see Figure 4). Therefore, we later continued with interviews of the Fipak team members who had been involved in the development process for the longest time, participating in the NPD 2 project since its beginning: The business manager, the technical manager and the sales manager. The interviews were conducted individually with each interviewee (except for the last one involving the technical manager and the sales manager), and some of the interviews were conducted by phone. Hanna Toiviainen and a student conducted 16 interviews in 2009 and 2010, Päivi Ristimäki and I conducted the one in 2010 and I conducted the last one in 2012. All 18 interviews were recorded and transcribed.

When a new development project in Fipak began, we started *following the new project by observing central events representing different phases of the development process*. I call this the *Module project* because the team members called it by its module name, referring to a standard package size. Some of the observed events did not form a part of the Module project but rather belonged to two other ongoing projects – the Customer project and the *Food project*. We were not able to follow all the phases of the Module project due to rapidly changing timetables, so the team members suggested we could observe similar events in the other projects. Some of the events we observed were meetings, and others consisted of activities on the factory floor. Most of the events took place in Fipak and included only the team members; one meeting also included representatives of a new design partner, and one meeting was held on the premises of a supplying partner. While we observed the meetings, we did not take part in the discussion except when we were addressed by the participants. During the observation of activities on the factory floor, we posed questions about what was happening, and at times the team members explained the functioning of the machines etc. while they were working. All observed events were recorded with field notes, and most of them were also audio recorded and transcribed. We were not allowed to take photographs or video record in the production facilities, but sometimes we used drawings to help in recalling some important artefacts.[10]

4.2.2 Identification of product and production concepts and development of tools

The development phase of the research collaboration, which began in spring 2010, aimed to identify Fipak's product and production concepts to explore how they could be continuously developed through learning. The development work

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[10] During a visit to Fipak in August 2015, I got the permission to take photographs on the factory floor to exemplify the artefacts and work practices in the thesis.

relied on workshops that we researchers arranged and assignments of the development team members between the workshops.

We organised *the feedback workshop* in May 2010 to conclude the data collection phase and to introduce the Fipak team to the development phase of the research collaboration. The feedback workshop aimed to identify learning needs based on the examination of current practices in product development projects. The participants included the whole development team, excluding two of the three operators, who were taking care of the production. The perspectives of customers and other network partners were mediated to the workshop participants through interviews, which were part of the collected data. The workshop dialogues between the researchers and the Fipak participants consisted of two parts. The first dialogue, which was reflective in nature, took place during the researchers' presentations of the 'mirror data,' which was based on data gathered from the three product development projects. The mirror data consisted of the observations that our research group had made when analysing the data; they were to serve as a "surface" against which the Fipak participants could reflect on their activity (Virkkunen & Newnham, 2013).[11] The Fipak participants not only responded to our observations but elaborated them in a dialogue among themselves and with us. Drawing on the first dialogue, the second dialogue was of a developmental nature, encouraging the participants to identify learning needs related to production concepts. The dialogue was lively, and the participants made many observations regarding the learning challenges, but it did not lead to the identification of the most critical development targets. Both dialogues and the prepared mirror data were structured according to three main themes: conceptions of the product, network relationships and principles guiding actions in the production network. The third theme included the use of different kinds of tools in the work practices, and the use of the tools was discussed in smaller groups (see Figure 7).

After the workshop, discussion on the learning needs continued both within Fipak's development group and between our research group and Fipak's representatives. Finally, the development group formulated four development targets for the development work. Our research group wrote a development plan describing the methods that would be used in the pursuit of the development targets; the plan also served as an agreement of the continuation of the research collaboration. In the development plan, we proposed a conceptual model of learning production concepts and a development process to facilitate the integration of learning into the development of production concepts. According to our preliminary model, the development of activity in production networks meant identifying the guiding concepts of the activity with the parallel development of tools and practices to align work processes with the logic of the concepts.[12]

[11] Examples of mirror data discussed in the feedback and the concept workshops are included in Chapter 7.

[12] A visualisation of the model of learning production concepts is provided in Chapter 7.

Figure 7. A video snapshot from the feedback workshop.

In the development work that began in autumn 2010, we worked together with Fipak's development team to create solutions to the development targets identified in the development plan. The development process relied on a series of workshops, which we called *concept workshops*, which aimed to identify product and production concepts. Our approach to developmental interventions derived from action research and dialogical methods (Lehtonen & Kalliola, 2008) on one hand and on developmental work research and the change laboratory method (Virkkunen & Newnham, 2013) on the other. Therefore, we planned to conduct parallel development work in Fipak: The three concept workshops each included a concept discussion and a tool discussion in order to integrate a planning phase with an implementation phase. The workshop method was based on researcher-led discussion, in which mirror data was collectively examined with the workshop participants. For the concept workshops, we pre-analysed the data about the studied product development projects; the produced mirror data preliminarily characterised the product and production concepts guiding Fipak's activity. In the workshops, Päivi Ristimäki and I presented the mirror data with Power Point materials and guided the discussion according to a facilitation plan to provide a common basis for the workshop participants. The preparatory assignments that the participants had completed before each workshop were preliminarily analysed and summarised for the workshop discussions. The concept workshops were audio and video recorded, and the discussions were transcribed based on the audio recordings.

According to the development plan, the development of tools was supposed to proceed in parallel with the identification of concepts. The purpose was to develop the tools within groups in Fipak, possibly involving some of its network partners, through experimentation and their evaluation (cf. Virkkunen, 2006a). However, the identification of the necessary tools took longer than anticipated; the development targets were specified while the workshop process was ongo-

ing. Fipak was planning to purchase a project management system, and the development of the tools was linked with the implementation of the system. Because Fipak did not purchase the system during our research collaboration, the team members were not able to experiment with the discussed tools at that time. Instead, the tool discussions in the concept workshops concentrated on the identification of needed knowledge to be taken into consideration when comparing project management systems and developing project practices. For the identification of needed knowledge, Fipak's development team members produced additional data: Before each workshop, they conducted a preparatory assignment related to information that they needed in their daily work.

After the concept workshops, we agreed to arrange two more workshops (not included in my analysis), which focused on the development of tools for product development projects. In the tool development workshops, we used a visual method similar to that in the process workshops to simultaneously document the issues raised in the discussion. The proposed tools and issues needed to be taken into account were placed under the identified phases of product development projects using post-it notes. As the outcome of the workshops, a model for product development projects was defined, which included a sequence of phases and tools for knowledge sharing and coordination.

We concluded the research collaboration with the case companies in spring 2011 with a mutual evaluation workshop in which key persons of both companies participated;[13] the data from this workshop are not included in my analysis. Discussions of the evaluation workshop focused on what people in each company had learnt from their participation in the research project and on a comparison of the experiences in the two companies. Before the workshop, we wrote a report for each company describing the research process and the analysis of the findings. After the workshop, we completed the reports as documentation of the process and outcomes of the research collaboration. In the reports, we also outlined the theoretical and methodological framework of the LPC project, which we further elaborated in research papers and a guidebook for other companies. The preliminary analyses conducted for the different workshops and for Fipak's company report contained important insights, some of which I have explored in depth in the analyses of this study.

4.2.3 Documenting the research interventions

The research process in the LPC project was based on the accumulation of data. Therefore, it was crucial to our research group to have the produced data available for initial analysis soon after each research intervention, be it an interview, workshop or observation. Because transcription of audio recordings is cumbersome and time-consuming work and because we were working with two companies at the same time in parallel research processes, we oftentimes shared notes that we had made during the research interventions with the whole research group to enable all group members to keep up with what had been going on.

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[13] These "key persons" had been involved in the research collaboration, particularly in the development phase, and were knowledgeable regarding the situation of their company.

The transcription of audio recordings was divided between the research group members and the employees of a commercial company providing transcription services, Tutkimustie. Transcription services were included in the LPC project's budget following the convention of the department. However, due to the huge amount of data produced in the two cases that belonged to the project, we could outsource only part of the required transcriptions. Therefore, we prioritised those research interventions that were most urgent and that required a lot of transcription time when outsourcing transcription. The rest of the most important recordings we transcribed ourselves; the students doing their master's theses based on the data produced in the project also took part in this effort. Still, a part of the recordings remain untranscribed to this day – we recorded almost all the meetings with the representatives of the case companies and also many meetings of our research group. Because I needed some of these data for the analyses in my thesis, I used the services of Tutkimustie during my thesis project to transcribe some additional audio recordings.

The transcription of the research interventions was divided in the following way. From the set of 18 interviews, a student and Hanna transcribed the first 16 interviews conducted in 2009 and 2010, while Tutkimustie transcribed the two later interviews. From the set of the observations, Anneli Pulkkis transcribed two meeting discussions, and I transcribed one meeting discussion and one interview; Tutkimustie transcribed three meeting discussions and the interactions on the factory floor. The workshop discussions were all transcribed by Tutkimustie.

Many recordings of the research interventions included natural conversation, which made the transcription of these recordings a difficult task. The workshop discussions were not structured according to questions and answers as were the interviews; overlapping talk, for example, occurred during the conversations. Moreover, the presence of several similar voices made the identification of the speakers troublesome. The recordings of the observed meetings and activities on the factory floor were even more demanding to transcribe, because sometimes the conversation was covered by the noises of the machines etc. Therefore, I paid special attention to these transcripts, both when doing the transcription and when reading the transcripts done by others. I checked the transcripts of the recordings whose transcription we outsourced to Tutkimustie. When I read them through for the first time, I paid special attention to episodes that the transcriptors had marked as uncertain and to word choices that sounded unfamiliar. Later, I listened to the recordings according to my markings and corrected the transcript; however, the transcripts were still missing some words because I could not hear them due to quiet voices or overlapping talk. Sometimes I used the notes taken during the research intervention to make sense of the transcripts.

The field notes made during the observations did not follow a predefined format. The three members of our research group, Anneli Pulkkis, Päivi Ristimäki and myself, who carried out the observations, shared the understanding that we observed the events to comprehend Fipak's product development practices. Before the observations, we had only a preliminary understanding of what these

practices were about. Because we were not present at Fipak on a daily basis, the observations were unique to us: We were not able to observe recurring practices. However, because we were following a product development process and were aware of its unfolding, we were able to connect our observations to the process, which helped us to make sense of what was going on.

The field notes were not written for personal use but rather for collective analysis, which directed the way they were written down. Once we had completed the notes, we shared them with the whole research group. During the LPC project, our entire research group gathered together to analyse the data. For these analysis workshops, each of us went through the data individually, and together we developed analytical tools to make sense of our observations. We often audio recorded our own meetings, but I rarely listened to them afterwards because it seemed that my own notes were sufficient to continue the work. The meetings of our research group and the conversations that I had especially with Anneli Pulkkis and Päivi Ristimäki during the LPC project served as reflective moments. Therefore I did not see it necessary to keep a diary of the research process; only later did I realise that my habit of recording conversations in my notebook mostly excluded my own thoughts because I was focused on what other people were saying. However, because the conversations built on the accumulating ideas when we responded to each other's thoughts, the notes documented the collective memory of our research group.

Some of the research interventions, mainly observations of events, were both audio recorded and documented in field notes. In my analysis, I have examined both forms of data. To aid the analysis of the transcripts, I added sections from the field notes that described the doings of the people whose sayings were recorded in the transcript. For example, in the field notes from the meetings, we had written down references to documents that were discussed in the meetings; I was thus able to add descriptions of the documents into the transcript in episodes where the conversation referred to the documents. Furthermore, the transcripts of the observations complemented the field notes. For example, they documented the exact terms which the participants of the observed practices used in their conversation. This enabled me to develop a deeper understanding of Fipak's production technology while doing the analyses. As Van Maanen (1988) states, understanding the practices of a research setting is a continuing process, during which comprehension accumulates. Even though I identified gaps in the produced data, I was able to interpret them from a wider perspective because I was aware of the continuation of the product development processes and their outcomes. Therefore, I was able to connect the situated observations with the trajectory of Fipak's products and production practices.

In addition to the materials shared by our research group, I had taken my own notes of the meetings and even the phone discussions in which I was involved. Most of these notes remain in the many notebooks that I filled during the LPC project. Furthermore, I saved all email communication related to the LPC project. When conducting the analysis, I sometimes referred to these data to trace the unfolding of the product development projects.

4.3 Analysing the research data

To answer the research questions, I selected certain data sets from the data produced during the research collaboration with Fipak. In the following sections, I explain the choices of data and the process of data analysis.

4.3.1 Selecting the data for analysis

After I began to formulate my research questions and conduct the analyses, it became possible to identify the data I needed to examine to answer the research questions. I proceeded with the analysis one research question and data set at a time, and therefore the decisions of which data to include in the thesis were made in different phases of the process. In addition, I refined the analytical tools during the analysis process as I refocused my interest due to the reformulation of the research questions.

To answer my research questions, I selected parts from the data produced during the research collaboration with Fipak, described above. The research data consist of transcripts of selected interviews, meetings and workshops during the research process at Fipak. The data also include field notes from the observed events. Additionally, I used email correspondence and notes made during phone discussions with the members of Fipak's development team as background material.

My analysis is mainly based on the examination of textual data, transcriptions of audio recordings and field notes, even though all the workshops were video recorded. The workshops relied mostly on discussion with material aids, which usually included Power Point presentations and sometimes also hand-made drawings or post-it note documentation. The interaction among researchers and the participants was mainly verbal, and therefore it could be followed in the transcriptions of audio recordings. Sometimes the conversation referred to material artefacts that the workshop participants had brought with them, and, in cases where these references played a role in my analysis, I consulted the video recordings to better understand the meaning of the conversation. The use of videos as a part of the analyses was also restricted due to the limitations of the video data itself. Because the workshops took place in quite small meeting rooms and the video recording was static (i.e. there was no one behind the camera), the videos do not properly display all the participants and the interactions taking place.

In the selection of data sets for the examination of the research questions, I employed the distinction between a unit of observation and a unit of analysis. *The unit of observation* represents a "sample" of the studied activity, such as an event, within which the activity is constructed as a locally unique process (Engeström, 2002). Thus, the unit of observation is empirically a temporal episode through whose identification the researcher defines a beginning and an end for the studied activity (Engeström, 2002; Rainio, 2010). When the analysis examines the practices of dividing the work and the interaction among participants within or across organisations, a unit of observation can be constructed of

a long-term process produced by many participants that is distributed locally (Engeström, 2002).

The unit of analysis is "the most basic (analysable) entity or object that represents the phenomenon under study" (Rainio, 2010, p. 67). According to Matusov (2007), it is not possible to define a generally appropriate unit for analysis for a certain phenomenon; the unit of analysis is defined partly by the studied object, the researcher's focus and the data as well as the research participants. Therefore, the unit of analysis cannot be completely known before the study begins (Matusov, 2007). It is through the interpretive work of the researcher that the unit of analysis emerges (Engeström, 2002; Rainio 2010). Nevertheless, it is important to define the unit of analysis and to ensure that it remains consistent throughout the analysed data to make the analysis comparable across the data (Matusov, 2007).

In the analyses presented in the following chapters (5–7), I have defined different units of observations as well as of analysis according to the focus of each analysis. Table 6 summarises the focus of the analysis, the research questions explored, the data sets analysed and the units of observation and analysis as well as the main analytical tools used.

In Chapter 5, I study the development process of the hybrid package and explore the first research question: How do boundary objects shape the unfolding of an innovation process and its outcomes? The data set under analysis includes 18 interviews. I analyse the trajectory of the innovation process from the early experiments until the launch of the first commercial product (see Figure 4), which thus represents my unit of observation. Here, the unit of analysis is a phase of the development process: I examine who the participants – human actors and artefacts – were and through what actions the development work proceeded in each phase. I use the notion of boundary objects to identify the particular artefacts that mediated actions in these phases and to trace their influence in the unfolding of the development process.

In Chapter 6, I study the mediating functions that boundary objects performed in the product development practices. To answer the second research question – How do boundary objects transform during a product development process? – I have formulated two sub-questions based on the relational approach introduced in Chapter 3. First, I analyse the data to identify the mediating functions that boundary objects performed in the product development practices during the process. Second, I trace the changes of the mediating functions of the same artefacts in different situations during the process. The data set under analysis includes observations of seven key events during the product development process. In this analysis, my unit of observation is a chain of events in the development process, which represent situated practices in different phases of the process. The unit of analysis is an episode within the event: I identify episodes of work practices where boundary objects act as mediators of actions. I use the mediating function of boundary objects as an analytical tool in this analysis.

In Chapter 7, I study the evolution of Fipak's product concepts and production concepts. To answer the third research question – How do product concepts and

production concepts evolve through the development of the product's proper-
ties and its production practices? – I have formulated a sub-question. I analyse
the data to identify the characteristics of the product concepts and the produc-
tion concepts in different phases of the concept development process. The data
set includes encounters between members of the Fipak team and our research
group in meetings, workshops and interviews. Here, the unit of observation is
the developmental trajectory of the product and its production practices from
the first product launch until the beginning of new kinds of product develop-
ment projects (labelled "other projects" in Figure 4). The unit of analysis is a
phase in the development process of the product and production concepts. I use
the notions of product concept and production concept, whose practice-based
definitions were presented in Chapter 3, as analytical tools to identify the char-
acteristics of the concepts.

Table 6. Research questions, data and analytical tools employed in the analyses.

Focus of analysis	Research question	Data set	Unit of observation Unit of analysis	Analytical tools
Develop-ment process of the hybrid package (Chapter 5)	1. How do boundary objects shape the unfold-ing of an innova-tion process and its outcomes?	Transcripts of 18 interviews con-cerning the Pilot (NPD 2) project and the preceding product develop-ment process (NPD 1 and earlier projects)	The develop-ment process until the first product launch The phases of the develop-ment process	Boundary object
Mediating functions of boundary objects in product de-velopment practices (Chapter 6)	2. How do boundary objects transform during a product develop-ment process? 2.1 What kinds of mediating functions do boundary objects perform in product development practices during the process? 2.2 How do the functions of the boundary objects change during the process?	Field notes and transcripts of 7 key events in the Module project (and Customer and Food projects)	Key events representative of the phases of the product development process Episodes of work practices where boundary objects act as mediators of actions	Mediating functions of boundary objects

Focus of analysis	Research question	Data set	Unit of observation Unit of analysis	Analytical tools
Evolution of product concepts and pro-duction concepts (Chapter 7)	3. How do product concepts and production concepts evolve through the development of the product's properties and its production practices? 3.1 What characteristics did the product concepts and the production concepts have in the different phases of the concept develop-ment process?	Transcript of the introductory visit Transcript of 2 process workshops Transcript of the feedback workshop Transcript of 3 concept workshops Transcripts of 2 factory visits Transcript of a seminar presentation Transcript of 2 in-terviews tracing the history of the product develop-ment process	The trajectory from the first product launch until the new kinds of product development projects The phases of concept development	Product concept, production concept

4.3.2   Conducting the analysis

As described in Table 6, I examined the different sets of data to answer my re-search questions. The analyses iterated between the data and literature, and the analysis of new data sets with new analytical tools required a reconsideration of the previous rounds of analysis. For each data set, I developed my own analysis procedure to answer the research question. In all the analyses, I used the Atlas.ti software developed for qualitative data analysis for coding the data and for searching for patterns in the coded data. I summarise the analysis procedures according to the focus of analysis here, and I describe the details of the analysis process in each of the analysis chapters – 5, 6 and 7.

My first focus of analysis was the development process of the hybrid package, from the initial ideas to the launch of the first commercial package. In the anal-ysis of the interview data, I identified the events of the innovation process, the participants of the development efforts and the potential boundary objects that had participated in the shaping of the innovation process. My coding was induc-tive, but it was based on the background knowledge that I had developed during the research process. Because I had analysed these data already during the LPC project, I knew the product development projects as well as the central partner organisations when I began the coding. However, I did not make a pre-defined list of codes but rather kept adding projects, actors and artefacts to my code list

as they appeared in the data. Based on the first analysis, I outlined a chronological timeline of the events of the innovation process and the central participants as well as a parallel timeline depicting the main phases of the pilot customer's development process of their new food product. I then proceeded with the identification of the boundary objects: I identified the central artefacts based on the frequency of their descriptions in the interviewees' accounts on one hand and based on their role as objects of the development efforts in the descriptions of the development process on the other. In the continuation of the analysis, I mapped the central boundary objects with the events and their participants. Based on this mapping, I identified three main phases of the innovation process according to the central object of the development efforts. Within these process phases, I analysed the engagements between the human actors and the boundary objects to discover how these interactions shaped the innovation process and its outcomes.

My second focus of analysis was a deeper examination of the participation of boundary objects in the product development practices. I investigated the observation data concerning the central events in the development process of the Module package. The analysis process proceeded iteratively but was informed by the literature, because I used the typology of boundary objects' mediating functions in the coding. I began the analysis by coding the data to identify the artefacts and the human participants of the events. I then wrote a narrative description of the unfolding of each event, describing the nature of the activity, the participating actors and the artefacts. After refining the analytical framework, I re-examined the artefact-related episodes that I had identified during the earlier analysis to investigate which artefacts mediated collaboration in the product development practices as boundary objects and which mediating functions these boundary objects performed. This round of analysis led to the rewriting of the event narratives to bring the artefact-mediated actions into foreground. After I had completed the narratives of all events, I compared the boundary objects and their mediating functions across the phases of the product development process to trace changes in the functions.

My third focus of analysis was the evolution of product concepts and production concepts through the development of concrete products and their production practices. I examined the conceptions of the product and the logic behind their production practices in the data derived from encounters between members of the Fipak team and our research group. In the analysis, I searched the transcripts for characterisations of Fipak's product and production concepts. For the analysis of product concepts, I identified episodes where the team members characterised the properties of the hybrid package as well as factors setting limitations to the properties. Furthermore, I identified the requirements of customers and the focus of product development as factors characterising the product concepts. For the analysis of production concepts, I identified episodes where the team members characterised the principles guiding their actions, the organisation of the work and their relationships with customers and suppliers as well as the choice of manufacturing technology and management tools. Because this analysis was close to those I had conducted during the LPC project,

my background knowledge guided the coding. Even though I had a set of pre-existing codes when I began the analysis, I added a great number of new codes to describe the product and production concepts in more detail. Based on the analysis, I distinguished between three different phases of concept development. Moreover, I identified the central characteristics of Fipak's product concepts and production concepts in the three phases of concept development. Finally, I traced the evolution of the concepts across the three development phases and studied the interaction of their trajectories.

4.4 Writing up the study

Writing up the study in this thesis has been a cumbersome project. Kivistö and Pihlström (2015) state that monographs aim to produce deep and serious insights; a monograph "attempts to provide theories and arguments that will help us understand complex phenomena which can only be addressed in the form of an extended text" (p. 21). It has taken time to outline the arguments and organise the evidence that support them. I have also struggled to develop the style that would portray the characteristics of the different narratives appearing in the thesis. The differences in style are most evident in the following three analysis chapters – 5, 6 and 7. Questions of style appeared for the first time as issues with expression when I was writing the narratives of product development events for Chapter 6, and the solutions that I developed were at first intuitive. Later, my supervisor, Hannele Kerosuo, recommended that I read Van Maanen's (1988) book about ethnographic writing; his insights helped me to recognise the different styles and to develop them consciously.

  I have written the accounts of the unfolding of the research process in this chapter in a personalised manner as a confessional tale (Van Maanen, 1988). My purpose was to make the process resulting in this thesis transparent by making the different phases of the process visible. This felt important because the data that I analyse in this thesis stem from the efforts of many people, not only mine. Furthermore, I intended to depict the research practices that have produced this study and relate the methodological choices to these practices. By reflecting on my experiences of the research process, I wanted to explore my learning to see how the process affected me as a researcher (cf. Van Maanen, 1988).

  The account of Fipak's innovation process in Chapter 5 is written as a realist tale (Van Maanen, 1988) of the unfolding of the process that led to the commercialisation of the hybrid package. In the account appearing in Chapter 5, the researcher is not present as a character of the story but merely as the voice narrating the tale. Likewise, the characters of the tale are present only through their job titles, which also makes the narrative impersonal. I reconstructed this narrative based on interviews conducted by other persons; I was present in only two of these 18 interviews. In addition to my distant relationship with these data, the interviewees themselves recalled passed events. In the first versions of the analysis, which I wrote for two conference papers, I did not reflect on the chosen style. When I rewrote the final version of the analysis for this thesis, I

retained the realist style to make it distinct from the two other analysis chapters (6 and 7).

The accounts of Fipak's product development practices in Chapter 6 are written as impressionist tales (Van Maanen, 1988). The narratives of the chapter illustrate the doings and sayings of human characters in interaction with a multitude of artefacts. An impressionist tale emphasises the uniqueness of the situation described by drawing the reader into the unfamiliar world and allowing her or him to obtain a sense of the situation together with the researcher (Van Maanen, 1988). The impressionist style seemed well-suited to the description of the observed events, which I experienced unique, because our research group followed the unfolding of the process through the observation of single events. However, I needed to balance the chronological description of the events with the purposes of the analysis: The descriptions emphasise the interactions between human actors and artefacts. Moreover, unlike the impressionist tales by Van Maanen (1988), which describe the emotions of the fieldworker on-site, my accounts focus on describing the observed practices rather than displaying my own impressions. I assume that the lack of the researcher's reactions in the field notes stems from the fact that our engagements with the observed practices were limited to these single events. Therefore, the observation and documentation of the practices required much effort and limited self-reflection. Furthermore, the observation of single events did not allow us to identify differences between particular and ordinary actions. Because we were mere observers and unable to participate in the observed actions, our reactions were those of a researcher, not a participant (cf. Adler & Adler, 1994).

The accounts in Chapter 6 are written in the first person when I describe my observations and in third person when I account for the practices of the persons I was observing or when these accounts are based on other researchers' observations. I draw a line between the narratives based on my own and my colleagues' observations by using the present tense in descriptions of events I personally observed, while narratives based on the observations of my colleagues use the past tense. In addition, I use the past tense for the narrative based on an interview because I did not observe the practices directly.

I began writing the narratives for Chapter 6 first as realistic tales but found the writing difficult. It felt unnatural to write about the real-time actions of persons with job titles; this style of writing also felt awkward because both in our communications with the Fipak team and in the interactions of our research group we always referred to the Fipak team members by their first names. When I realised that many ethnographic accounts use names in the descriptions of human actions, I began to invent names for the team members. I chose to use Finnish names, because it seemed awkward to use English names. Furthermore, I maintained the gender of the individuals: Even though I do not address the issue in the analysis, the fact that key persons on the team were female says something about the business unit. Once I started using names in the narratives, the writing became easier, and the tales seemed to convey the atmosphere of the observed events better. After I had named the team members, I realised that writing about anonymous researchers did not suit the genre of the texts. With the

agreement of my colleagues, I decided to use their real names across the whole thesis. It seemed that in this way I was also able to make their contribution in the LPC project visible. However, I restricted the use of fictional names to the Fipak team, and I refer to the partners with anonymous company names and job titles.

The accounts of the encounters between the members of the Fipak team and our research group in Chapter 7 focus on the identification of the characteristics of Fipak's product concepts and production concepts that the participants of the research interventions articulate. These accounts do not clearly represent any of the styles identified by Van Maanen (1988). This probably has to do with the fact that the data analysed in the chapter are based on research interventions in which the researchers acted in a role different from that of fieldworkers. When interacting with practitioners to support them in the analysis of their own work practices, we concentrated on the reactions of the participants and on following the intervention plan. Even though we did reflect on the interventions within the research group afterwards, my analysis is based on the examination of the transcribed discussions. And despite the presence of myself and my colleagues in all these encounters, we are hardly present in the text. Our presence is marked by the use of the pronoun "we," which mostly refers to the members of our research group but sometimes to all the participants in the encounter. I have paid attention to my use of "we" and have tried to clarify to which individuals the pronoun refers in the text. In the accounts, I also draw a line between members of the Fipak team and our research group by referring to the team members as the participants of the workshops; I think of us the researchers as the organisers of the workshops.

The translation of the excerpts for the analysis chapters has been a demanding part of the writing process. All the data are in Finnish, and translating the sayings of the research participants into English has required a lot of effort. I have tried to balance the translations between intelligibility of the text and vividness of expression. The Fipak team members used rich language and often made self-ironic jokes about their activities – many dialogues in the workshops included laughter. Oftentimes, the expressions the team members used cannot be directly translated into English, and I have done my best to maintain the meaning of the original conversation while finding an expression close to its style.

Two members of the Fipak team read the analyses of this thesis during the writing process. I wanted to make sure that they accepted the publication of my accounts, which disclose details of their products, production technology and product development practices. During the research collaboration, the Fipak team required that we write very generally about the innovation process and the technological solutions. Furthermore, I was convinced that the participants of the study have the right to read my analyses of their activity and suggest corrections. To my relief, they found very few technical issues which revealed too many details of the developed solutions and which I therefore left out of the thesis. Moreover, they accepted the degree of anonymity my pseudonyms provided, even though we both agreed that any insider of the packaging business could easily conclude which company the study is about. Their feedback also enabled

me to clarify some details of the innovation process that the data had left obscure. Furthermore, they corrected some technical details about the production technology, which I had misunderstood.

When writing up the thesis, I chose not to discuss certain issues that seemed delicate within the Fipak team. During our research collaboration, we came across sensitive issues related to terms of employment or the relationships between Fipak and their partners. Furthermore, the team members spoke carefully when they referred to financial issues: They never disclosed to us the price of the hybrid package, Fipak's investment budget, revenue, etc. We respected this omission and did not inquire about their business figures, because we did not find that knowledge necessary for our research. Nevertheless, hints provided by the participants of the study enabled an understanding of the scale of Fipak's business activity.

5. The construction of the hybrid package

To explore the ways in which interactions of human actors and artefacts shape the innovation process, I analyse the development process of the hybrid package. The process resulted in the market launch of the first commercial package and in the establishment of Fipak as a business unit to continue the commercial development and production of hybrid packages. The development of the hybrid package proceeded through the elaboration of different artefacts required for its manufacture and involved the work of several people in different organisations. The development process began with experiments with a possible manufacturing technology and proceeded through several product development projects, which involved a growing number of industrial and research partners. The nature of the hybrid package as both an industrial product and a consumer product was reflected in the development process, which concerned both the construction of a highly automated production infrastructure and the development of attractive product concepts.

I trace the phases of the development process by analysing the retrospective accounts of 17 participants from eight organisations describing the activities they had engaged in as well as their understanding of the artefacts they had been working on. In the analysis, I examine *how boundary objects shaped the unfolding of the innovation process and its outcomes*.

5.1 Research design

I started tracing potential boundary objects in a data set of 18 interviews, which concerned the development process that resulted in the commercialisation of the hybrid package and the creation of Fipak as a business unit of the case company. The interviews were conducted by a member of our research group, Hanna Toiviainen, and a student who wrote her master's thesis based on the interview data. They interviewed the central actors who had participated in the product development process of the first commercial package soon after its product launch in winter 2009–2010. The interviewees included employees from Fipak and central actors from partner organisations named by members

of the Fipak team (see Table 7).[14] The interviews focused on the phases of the development process and the roles of the different partners. When analysing the accounts of the interviewees, we discovered that the innovation process, whose outcome was the first commercial package, had begun already before the product development project we had been investigating. To discuss the origins of the process and its unfolding over time, we conducted two more interviews with three key persons of Fipak who had been involved in the process for the longest time.[15] I conducted the first of these interviews with another researcher from our group, Päivi Ristimäki, and the second one by myself.

Table 7. Interview sets and their participants.

Interview set	Time	Network partner	Participants (17)
Development process of the first commercial package	December 2009	Fipak	Sales manager, technical manager, production engineer, development engineer, product designer, tool designer, operator (7)
	December 2009–February 2010	Pilot customer	Product development manager, product development engineer (2)
		Printing house 1	Engineers (2)
		Printing house 2	Sales manager (1)
		Graphical design provider	Foreman (1)
		Tool provider	Manager (1)
		Equipment provider	Manager (1)
		Automation provider	Engineer (1)
Unfolding of the innovation process	December 2010	Fipak	Business manager (1)
	March 2012	Fipak	Sales manager and technical manager (2)

In my analysis, I reconstruct the development process of the hybrid package through the engagement of various human actors and artefacts. I searched the data to identify the different phases of the process and the potential boundary

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[14] The partners who were involved in the first phases of the development process (before the pilot customer entered the project) were not interviewed, because the initial focus of the interviews was on the development efforts leading to the commercialisation of the hybrid package. The analysis of the participation of these partners is based on the accounts by Fipak team members who engaged in development efforts with them.

[15] In addition to this data set, I conducted a further interview with Fipak's sales manager and technical manager in August 2015, during which I asked about some details of the development process which had remained vague in the previous data. I have used the interview to ensure that the account given here was precise but it is not included in the analysed data.

objects that helped to mobilise participants to join the development work and to organise their efforts.

First, I coded the accounts of the interviewees as part of the innovation process when they described the events and actions in the development of the hybrid package. Furthermore, I coded their descriptions of events and actions as part of a certain product development project in which the development work to create the hybrid package and its production technology was carried out. During this analysis, I also identified the participants of the described activities. Once I had processed all the interviews, I collected together all the events of the development process with the help of the qualitative data analysis Atlas.ti software by extracting all episodes from the interviews, which were coded as descriptions of the process. By referring to these episodes, I outlined a chronological timeline of the events structuring the innovation process of the hybrid package with their central participants. Additionally, I outlined a parallel timeline depicting the pilot customer's development process of their new food product. Based on these timelines and the collection of interviewees' accounts of the events, I constructed a preliminary narrative of the innovation process.

Second, to identify the potential boundary objects, I coded a passage in the data as related to a certain collaboration artefact when the interviewee mentioned the artefact with regard to having been (a) constructed in collaboration or (b) used collaboratively between members of different communities or organisations during the product development process. This analysis resulted in a set of 30 artefacts, which I examined further to identify the central boundary objects that participated in the collaborative development efforts in the innovation process. In the accounts of the interviewees, two artefacts stood out as the most central ones, in whose development a majority of the interviewees had participated. In the majority of the episodes where the interviewees talked about these boundary objects, they referred to the artefacts generally as "the package" (35 times) or "the moulding tool" (44 times). However, at times, the interviewees described the development efforts including a specific instantiation of the artefact, such as the Prototype package (10 times) or the first Pilot mould (12 times). Two other central artefacts were the paperboard blank (mentioned 37 times) and the injection moulding machine (mentioned 42 times). By examining the episodes coded as collaboration with these artefacts, I concluded that all of them had shaped the innovation process as boundary objects. However, I decided to focus my analysis on the two boundary objects – the hybrid package and the moulding tool – whose instantiations had been the object of development efforts throughout the process. The paperboard blank and the injection moulding machine became more central in later phases of the process.

In the continuation of the analysis, I mapped the central boundary objects with the phases of the innovation process and their participants. Based on this mapping, I identified three main phases of the development process of the hybrid package according to the central object of development efforts. Within these process phases, I analysed the engagements between the human actors and the boundary objects to discover how these interactions shaped the innova-

tion process and its outcomes. I studied the ways the boundary objects participated in the development efforts with the human actors and the consequences of their participation. Thus, I analysed the innovation process as a trajectory (Strauss, 1993) involving different phases, where the boundary objects served different purposes. I also traced transitions in the ways boundary objects participated in the events in the different process phases.

5.2 The development process of the new kind of package

Over the years, the Paper Company had funded different product development projects to explore new uses for the paperboard materials it produces and to develop their functionalities. The development of the hybrid package has its roots in preceding development projects and belongs to those that have been successfully commercialised. The development efforts took place in consecutive product development projects, the last of which ended with the establishment of a new business unit, Fipak, and the commercial launch of the hybrid package.

The design and manufacturing of the hybrid package required the manipulation of an enormous number of different artefacts and involved the work of many people in different organisations. Most of these artefacts were unknown at the beginning of the product development process, which began with the idea of inserting a plastic rim into a paperboard package to make it air-tight. The novel combination of the two materials and the application of a plastic manufacturing method, injection moulding, in the production of paperboard packages required expertise from different disciplines as well as equipment for the experiments. Throughout the process, new participants were recruited to acquire the expertise needed for solving the various problems that arose.

The development process of the hybrid package began in 2005, when the researchers of the R&D Centre of the Paper Company started to explore the possibilities of developing a tight paperboard package for food products. The company had developed a new kind of paperboard for packages and sought new uses for the material to increase its sales volumes. Among the customers of the company, there was a growing interest in paperboard as packaging material due to increasing ecological concerns among consumers; paperboard was seen as renewable material compared to conventional plastic and aluminium packages. The researchers of the R&D Centre had the idea of realising the initial product concept by manufacturing paperboard packages with injection moulding technology. However, the R&D Centre did not possess this kind of technology; their main expertise focused on fibre-based materials. Therefore, experts in injection moulding and plastic materials were needed as partners in different phases of the development process.

Figure 8 summarises the main phases of the development process by depicting the participants and their contributions to the development efforts, as suggested by Lehenkari (2000). Each phase produced artefacts as their outcomes, which were experimented with and further developed in subsequent phases.
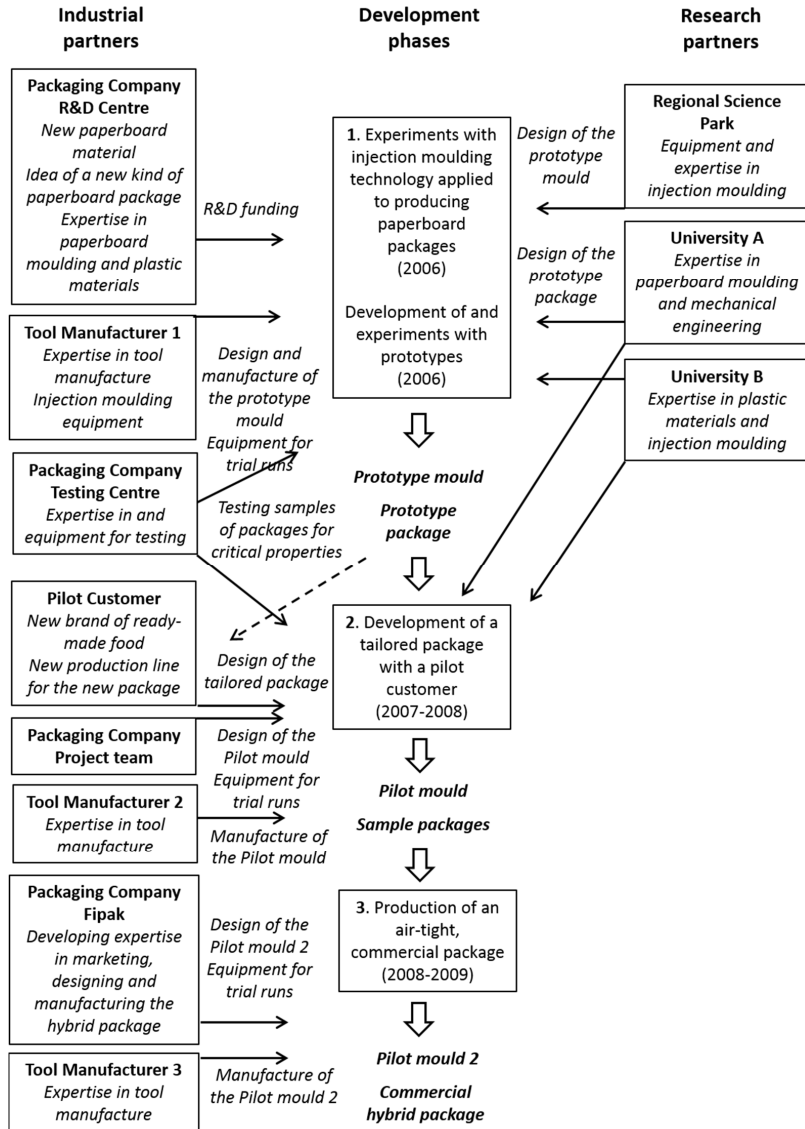
Figure 8. Development process of the hybrid package, focused on the parallel development of the moulding tool and the package.

In the first phase of the process, a central question was the development of a moulding tool that could manufacture the hybrid package in an injection moulding machine. As the experiments with injection moulding proved promising, in 2006 a development project, *NPD 1*, was established in the R&D Centre to develop a package made of paperboard and plastic. The participants in the devel-

opment efforts included researchers from the R&D Centre and from Universities A and B as well as from a Regional Science Park. Additionally, the researchers collaborated with Tool Manufacturer 1. During the NPD 1 project, a prototype mould and prototype package were developed, but the prototype did not yet fulfill the requirements for food products.

In the second phase, the prototype package was further developed towards a tailored product for a pilot customer. The R&D Centre established a three-year product development project, *NPD 2*, with the target of commercialising the hybrid package.[16] The aim of the R&D Centre was to develop commercially viable products, and collaboration with potential customers was typical of its development projects. In addition to the Paper Company's R&D funding, the project received external funding from a governmental R&D funding agency. Soon after the NPD 2 project had begun, its project manager succeeded in persuading a pilot customer, a food company, to join the project. The development efforts in the NPD 2 project engaged a growing number of participants from industrial companies, including new tool manufacturers. The development proceeded with experiments with the prototype mould and the prototype package; later, the Pilot Customer designed a tailored package, and a corresponding mould for this pilot package was designed and manufactured.

In the third phase, work in the NPD 2 project proceeded from experiments to production while the construction of an automated production infrastructure for hybrid packages began. The Paper Company decided to establish a new business unit, Fipak, to continue the commercial production of the hybrid package. The new unit was located on the premises of a production facility for food packages, which had become vacant due to a relocation of the previous activity. The development of a commercially usable package corresponding to the Pilot Customer's requirements called for intensive collaboration with both existing and new partners. The NPD 2 project culminated in the product launch of the hybrid package in autumn 2009.

5.3 The construction of the hybrid package through experiments with artefacts

The following analysis traces the development of the hybrid package from an idea to a commercial product as well as the development of the moulding tool. The process included also the development of the paperboard part of the package, but this became more important in the later phases of the process and was related to the experiments with the moulding tool. Therefore the paperboard

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[16] In the analysis, I distinguish between the product development project NPD 2 and the commercial project, which I call the Pilot project. The distinction originates from the members of Fipak's development team: They referred to the entire development project (NPD 2) with an abbreviation of its name, while they talked about the Pilot project with the brand name of the pilot customer. The Pilot project was part of the three-year NPD 2 project, and the involvement of this particular customer was not known at the beginning of the project. The NPD 2 project had a broader focus to develop a viable product concept and a cost-effective manufacturing method, while the Pilot project focused on the design and production of a tailored package for a commercial customer.

part is only discussed in association with the experiments conducted in the different phases of the process. Figure 9 provides an artefact-centred depiction of the intertwined development processes of the package and the moulding tool.
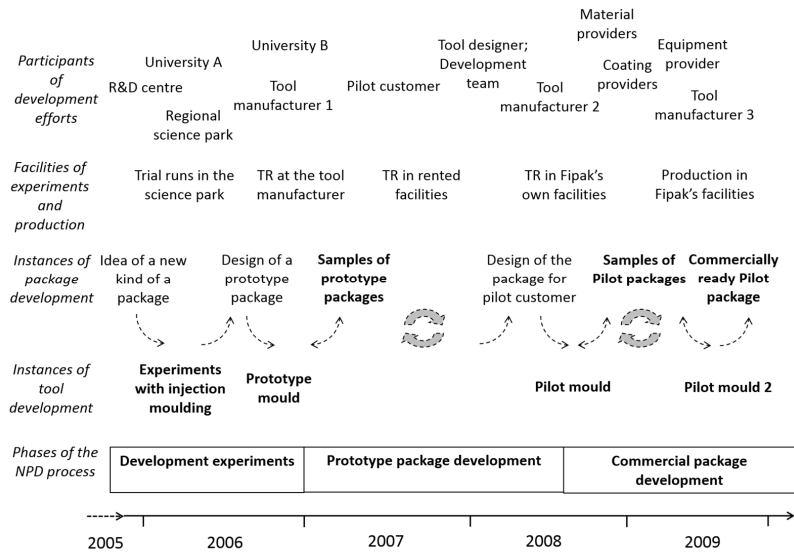
Figure 9. The intertwined trajectories of the hybrid package and the moulding tool including the collaboration partners.

5.3.1 Phase 1: Experiments with a tool and development of a prototype mould and prototype package

Development efforts to explore how to produce an air-tight paperboard package with a plastic rim began in the Paper Company after people in different parts of the organisation had come up with the idea. In discussions about how to make a fibre-based package air-tight, a researcher from the R&D Centre (whose disciplinary background was plastic manufacture) proposed adding a plastic rim to the package. At that point, the proposition did not lead to further action. Around the same time, similar ideas about the combination of paperboard and plastic were played with in a manufacturing unit of the Paper Company, whose manager explored collaboration possibilities with a Packaging Company. The researcher from the R&D Centre was invited to some of these meetings, which did not lead to collaborative efforts between the companies to develop a novel package. Nevertheless, the unit manager was interested in the opportunity of developing a new kind of package and organised a small-scale development project, the NPD 1 project, to encourage such efforts.

After the idea about producing an air-tight paperboard package with the addition of a plastic rim had first been proposed, researchers from the R&D Centre and from University A started experimentation with different technologies. The

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researchers had worked in previous product development projects of the R&D Centre. Because their first experiments with available technologies showed that these did not enable the manufacture of a sufficient rim, the researchers needed to expand their experiments with inserting the rim into a paperboard package with injection moulding technology. Through the contacts of another researcher from University A, a partner with such equipment was found from a Regional Science Park focused on plastic technology development. A small team of researchers was formed when the researcher from the R&D Centre, who had expertise in both plastic and paperboard manufacturing, started to work together with two researchers from the University A, a researcher from the University B and a researcher from the Science Park. Together they began to experiment with the equipment of the Science Park to explore, whether it would be possible to mould paperboard packages with that kind of technology.

A central question in these early experiments with a combination of plastic and paperboard manufacturing technology was *the moulding tool*, a central component of the manufacturing equipment. The tool needed to form the package in the equipment by moulding the paperboard blank into the designed shape and injecting the plastic rim around it. The researchers carried out trial runs in the science park to test paperboard material in *the injection moulding equipment*. The R&D researcher, who later became technical manager of Fipak, told about the collaboration and the division of labour:

> Technical manager: *Those tests were made during spring. Here [in her notes] is for example the 6th of April [2006]. Then somewhere in between we made a test mould, we cut a corner of a paperboard package and then moulded a plastic rim into the corner and tested that 'see, this could start to work like this.' Here [the researcher from the Regional Science Park] was really much involved, he did quite a lot of testing on his own (…) he developed maybe more that injection moulding part and we [she and the university researchers] kind of developed how this pressing [of the paperboard] could be made function there.*

Here, the moulding tool mediated the work of the researchers as a boundary object: It provided motivation for them to work together, organising their autonomous and collaborative efforts. The researchers worked apart based on their expertise and gathered together to make experiments and see whether their work had advanced the development.

During the the NPD 1 project, the researchers designed *a Prototype package* and a corresponding *Prototype mould* (see Figure 8). The package and *a Prototype paperboard blank* (see Figure 10) were designed by a researcher from University A who had participated in paperboard development projects of the R&D Centre. The shape and size of the Prototype package followed the form of conventional packages used for microwave-heated ready meals; the researchers collected packages from grocery shops and measured them to design a package that could attract potential customers. The prototype mould consisted of two parts, a rear mould (mould core) and a front mould (mould cavity) The researcher of the Regional Science Park designed the rear mould based on the experiments; he was not familiar with hot channel systems of injection moulding and so the

research team sought a tool manufacturer that could design the front mould and manufacture the entire mould. The collaboration with the Tool Manufacturer 1 began with the design of the front mould and the manufacture of the Prototype mould.
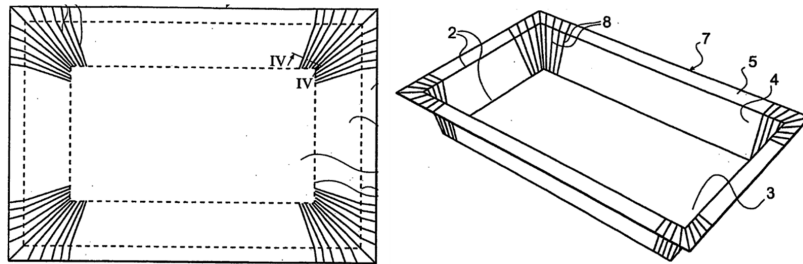
Figure 10. Sketches of a hypothetical paperboard blank and hybrid package.

Once the Prototype mould was manufactured, the development of the Prototype package proceeded in cycles of research, trial runs and testing. Researchers from University A provided knowledge on paperboard moulding and mechanics of the moulding tool, whereas the researcher from University B was studying plastic materials and their behaviour in injection moulding. The trial runs were now conducted on the premises of the Tool Manufacturer 1, where the researchers gathered to carry out experiments with the mould. The manufacturer had the required injection moulding equipment and an operator helped the researchers to run the machine. The researchers met at the manufacturer every couple of weeks for one-day trial runs, experimenting to manufacture a plastic rim and a paperboard package that would not break. Each trial run was planned in advance to test certain materials or methods. After each trial run, the researchers took *samples of the packages* with them and sent them to the Testing Centre of the Paper Company for testing for air-tightness.

Here, the Prototype mould organised the division of work among the partners that now included more researchers and the operator of the manufacturer who helped to conduct the experiments with the equipment. The Prototype mould was a representation of the moulding tool: It was a material artefact whose functioning could be examined. Likewise, sample packages produced with the mould in the trial runs represented the product concept of the hybrid package. The properties of the packages could be visually examined and tested with standard procedures. Based on the examination of the packages, the participants were able to come up with ways to advance the development of the package, which were then translated into material changes in the Prototype mould and the Paperboard blanks.

After some six months of research and experiments, the NPD 1 project succeeded in producing a Prototype package, which thus represented the product

concept of the hybrid package. Despite having a good appearance, the prototype was not air-tight enough to be used for ready-made food; it was still "leaking like a sieve."

5.3.2 Phase 2: From a prototype towards a tailored product

In the NPD 2 project, the focus was shifting to the development of the package with the Pilot Customer joining the project (see Figure 8). This shift was also connected with the expansion of the project team involved in the project in the R&D Centre: it included engineers, economists and designers. While experiments with the Prototype mould continued, the team members were studying also alternative uses for the hybrid packages. The project team collaborated with an Advertising Agency to create different kinds of product concepts: Most of the package concepts were designed for different kinds of food products, but other kinds of end uses, such as cosmetics and homeware, were also included.

Over the course of the NPD 2 project, which started at the beginning of 2007, more participants got involved in the development efforts. The project was led by a project manager of the R&D Centre, who later became the business manager of Fipak. The project was organised in several sub-projects, focusing on areas such as product design, materials research, manufacturing technology, testing and IPR, which employed many employees of the R&D Centre. Also more researchers from the Universities A and B were involved in the project. The business manager told that collaboration with universities was usual in projects of the R&D Centre: "First because we haven't had that kind of resources and then second thing has of course been that it has required so much research so it has been smart to do with universities."

Because the NPD 2 project aimed at developing a commercial package, collaboration with a potential customer was sought early on. Soon after the project had begun, the project manager succeeded in persuading a Pilot Customer, a food company, to join the project. The customer decided to participate due to a coinciding product development project and acknowledgement of sustainability issues, which made paperboard an attractive material. Additionally, the CEO of the Pilot Customer had previously worked for packaging industry and participated in product development projects with the project manager of the NPD 2 project. The business manager of Fipak summarised the Pilot Customer's joining the project: "So in a way everything then fell into place."

For the Pilot Customer, the introduction of the prototype of the hybrid package came in the right time because they were studying different package alternatives for their new brand. In food industry, ordering a new package for some product means significant investments in new automated production lines that need to be designed according to the package. The Pilot Customer had already made the decision to invest in the new brand and they were seeking the most suitable package that would communicate the qualities of the new food products. The customer sought to renew their image in the eyes of consumers by introducing this new brand, which was targeted to a consumer segment that usually does not buy ready meals. The Prototype package was included in the

Pilot Customer's consumer tests; according to the test results, the hybrid package corresponded to the features of the new brand. The customer's product development department saw that the hybrid package developed by the Paper Company fulfilled not only the criteria of the brand and the consumers but also the requirements of their production. Because the customer aimed to produce the products of the new brand in high volumes, effectiveness in production was an important criterion. The hybrid package was unique in having a plastic rim around the paperboard package, which meant that "It can be sealed tightly and it is exact in measures, then it functions with maximum speed in production," a customer's product development engineer explained. Although some competing packaging companies were also developing new kinds of paperboard packages, none of these were in a production phase.

Here, the Prototype package mediated the collaboration between the Pilot Customer and the R&D Centre: The Prototype package represented the properties of the hybrid package that could communicate the qualities of the customer's new brand. Furthermore, the Prototype package was tested in the Pilot Customer's production. Due to the available material representation, the customer was persuaded that the hybrid package would be manufacturable. The incorporation of the Pilot Customer in the project became a motivating force for the project team because their work received a concrete goal.

Meanwhile, experiments with the Prototype mould and the Prototype package continued. Over the course of the development work, the project team needed to find a new place for the trial runs because the Tool Manufacturer 1 went bankrupt. To continue the experiments, the project purchased *an injection moulding machine* from the manufacturer and rented facilities where the trial runs could be continued. The project also hired the manufacturer's operator who had been involved in the trial runs and one of their tool designers. Expertise in moulding tools and the injection moulding technology were seen central to the development and due to the commercial orientation, the NPD 2 project could no more rely on external expertise only.

In spring 2008, after having made customer surveys and production tests with the Prototype package and competing packages, the Pilot Customer chose the hybrid package for their new brand and revealed its shape to the project team of the R&D Centre. The Pilot package would have an oval shape, whereas the Prototype package had a rectangular one. However, the customer did not yet disclose the food product to be packed. Now that the commercialisation of the hybrid package was settled and its design had been defined, the Pilot Customer agreed to pay the moulding tool that would be used for their product only. The tool designer now working for the project needed to design the new mould and Tool Manufacturer 2 was chosen to produce the moulding tool for the customer's package.

The moulding tool was still a central concern of the development efforts; only after the tool was in proper shape could other features of the manufacturing technology be tested. The tool remained a boundary object also because the participants changed: Neither the designer of the Prototype mould nor its manufacturer were involved in the development process any more. For the new tool

designer, the Prototype mould was a boundary object in the design of a Pilot mould for the Pilot Customer's package, as he used it as a model in his design work. He used the Prototype mould as a representation of the design choices of the previous tool designer because he did not have comprehensive drawings or digital models of its design.

> Tool designer: In principle we left from having kind of an existing test [the Prototype] mould, which produced a certain kind of package model [the Prototype package]. ... But everything that was related to geometry [of the mould] had to be dug, I didn't have [information about] it either. It happened that there was [the researcher from the Science Park] who has been kind of the father of the moulding tool design there. Of course it [the mould] was refined over time and we searched for the correct geometries to get this work partly. Well the moulding tool existed but we didn't have exact product pictures or specs [specifications] of it. It went like that we didn't have all of them documented. I actually started from that we had the tool design and I kind of dug up the things that were developed for it. And we developed the new product [the moulding tool] based on that.

When the Pilot mould for the customer's package was available for testing, the trial runs intensified. New problems with the mould emerged: The plastic materials were damaging the mould and therefore the tool designer needed to find suitable coating to protect the tool. He also contacted steel material providers to discuss alternative materials for the moulding tool and their behaviour in such production. The problems with the combination of the materials and the mould showed that the project did not have all required expertise to produce the hybrid package in a sustainable way, which called for the recruitment of new partners.

In addition to the experiments with the coating of the mould and the plastic materials, the project team members were struggling with the paperboard material. Earlier trial runs had been carried out with unprinted paperboard blanks, but when a preliminary graphical design was printed on the selected paperboard it appeared that this material was difficult for printing. Furthermore, the determination of the correct size of the paperboard blank turned out to be difficult, especially because the testing equipment did not have adjusters which would have positioned the blank precisely in the mould.

> Production engineer: Normally, in injection moulding you just close the mould and put plastic in (...) In our case, we first take the paperboard and it's double times more difficult if not ten times more difficult because it needs to be positioned correctly there. It's easy when you hit two irons together and inject the gap full [of plastic]. But when you take it [the plastic] to the edges and try to do it with the accuracy of a tenth of a millimetre. That's kind of its own world.

Consecutive rounds of trial runs were carried out in order to solve the production problems. The project team managed to find a suitable coating for the mould together with coating providers and collaborated with printing houses to

improve the printing of the paperboard. Between the trial runs, sample packages were delivered to the Pilot Customer and the Testing Centre of the Paper Company for different kinds of tests. Despite all these efforts, the packages produced in the trial runs were still not air-tight, and the project team needed to find out why.

5.3.3 Phase 3: Towards the launch of the first commercial package

The launch of the package for the Pilot Customer was approaching and the Paper Company decided to establish a new business unit, Fipak, to continue the commercial production of the hybrid package.[17] The team running Fipak united expertise developed during the NPD 2 project and consisted of nine persons: a business manager, a technical manager, two sales managers, a product designer, a tool designer, two production engineers and an operator. The paper company located Fipak in the premises of a production facility for food packages, which had become vacant due to the relocation of the previous activity.[18] Fipak's production personnel started to carry out trial runs in the acquired production facility. Now that they could work on them on a daily basis without needing to make travel arrangements, the university researchers did not participate in trial runs anymore.

In spring 2009 the customer increased the sales estimates of the new food brand, which multiplied the volumes of required packages. Finally the customer also disclosed the food products to be packed with the Pilot package and its graphical design. Printing of the ecological-looking design resembling the look of recycled fibre proved to be a difficult task, which made the development team collaborate with printing houses to fulfil the customer's requirements.

Fipak had planned the purchase of production-scale manufacturing equipment for the commercial production of the Pilot package, but the increased production volumes required also the purchase of a second, more effective moulding tool. The Pilot mould only had one cavity, meaning that it could produce one package at a time; *the Pilot mould 2* was designed with two cavities, thus doubling its effectiveness in production. Members of Fipak's development team needed to estimate what kind of packages the unit would produce in future and what kind of production volumes the equipment needed to deliver. The decision about the type of equipment to be purchased needed to be done quickly so that the new mould could be designed; the equipment determined the possible size of the mould. Fipak's tool designer told that the decision was made by "pulling it off the cuff."

Now that Fipak was planning the production of future packages for commercial customers, the development team practiced new ways of choosing partners. The providers for the Pilot mould 2 and proper injection moulding equipment were selected through a tender process, whereas the previous providers were

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[17] Production of consumer packages was exceptional in the Paper Company's business. Originally, the development of the hybrid package had not aimed at in-house production.

[18] The production of hybrid packages needed to take place in production facilities qualified for contact with food products. Therefore it was important that the facilities Fipak acquired had already been used for food packaging.

found via personal contacts. The tool designer and the technical manager chose Tool Manufacturer 3 as the provider of the new mould. The Equipment Manufacturer was chosen to be the provider of *the production-scale injection moulding equipment*. Both new partners were keen on collaborating with Fipak, because they expected that the hybrid package could make a breakthrough in food markets.

> Equipment manufacturer: It was the innovativeness part which interested us and we see that it [the hybrid package] has potential and that's why we want to be involved in this group. It's linked with that paper or paperboard which is always so topical in the Finnish circumstances is connected with this world of plastic so that it maybe raises new areas of demand.

In this situation, the Pilot mould 2 – which the Fipak team members sometimes called "production mould" because it was designed for production-scale manufacture corresponding to the high volume of Pilot packages – became a boundary object only to a limited extent between Fipak and the new partners. Both the Tool Manufacturer 3 and the Equipment Provider told that the development team shared information concerning the production process only limitedly, which made it difficult to optimise the technologies to Fipak's particular kind of use. The manufacturers learnt only later that Fipak needed to change moulds in the injection moulding machine, which was not typical of the industry.

> Equipment manufacturer: It's kind of related to questions of usability. When these kinds of packaging applications are made it's pretty rare to change the product which is ran with a certain machine. They often are products with big volumes and once a certain mould for a certain product is put into the machine then it's run many years and the mould goes to maintenance sometimes but nothing else is changed. Now in the beginning that they [Fipak] have got a limited amount of machines with which you can run anything so they need to change the mould quite often. (...) This was one thing that hadn't been underlined in the plans at all and maybe we didn't have enough conversation about such details.

Thus the Pilot mould 2 did not become an object of collaborative development efforts but rather a technical object to be produced according to pre-defined division of labour. This position of the mould among the partners involved in the late development phase suggests that the emergence of a boundary object does not depend on the properties of the artefact only but on the relationships between the involved parties as well.

  Despite the increasing centrality of the package as the object of development efforts and attraction that drew new participants to the product development network, the moulding tool held on to its important position while the development was advancing. Although the tool lost some of its epistemic meaning as a mysterious artefact, the team's efforts to build a proper production infrastructure for commercial packages concentrated to a great extent on the problems encountered with the mould in the trial runs. These problems were connected

with other properties of the manufacturing process and materials but they manifested in the behaviour of the mould and in the produced test packages.

Finally, due to the persistent experiments, the Fipak team managed to make the Pilot package air-tight. Based on their experiences in subsequent product development projects to tailor the hybrid package according to customers' needs, Fipak's technical manager and sales manager retrospectively reasoned that the final success in making the hybrid package air-tight was due to both systematic work and favourable coincidences. It had been important to test the packages systematically after each modification of the moulding tool and each adjustment of the manufacturing parameters. Furthermore, working under commercial pressure to produce a usable package had forced the development team to finalise the product. Additionally, the design of the Pilot package determined by the customer happened to be favourable because the round, oval shape of the package suited the manufacturing requirements in Fipak.

The production of the first commercial package was a great effort for Fipak's development team because the purchase and delivery of the production-scale equipment was delayed. This meant that the production engineers and the operator needed to run the testing equipment which only had a slow robot and to work in three shifts to produce the packages. The new equipment was taken into use only after the commercial launch of the Pilot package. Fipak's development engineer recalled the busy times:

> Development engineer: Always when the delivery [of a batch of Pilot packages] was supposed to be on Friday, on Thursday evening we managed to run the required quantity. All the time we were on the risk limit whether we can make it or not.

The NPD 2 project culminated in the product launch of the Pilot package in September 2009 at the same time with the customer's new food brand. Fipak's sales manager characterised the hybrid package as an innovation a couple of months after the launch of the Pilot package:

> Sales manager: Afterwards having seen where it ended up you can say that together we developed the first recyclable package for ready-made food so that it's based on paperboard and applicable to industrial foods that use protective gas. (...) So in practice the novelty is that we're making paperboard so tight that it's applicable to these kinds of new uses.

The product that was packed with the hybrid package was considered a success soon after its product launch, but it did not become a commercial success in the long run: It was later removed from production. Nevertheless, the hybrid package development continued with both the Pilot Customer and with new customers, benefiting from the work accomplished during the many phases of the development process. Many of the factors and their interdependences influencing the behaviour of the materials in the manufacturing equipment remained unknown even after the launch of the first commercial package. Hence, each new

package that was tailored for a customer required an iterative product development process whose success was uncertain in the beginning.

5.4   Emergence of boundary objects and the unfolding of the innovation process

The previous reconstruction of the development process of the hybrid package distinguishes between three phases in which different artefacts became boundary objects and shaped the unfolding of the process. This analysis casts light on how boundary objects influenced the innovation process and its outcomes.

The development process began with experiments to explore whether the idea of a hybrid package, a novel combination of paperboard and plastic, could be developed into a usable package with injection moulding technology. The open and question-generating nature of the moulding tool and later of the hybrid package attracted partners to join the development efforts. The new combination of materials and manufacturing technology allowed all the partners to expand their expertise and participate in the creation of the innovation. As the viability of the hybrid package as a product was proved, it also promised economic results. The Pilot Customer aimed to change the company image in the eyes of consumers by introducing the new brand, and an appealing package was regarded as one means to market the new products. The tool manufacturers needed to extend their customer base due to the restructuring of the mobile phone industry, which had been their major customer sector. For the manufacturers, the Paper Company represented an important reference customer. The interest of the partners in participating in the product development work indicates that they sought to change and expand their activity (Miettinen, 1999). The artefacts that became attracting boundary objects were tertiary, imaginative artefacts that represented a potential future (Wartofsky, 1979). They shaped the development process by engaging new partners whose competence was crucial to advancing the development of the hybrid package.

The ways in which the moulding tool acted as a boundary object between different actors exemplifies that the same artefact can have different meanings for different participants. The moulding tool mediated the collaborative work between the actors in different ways in the three phases of the development process.

In the first phase of the process, the moulding tool was an object of inquiry which did not yet exist, and the development efforts sought to materially define its properties, thus motivating collaboration (Ewenstein & Whyte, 2009; Knorr Cetina, 2001; Miettinen & Virkkunen, 2005). In the experimental activity between the researchers, the moulding tool allowed the partners to do autonomous development work and acted as a focus for the collective experiments, thus maximising the autonomy and communication of the partners (Star & Griesemer, 1989). In the trial runs, all participants could observe the mould's behaviour and discuss it together. In the field-specific research and testing, the participants developed certain properties of the tool and the materials autonomously. This interplay between the weak and strong forms of a boundary object

and its effects on the outcomes of collaborative work practice has remained marginal in organisational research, which has focused on the communicative role of boundary objects between representatives of different professional or organisational communities (Zeiss & Groenewegen, 2010). Further on, the moulding tool materialised as the Prototype mould, which produced samples of the Prototype package. The material mould as a primary artefact became a boundary object between the researchers and the manufacturers; its functioning was tested in the trial runs and evaluated according to the sample packages to determine the modifications to be done by the manufacturers.

In the second phase, the moulding tool took on a different meaning when the participants of the development efforts changed. The development work in the first phase had demonstrated that it was possible to produce paperboard packages with a plastic rim, and the researchers had designed a functioning Prototype mould for this purpose. For the new tool designer, the Prototype mould was a model, a representation that he could use to design the Pilot mould; the moulding tool functioned as a secondary artefact (Wartofsky, 1979). Here the mould as a physical artefact mediated the solutions that the previous tool designer had developed: The new tool designer investigated the structure and functioning of the Prototype mould to infer how the mould was designed in order to compensate the lacking design documentation. The moulding tool also acted as a different kind of boundary object when problems that occurred with the Pilot mould in the trial runs called for collaboration with new partners (see Figure 9). Here, the Pilot mould functioned as a primary artefact directly used in the development efforts (Wartofsky, 1979); the development work could not proceed before the mould's functioning was improved. Miettinen (1999) calls this phenomenon "resistance of nonhuman elements." Pickering (1993) argues that efforts in science advance through a dialectical process of resistance and accommodation: When practical obstacles inhibit scientists in continuing their line of research, they need to accommodate their research process and practices to continue pursuing their goal or even to redefine the goal. Such instances of resistance and accommodation occurred in the development process of the hybrid package. The unexpected behaviours of the artefacts taught the human actors about the functioning of the artefacts and made them look for new expertise and new kinds of resources. In such situations, artefacts transformed the course of action through surprises and setbacks.

In the third phase of the process, the moulding tool transformed into an artefact that could be accurately defined and manufactured according to a technical model (cf. Ewenstein & Whyte, 2009). When the tool was given to the manufacturers in such a position, they were not invited to participate in its technological development. The contribution of these partners to the product development would have required more knowledge of the properties of the hybrid package and the requirements of the production infrastructure, which the partners gained later as their collaboration with Fipak continued. Nevertheless, even as an unproblematic primary artefact, the moulding tool contributed to the development of the hybrid package: Because its design could be defined, the func-

tioning of the manufactured tool could be compared with the planned properties. Making comparisons between a model and the outcomes of experiments is a key feature of experimental research in both science and technology development (Rheinberger, 1997).

Hence, boundary objects shaped the development process of the hybrid package in four ways. First, boundary objects attracted partners to join the collaboration by generating expectations and shaped the innovation process by engaging new partners whose competences were crucial to advance the development of the hybrid package. Second, boundary objects facilitated both autonomous, within-community and collaborative, cross-community experimental work. Third, boundary objects enabled the transfer of work tasks between people without direct communication between the individuals when the artefacts themselves contained the documentation of the work. Fourth, boundary objects transformed the course of action in the process through resistance by causing surprises and setbacks.

My analysis of the collaborative development work in the innovation process suggests that the roles that artefacts play emerge in practical activity. Many studies have defined characteristics of boundary objects (Levina & Vaast, 2005). However, the roles artefacts play do not derive from some assumed characteristics but rather emerge in collaborative work practice (Nicolini et al., 2012). It is the work people do together, the interests they pursue and the means they develop to accomplish the work that give meaning to the relationships between people and artefacts in the work context; work practices structure the collaboration (Star, 2010).

The analysis also shows that artefacts evolve during the different phases of the development process. The moulding tool developed stepwise through new designs and the experiments carried out with them: First it was not clear whether such a tool could be developed, and then the Prototype mould was created. The Prototype mould was later used as a model for the design of the Pilot mould for the customer's package. This kind of temporal evolution of artefacts due to the interplay of experiments with earlier forms of the artefact requires further exploration and analytical tools. I will focus on the temporal nature of boundary objects in the next analysis chapter to explore how the functions of boundary objects transition over the course of a product development process (Ewenstein & Whyte, 2009; Nicolini et al., 2012).

6. The experimental nature of product development and the shifting functions of boundary objects

The analysis of the innovation process of the hybrid package demonstrated the importance of the development of a set of artefacts to the emergence of the innovation. The development process of the new package appeared as a series of experiments where human actors studied the behaviour of the artefacts. Instruments, models and other artefacts are central to the experimental nature of scientific work (Rheinberger, 1997). According to cultural–historical activity theory, forms of activity develop in relation to the means that mediate the activity: Cultural artefacts carry norms and purposes of use (Miettinen, 1998, 2006). Thus, the outcomes of experiments can be communicated to other individuals by using cultural artefacts. These artefacts may therefore be used as resources in problematic situations faced by individuals or groups in the definition of a problem, the formulation and testing of a hypothesis and the evaluation of the outcomes of the inquiry. Different artefacts may be used as intermediary representations of the product under development (Vinck & Jeantet, 1995); the representations needed may change as the development process advances.

In this chapter, I analyse the development process of a hybrid package for a new customer, which began soon after the launch of the first commercial package to the market. The process proceeded through experiments, which produced intermediary instantiations of the package that could be compared with the customer's requirements and experience gained in earlier product development projects. A great number of artefacts participated in the development process in its different phases: Some artefacts were used only in particular development practices, while other artefacts played a central role throughout the process.

We studied the phases of the development process by observing the work practices. I examine the data describing the development practices to explore *how boundary objects transformed during the product development process.* To identify the transformations, I analyse the data based on two sub-questions: (1) *What kinds of mediating functions do boundary objects perform in product development practices during the process?* and (2) *How do the functions of the boundary objects evolve during the process?*

6.1   Research design

The analysis focuses on one of Fipak's product development projects that we followed from its beginning to study the work practices in different phases of the development process. I call this the Module project according to its object of development, a module package, because Fipak's development team used its module name, which referred to a package standard. We had previously agreed with the Fipak development team that our research group would follow a new product development project when one began. In December 2009, we received an email from Fipak's sales manager, who stated that they now had a new product in sight and invited us to "shadow" the kick-off meeting of the team. Our research group was very excited about this opportunity, which enabled us to observe practices both within the Fipak development team and between representatives of Fipak and some of their partners.

Fipak's team was working on several product development projects at the same time, and the members of the team were engaged in the various projects from time to time. This meant that the development work of the Module package did not take place every day. Therefore, we decided to follow the project by observing central events in the product development process. In the identification of central events, we relied on the representatives of Fipak, because we had only a preliminary understanding of the unfolding of the process. Because we could not observe all the occasions when the new product was worked on in some form,[19] the data may give a limited view of the more mundane aspects of the work required in developing new products.

The observed events represented the different phases of Fipak's development process of a new product, which included the design and production of the components necessary for its manufacture; a simplified model of the process is depicted in Figure 11. The process began with negotiations with a customer: The requirements of the customer's end product and production lines were discussed to preliminarily determine the design of the package and estimate its production costs. If the customer decided to order the package, the process proceeded to product design, which defined the form of the package and the materials required for its production according to the customer's requirements, resulting in a 3D model of the package. After this, the design and production of the moulding tool and the paperboard blank took place in their own processes in collaboration with network partners, until they were brought together in the iterative trial runs. In the trial runs, the functioning of the moulding tool and the correctness of the size and shape of the paperboard blank were tested by producing test packages with the manufacturing equipment. When corrections were needed, the tool was taken back to the manufacturer for modifications, and modified paperboard blanks were ordered. When the appearance of the package was satisfactory, sample packages were tested for air-tightness and other functionalities, and corrections to manufacturing parameters were made. When the

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[19] Because our research group was conducting research in two companies at the same time, continuous observation of development practices in both companies was not possible. Furthermore, geographical distance and travel costs limited the time we could spend in each company.

customer had tested and accepted the package, the process proceeded to pro-
duction runs and the delivery of packages to the customer.
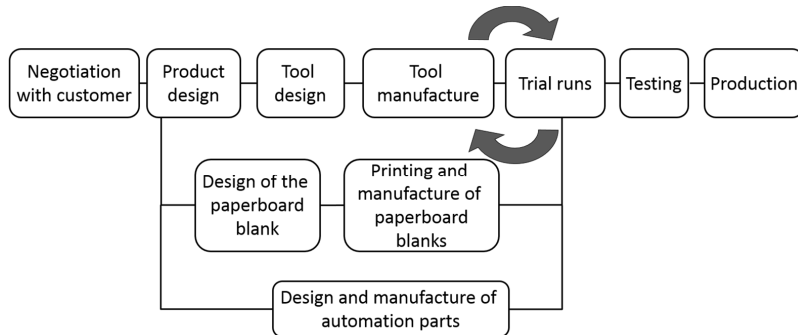
Figure 11. The production process of the hybrid package (adapted from the depiction used in Fipak in autumn 2009).

Table 8 lists the observed events that represent the phases of Fipak's develop-
ment process; the "testing" phase was included in the trial runs and production
runs in the projects we studied. Some of the studied events – the second trial
runs and the production runs – did not belong to the Module development pro-
cess but to two other projects: The Food project and the Customer project, which
were taking place at the same time. I use these project names because the Fipak
team referred to the product development projects either with the targeted end
use of the package or with the name of the customer. Our participation in the
events depended on an invitation by the members Fipak team, but they had dif-
ficulty in predicting the timing of the trial runs, which sometimes started earlier
than expected. Therefore, we agreed to gather complementary data by observing
other ongoing projects in order to understand the practices better. The observa-
tions started in December 2009, when a customer had decided to order the
Module package from Fipak, and they ended at the beginning of the develop-
ment phase of the LPC project in August 2010. The Module project did not pro-
ceed to a production phase during this time, and therefore we observed the pro-
duction runs of the Customer project. Figure 12 locates the studied projects on
the timeline of the innovation process.

I analyse the data of these events to examine the artefact-oriented practices in
Fipak's development process. The analysis is based on the field notes and the
transcriptions of recordings from these events. During the observation, we did
not participate in the activities but rather were mostly present as listeners and
note-takers. The observed activities required education and work experience
that we did not possess, which hindered us from becoming skilful participants.
When we observed meetings, we did not intervene in the discussions unless the
other participants spoke directly to us. When we observed activities on the fac-
tory floor, we questioned the participants about their actions and the artefacts
they were working with. We recorded the meetings in which we participated as

well as the majority of the trial runs and the production runs. In the first trial runs, recording was not possible on the factory floor due to noise.

Table 8. Data on work practices in Fipak's product development process.

Studied project	Development phase in the process	Studied events	Methods and data	Timing of the data collection
Module project	Negotiation about the project	A kick-off meeting	Observation Transcription and field notes	December 2009
	Product design	The work of the product designer	Interview Transcription and field notes	February 2010
	Tool design	A meeting with a new partner	Observation Transcription and field notes	December 2009
	Tool manufacture	A meeting with a manufacturer	Observation Transcription	March 2010
	Trial runs 1	A meeting setting the goals for the trial runs The first trial runs with the tool	Observation Field notes and transcription Documentation	March 2010
Food project	Trial runs 2	The third round of trial runs with the modified tool and different sizes of paperboard blanks Two meetings dis-cussing the goals and outcomes of the trial runs	Observation Transcription and field notes	February 2010
Customer project	Production runs	Production runs to deliver packages to the customer	Observation Transcription and field notes	August 2010
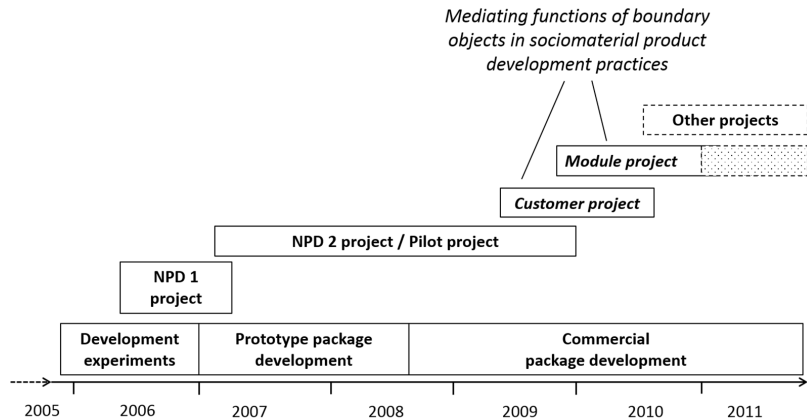
Figure 12. The location of the projects analysed for the identification of mediating functions on the timeline of the innovation process.

The analysis process had three phases. First, I coded the data to identify the artefacts that were used in the events and the human participants of the practices. I used the same criteria as in the analysis for Chapter 5 to identify potential boundary objects: I searched for artefacts that were (a) constructed in collaboration or (b) used collaboratively between different communities. In the coding, I used the artefact codes that I had developed during the previous analyses and added new artefacts when I encountered them in the data. While I was coding the data, I came across artefacts that (c) human actors used in solitary work when carrying out their actions; I included these in my code list of potential boundary objects. I identified 64 artefacts as potential boundary object in these data. When I had concluded the first round of analysis, I wrote a narrative, chronological description of the unfolding of each event, describing the nature of activity and the participating actors and artefacts to describe the practices taking place in the events.

Second, I re-examined the artefact-related episodes that I had identified during the first round of analysis to investigate which artefacts mediated collaboration in the product development practices as boundary objects and which mediating functions these boundary objects performed. I used the preliminary typology of the mediating functions identified in the previous literature as the starting point for coding the artefact-related episodes as representing a certain function. During the analysis, I added functions to the typology when I encountered uses of artefacts that the previously identified functions did not seem to describe accurately. Furthermore, I did not encounter all the previously identified functions in the data and thus removed those from my analytical framework. Due to the added functions that appeared during the analysis, I returned to the events I had analysed first to see whether those functions were present in these events. The identification of mediating functions required the examination of situated

actions, which were sometimes short but could last for several minutes. Furthermore, these actions often included a number of different artefacts, which means that mediation was a distributed accomplishment of these artefacts. This round of analysis led to the rewriting of the event narratives, presented in sections 6.3–6.9, to bring the artefact-mediated actions to the foreground. I also added a discussion of the mediating functions after the description of the practices in each event. To illustrate the analysis process, I have included a coding example of one event – first trial runs of the Module project – which maps the identified boundary objects with their mediating functions (see Table 22 in Attachment 1). I discuss the identified mediating functions in section 6.10.

Third, I compared the boundary objects and their mediating functions across the phases of the product development process to trace changes in the functions. I searched for artefacts that performed as boundary objects in at least two events to compare the mediating functions they performed. I discuss the findings of this analysis in sections 6.11 and 6.12.

6.2 The typology of the mediating functions of boundary objects as an analytical framework

As described above, I refined the preliminary typology of the mediating functions identified in the previous literature (see Table 4 in section 3.4) during the analysis of the observation data. In the following event narratives and their analysis, I use the refined analytical framework, which includes 11 mediating functions. I describe the mediating functions in the order of their frequency in the data (Table 21 in Attachment 1 displays the frequency of the functions across the observed events).

Problem solving. In the analysis, I identified situations in which artefacts became the centre of attention because they were not functioning as expected. The artefacts thus represented problems in the actions that were carried out, and the problems called for changes in the practice. Problem solving often required the use and evaluation of several artefacts to detect the source of the problem and its solution. I identified 57 episodes in the data in which artefacts triggered problem solving.

Evaluation. In the analysis, I identified situations in which artefacts, such as sample packages produced in trial runs, were used for evaluation purposes. They served as representations that could be compared with the designed characteristics of the artefact in question. I identified 54 episodes in the data in which artefacts mediated evaluation.

Explanation. In the analysis, I identified situations in which artefacts were used to illustrate actions or principles guiding the actions to an actor from another community. These artefacts were used as means of translation to communicate concerns of one community to another. I identified 46 episodes in the data in which artefacts mediated explanation.

Communication. In the analysis, I identified situations in which artefacts were used to share information between participants. The artefacts functioned as representations of the issues and concerns that the actors wanted to communicate

to others. Communication has been identified as a key function of boundary objects and analysed in similar ways in the previous literature. I identified 33 episodes in the data in which artefacts mediated communication.

Anticipation. In the analysis, I identified situations in which artefacts were used to anticipate future actions and propose alternative ways of carrying out actions. Often the proposals stemmed from past experiences that were anticipated to recur in the project at hand. Sometimes the speculations also broadened the horizon of actions – for example, concerning the actions of the future users of the products to be designed. I identified 29 episodes in the data in which artefacts mediated anticipation.

Action. In the analysis, I identified situations in which artefacts and human actors collaborated – their actions were mutually interdependent. Often in these situations, single actors were carrying out actions through the manipulation of a system of artefacts, as observed in the trial runs and production runs. I identified 27 episodes in the data in which artefacts were collaborators in action.

Documentation. In the analysis, I identified situations in which artefacts, such as notebooks or computer files, were used to document the conditions and the outcomes of actions. Such documentation was meant for remembering how to carry out similar actions later or for collecting information on different alternatives for future decision making. I identified 26 episodes in the data in which artefacts were used for documentation.

Decision making. In the analysis, I identified situations in which artefacts were used for making decisions about further actions. Oftentimes in these episodes, a reference to the artefact triggered a discussion about the actions in the artefact's development process until the participant made a decision, which often included the scheduling of actions. I identified 18 episodes in the data in which artefacts mediated decision making.

Delegation. In the analysis, I identified situations in which (1) artefacts delegated actions to humans by requiring them to act in a certain way – for example, to ensure the functioning of the equipment in trial runs or production runs – and (2) humans delegated actions to artefacts – for example, by increasing the level of automation in the production to reduce human work. The majority of episodes that I identified in the data corresponded to the second mode of delegation; altogether I found 13 episodes of delegation.

Organisation. In the analysis, I identified situations in which artefacts affected the division of work between human actors and communities. They thus organised the way actions were carried out to reach the pursued objectives. I identified nine episodes in the data in which artefacts took part in the organisation of work.

Standardisation. In the analysis, I identified situations in which artefacts were used to routinize certain actions: The standardisation determined the way these actions were carried out. However, I identified only two episodes representing the standardisation function.

In the following analysis, I narrate the unfolding of the events with a focus on episodes in which artefacts played a mediating function. In addition to identifying the function that the artefact performed in the episode, I characterise the

artefacts to see whether particular kinds of artefacts are more prone to play particular roles. I categorise the form of the artefacts between verbal – meaning there was no observable representation of the boundary object in the episode, visual – a visually observable representation – and physical – a tangible representation. I categorise the manipulability of the artefacts as dimensions varying between open – allowing different interpretations and actions, intermediate – preliminary determined meaning and actions – and closed – determined meaning and actions.

6.3 Event 1: Kick-off meeting of the Module project

To understand what issues were important when starting a new product development project, we participated in the kick-off meeting, where members of Fipak's development team discussed the Module project together for the first time.[20] Negotiations with the potential customer had lasted a couple of months and now the customer, whom I call Customer 2, had decided to order a hybrid package from Fipak. The participants of the meeting included Fipak's sales manager Janne, technical manager Erja, product designer Niina, tool designer Markku, development engineer Tommi and production engineer Risto. I was observing the meeting together with my colleague Anneli. The meeting took an hour and it centred on the package to be developed and the customer's requirements. The team also planned the timing of the development phases and made decisions regarding the division of work within the team and with their partners.

6.3.1 Speculating about the requirements of a hypothetical standard package

In the kick-off meeting, interactions centre on topics defined by a project status document about the properties of the package and the phases of its development process which Janne is filling in with his laptop during the meeting. The document, which is projected on the wall most of the time, includes a list of material artefacts required for the design and production of the package: 3D print, mould, paperboard blanks, die cutting tools, tools for automation, etc.

In the meeting, many of the participants seem to know only little about the Module project because they ask Janne about the end use of the package. Janne tells them about the customer and their food products; Risto enquires about the anticipated production volumes and Janne answers that they are quite small but the package can be used by other customers as well. Niina ponders how the customer's products look like and whether she has seen them in shops. Janne tells that the Module package is to replace a plastic package that the Customer 2 is currently using. However, the new package cannot be an exact copy of the former package, because its dimensions need to be adjusted to Fipak's manufacturing technology.

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[20] This was the first ever kick-off meeting of a beginning product development project; such meetings were planned to become a common practice for all projects in Fipak.

Niina has made a preliminary 3D model of the package, but its measurements are still unclear; it is not certain whether the designed package will fit the customer's packing lines because documentation of the production lines is not available. Niina and Markku have visited the customer's production line to find out the critical measurements of the line but they were not able to measure all details. Together with Janne they recall how the packages were handled in the customer's production. To make sure that the hybrid package will be designed correctly, the team decides to make a rapid model of the package with 3D printing, to be physically tested on the packing line. Because the team want to test the fit of the package, they state that the outside measures of the rapid model need to be correct.[21] Later the participants return to the rapid model: Janne wonders whether the thin plastic model can withstand the testing on the packing line and the participants speculate if it is better to have a harder or more flexible model.

> *Sales manager: Or would it help to make it with thicker material, to add it inwards?*
>
> *Product designer: Yes, surely it helps to have the structure less fragile.*
>
> *Tool designer: On the other hand that kind of stringy fragile structure is more elastic when it's not very strong, it becomes just the opposite.*
>
> *Product designer: It would be good to have it [the rapid model] close to correct measurements because somebody will want to try out the internal volume anyway.*

One topic of the team's discussion is the behaviour of consumers: The team members speculate how consumers would use the package and whether this would influence the requirements of the package. Consumer studies were not part of Fipak's development process; in the Pilot project such studies had been the customer's responsibility. Still, the team members try to anticipate how consumers would use the packages and how this could be taken into account in the design and production of the Module package. The team members tell how their family handles the kind of food that would be packed in the new package and estimate how the package would withstand that kind of use. They also refer to earlier experiments with other kinds of foods and packages that they have carried out at home.

Along the meeting, the team members bring up issues concerning the different phases of the development process. They decide to outsource the design of the mould for the Module package, because Markku has enough work with the iterative development of several moulds in the ongoing projects. This outsourcing means collaboration with a new partner, an engineering company that has worked with two of the three tool manufacturers Fipak is currently using. Markku suggests that tenders for tool manufacturing will be asked from these two as the third one is already manufacturing moulds for other projects. The

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[21] Rapid models are made with 3D printing by adding thin layers of plastic material; this means that either the inside or outside measures of the model will be exact. Therefore the team needed to decide, which measures were more important for their testing.

team agrees to invite people from the Engineering Company for a visit to provide them with background information of Fipak's production process to support the tool design. Niina asks Janne to discuss the graphical design of the package with the customer because the preliminary design which Janne has seen suggests that the printing of the chosen colours require careful design.

At the end of the meeting, Janne goes through the "action points" of the project. These include the rapid model, the meeting with the Engineering Office, the call for tenders to the two tool manufacturers and the inquiry about the graphical design of the package to the Customer 2.

6.3.2 Analysis of the functions of the boundary objects

Even though the picture of the 3D model was the only visual representation of the Module package and it was available only for a short while, the package was clearly at the centre of interaction in the meeting. At this point, the package was only loosely defined by the requirements of the customer's end product and production process; its definite shape needed to be determined during product design (see Table 9). The Module package appeared as a boundary object in the anticipation function: its development would require the contribution of all the participants and of many other actors, while its material definition would occur only later in the process. Compared to other packages under development in Fipak, the Module represented a new kind of commercial product, a package of an existing standard size that could be offered to new customers in future. This expectation was reflected in the way the team referred to the package: Whereas the development team called other packages either with the name of the customer or the end product the package would be used for, this one was called with its module name.

While the interaction characterises the infusion of material artefacts in Fipak's product development practices and the way they structured the organisation of the development process, these artefacts were mainly present in the talk of the participants. Only two artefacts, an excel document of the project and a picture of the preliminary 3D model, were visually present. They were both temporary representations of the project, used to communicate the requirements of the package. The project status document, which was on display at times during the meeting, prompted discussion about the coming phases of the development process and the tasks included in the phases. The document also served as the documentation of the decisions made concerning the tasks, but the timetable that was discussed in the meeting only reached until the phase of trial runs.

Because the Module package was going to replace an existing package and needed to fit the customer's packing lines, the measurements of the package appeared as a central concern in the meeting. This concern was emphasised due to lack of documentation of the customer's packing line, which meant that the exact measurements were still uncertain. The team members anticipated possible factors, which could influence the measurements. To determine the correct measurements of the package, a decision was made to order a rapid model to test its fit on the customer's production lines. The rapid model was planned to

represent the measurements so that they could be evaluated against the production line.

Table 9. Mediating functions of central boundary objects in the kick-off meeting.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
Module package	Open Verbal	Speculating its fit with the customer's production requirements, consumers' ways of using it and its meaning as a standard product	Communication Anticipation
Picture of a 3D model of the package	Intermediate, Visual	Discussing the shape and measurements of the package	Problem solving
Project status document	Intermediate Visual	Prompting discussion of the project's tasks and documenting the decisions	Decision making Documentation
Measurements of the Module package	Intermediate Verbal, visual	Speculating the correct measurements to fit the customer's production line	Anticipation Problem solving
Rapid model	Intermediate Verbal	Ensuring the fit of the designed package with the customer's production lines	Anticipation Problem solving

6.4   Event 2: The work of the product designer

To gain insights of the concerns in the product design phase of the Module project, I interviewed Fipak's product designer Niina about a month after the Module project had begun. Niina was not working in Fipak every day because she was about to change jobs; the tool designer Markku would take over product design. Niina told me about her work in the product and paperboard blank design for the Module project. We were sitting at her desk in the office she shared with Markku; to concretise the issues she had been dealing with, Niina showed to me computer files, paperboard blanks and sample packages she was referring to. A major concern in her work appeared to be the measurements of the designed packages, which could not be properly determined in the design phase.

6.4.1   Caring for the measurements of artefacts in product design

Niina was tracing the work she had done for the Module project according to the dates of the computer files in the project's folder. She had made a preliminary 3D model of the Module package a couple of months before the project started. This modelling was used to make cost and pricing calculations when offering the package to the Customer 2. After the customer had decided to order the new

package from Fipak, the product design began with the initial information about the package provided by a form, which Fipak salespersons filled in based on discussions with the customer. However, like in other product development projects, in which a hybrid package was developed for existing production lines, the customer could not provide adequate information of the lines that would ensure correct measurements. Therefore, the Fipak team had decided to order a rapid model of the Module package to test its measurements on the packing lines of Customer 2.

After the kick-off meeting, Markku had visited the customer's factory to test the rapid model on the production lines. The rapid model had broken in the experiment, possibly because the customer's operator had been handling it quite roughly. Niina had drawn a proper 3D model with CAD software, which the rapid model followed. After the field testing, she had made the 3D model (see Figure 13) a bit smaller to make sure it would fit the packing line. Furthermore, she used knowledge gained in the development of another hybrid package about tools that some customers used to transport packages on the production line to determine the dimensions of the Module package.

For the 3D model to be usable in the tool design, Niina needed to convert the model file into a standard format, because she and Markku used different software but needed to be able to modify each other's files. Markku had sent the 3D model to the Engineering Office for tool design. However, Niina and Markku had realised that they needed to change the package design once again because they had forgot to implement a change to the rim profile resulting from the behaviour of a similar package. They had postponed the tool design to make this change in their own system first and then Niina had sent the latest version of the 3D model to the Engineering Office; now Markku was coordinating the tool design and manufacture.

The picture of the paperboard blank (see Figure 14), which Niina had drawn with software for packaging design, was needed in the tool design to determine the positioning of the blanks in the moulding tool. Later on, the picture of the blank would be used in the printing and die cutting of the paperboard blanks. Niina told she had started to draw the blanks a bit smaller than the 3D model would suggest: experience had shown that the designed blanks were too big. Niina supposed this had something to do with the stretching of the paperboard in the mould. An important part of paperboard design was the modelling of creases on the corners of the paperboard blank (see Figure 14). Creases are patterns carved onto the paperboard which serve to shape it into the designed shape when it is moulded; this carving seemed to cause stretching. Niina told the sizing of the paperboard blank was a primary concern of the development team to avoid excessive experimental testing and many rounds of trial runs.

After finishing the 3D design and the paperboard design of the Module package, Niina was only involved in the project if these needed adjustments. However, she was still engaged with some of Fipak's own development projects, where the development team was experimenting with different kinds of shapes and sizes. Niina described: "Usually we've had the difficulty that we should push [packages] into sizes and shapes of existing products with this technology and

it isn't necessarily the ideal situation always." She continued that now that the team was working on many products for real customers they had obtained lots of information about the issues that influenced the behaviour of the packages in the production. Therefore it was possible to optimise the sizes of the paperboard blanks more correctly already in the design phase.
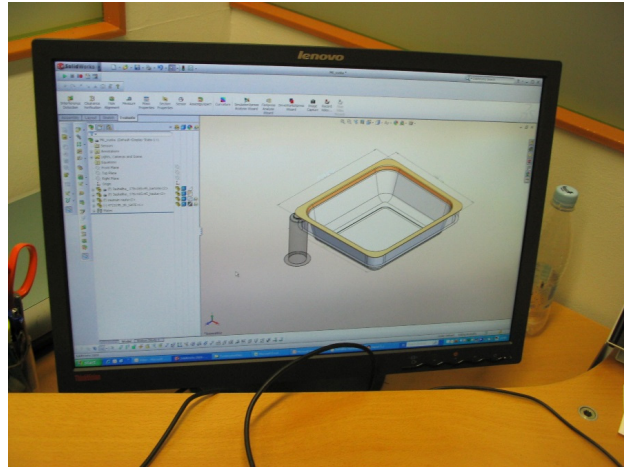
Figure 13. The 3D model of the Module package.
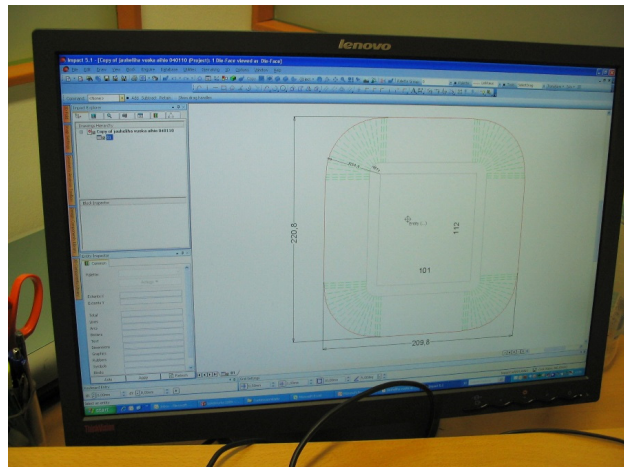
Figure 14. The design of the paperboard blank of the Module package.

Anticipating her leaving from Fipak, Niina had made general instructions for designing graphics for different shapes of packages to be used by customers' advertising agencies. In the preceding projects, Niina had taken care of the optimisation of the graphical design of the packages because the advertising agencies were not familiar with designing graphics for 3D shapes. Another concern for Niina was the printing of different colours on the paperboard material Fipak used: she had examined the printing Customer 2 was using on the current package to estimate possible problems with the printing of the Module package. She had experiences from the previous package projects that it was difficult to print some colours evenly on the blanks. She inquired the sales manager Janne about the graphical design of the Module package when we went for coffee with him. Janne had visited the customer a couple of days earlier and discussed also the graphical design with them; the design would be similar to the current package. Niina calculated the colours used in the current package and concluded that the printing should not cause problems.

6.4.2 Analysis of the functions of the boundary objects

The phase of product design was occupied with a multitude of artefacts – forms, models, drawings and software used for their creation, organisation and maintenance. The task of the product designer was to create representations of the Module package, which would determine not only the dimensions of the product but also the required amount and cost of materials for producing it. The contradiction of this design work was that the produced representations would probably be found inaccurate once the corresponding mould and paperboard blanks would be tested in trial runs. Even though the product design aimed to produce unequivocal models – to be reliably transferred by computer files and used in the production of the material components of the Module package – testing of those components usually resulted in the modification of the original representations. This iterative development of representations and material artefacts made the product development process uncertain, as its success could not be reliably estimated. This uncertainty embraced all the actors who participated in the process, including Fipak's customers and subcontractors.

The central boundary objects that came up in the interview with Fipak's product designer are listed in Table 10. The 3D model was the basis of the whole product development process: It was used already in the negotiation phase with the customer to communicate the future shape of the package. The product design needed to produce a closed artefact because the mould and the paperboard blanks were later designed and manufactured based on the shape and measurements determined by the model. Therefore the 3D model also organised the work among the participants of product design and tool design. In the design of the 3D model, the product designer used experience gathered from other product development projects to determine the measurements of the Module package as exactly as possible.

The rapid model that had been tested on the customer's production lines corresponded to the preliminary 3D model. Due to it breaking in the test, the product designer had adjusted the measurements of the model. Thus she used the

physical rapid model to evaluate the measurements represented by the visual 3D model. The picture of the paperboard blank was at an intermediary position during product design: It followed the measurements of the 3D model but the product designer expected that its dimensions would be changed according to the experiments in trial runs. The picture would communicate the dimensions and the creasing pattern of the Module package to the manufacturer of the paperboard blank.

Table 10. Mediating functions of central boundary objects in product design.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
3D model of the Module package	Open – closed Visual	Representation and shareable documentation of the customer's requirements as shape and measurements	Communication Organisation
Measurements of the Module package	Intermediate Visual	Using measurements of another package in the sizing of the 3D model to avoid possible problems with fitting the package to the customer's production lines	Anticipation Problem solving
Rapid model of the Module package	Closed Physical	Observing the behaviour of the model to determine the correct measurements of the package	Evaluation
Picture of the paperboard blank	Intermediate Visual	Representation and documentation of the package in 2D; to be modified based on experiments	Communication

6.5   Event 3: Meeting about tool design

I got a glimpse of the concerns in the phase of tool design by observing a meeting between Fipak's tool designer and two representatives of the Engineering Company, which had been chosen as the tool designer of the mould for the Module package. The meeting took place already the day following the kick-off meeting of the Module project. It seemed the managers of the Engineering Company were eager to collaborate with Fipak because they agreed to pay a visit on such a short notice; it required a four-hour drive to come to the meeting at ten o'clock in the morning. The meeting centred on familiarising the representatives of the Engineering Company with Fipak's manufacturing technology and on negotiating about the ways of collaboration.

6.5.1 Familiarising a new network partner with the manufacturing technology

In the morning Anneli and I arrive to Fipak at the same time with two men, who happen to be the manager and the project manager of the Engineering Company. Fipak's tool designer Markku welcomes us in the lobby and takes us to a meeting room located in the office part of the factory building. After introductions, Markku tells the men that Fipak needs to use external tool designers due to changes in the work organisation: the product designer Niina will change her job and therefore he needs to take charge of the product design. While Markku is talking, the men take notes in their notebooks. Markku describes his expectations towards the collaboration:

> Tool designer: I hope to get from everyone with whom we are cooperating good ideas for everything so that we won't go forward with only my ideas and copies. This kind of development and collaboration is welcomed (...) I'm not afraid of responsibility but it's nice to have someone to discuss in the same language, not too many have yet appeared in these circles. [The paper company] hasn't injected plastic at all until now (...) there's knowledge and expertise about paperboard and I've been trying to study that as well, it's as new for me as I guess it's for you. Now I already understand a little bit about it but I suppose I'll learn more on the way.

Then Markku brings the two men to the factory and we follow them. He first takes us to the equipment where production runs of Fipak's first commercial product, the Pilot package, are taking place; I cannot hear or record everything the men say because the machine is making noise. While they are observing the operation of the mould, Markku tells that the moulding tool the Engineering Company will design for the Module package – as well as other future packages – will follow a similar construction because the injection moulding equipment will be similar to this one. The three men discuss the functioning of the mould and the production equipment by referring to the artefacts they are observing.

Later Markku takes us to another equipment where two operators are carrying out trial runs: First we observe the operation of the mould. Markku points out the mould that is tested is similar to the one they saw in the production equipment, only the mould cavities, which give the packages their distinctive shape, differ between the moulds (see Figure 15 that shows an example mould).[22] The project manager of the Engineering Company pays attention to the fact that the mould is not coated; Markku tells that they carry out tests before the mould is coated in order to make sure the measurements are correct. He remarks that the design of the mould is still half mystery: "This shape has been sought for long and hard to find the correct geometries."

Then we go to the other side of the equipment, where the robot moves the paperboard blanks to the mould and brings the produced packages to the line. While the men are speaking, I observe the operators who are working to replace

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[22] The number of cavities determines the number of packages that the injection moulding machine produces each time. The moulds that Fipak was developing during our research collaboration typically had two cavities.

the paperboard blanks with new ones in the equipment. One of them is detaching the blanks from sheets of paperboard with gloves on: He is removing a bunch of blanks from several sheets at the same time. This manual work seems to require force: Some blanks and sheets tear and the operator puts the whole blanks in one pile and the torn ones in another. Then he places a pile of the detached blanks on two magazines located in the closet of the robot, which is attached to the machine. When he has closed the closet, both operators move to the other side of the equipment and start operating it. The robot begins to move: A pair of grippers goes down to pick up two paperboard blanks, brings them up and places them in the mould. Because the grippers are two-sided, they place the blanks on one side of the mould and remove the two ready packages from the other side with the same move.
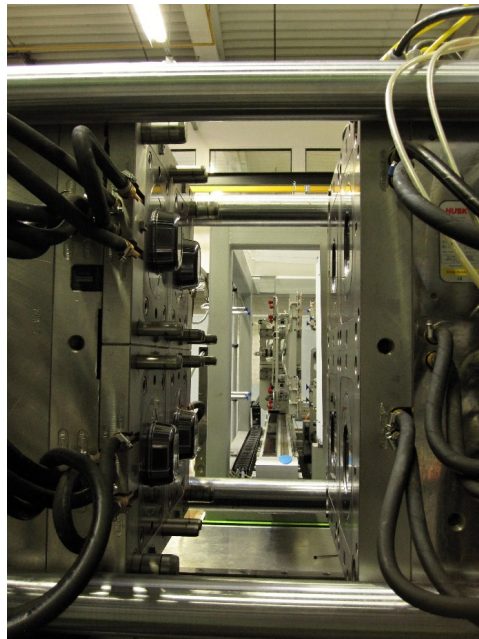
Figure 15. An example of a Fipak mould with four cavities.

Markku observes that there are some problems with the plastic rim of the packages produced in the trial runs; the rims are not whole. He uses an example package to explain the problem: The positioning of the paperboard blank in the mould is not optimal, which affects the injection of the plastic rim. He tells the men it takes great effort to find the proper size of the paperboard blank; the development team has tried to solve the positioning problem by making the robot adjustable:

> Tool designer: Clearly the paperboard blank does not position properly, it rises to the side of the cavity there. So in this design and making of the blank there's

> *always quite a snag to find the proper size. Because these corners tend to stretch*
> *more [than] these straight sides here. You can see there that if it goes down then*
> *here it starts to tear [...] That's why we've had to build these so-called control*
> *tables so that we can still adjust the positioning of the blank cavity-wise.*

The men from the Engineering Company wonder whether the correct size of the paperboard blank could be simulated with some software. Markku tells that theirs is the "hard way": The Fipak team makes a good estimate and orders a couple of different sizes of the blank, which are then tested to determine the proper size. When the shape of the package changes, the paperboard behaves in a different way; by testing the different sizes the team can make sure they end up with the accurate one. The men discuss how different shapes behave in the equipment. Markku concludes the 40-minute factory visit by stating that the men have now seen the results of the current phase of development.

After our return to the meeting room, Markku starts to discuss the relationship between Fipak, the Engineering Company and the tool manufacturers. He tells Fipak is looking for an independent tool designer, whose designs could be used by several manufacturers; at the moment they are working with three manufacturers, one of which provides also tool design. Markku describes their logic of subcontracting: "You can't keep too many and you can't keep one." The manager of the Engineering Company cautiously inquires about the prospects of their collaboration, how much work his company can expect to get. Markku tells Fipak is working with four new commercial products and he is designing some test moulds; he urges the men to make good groundwork which they can continue with. When the meeting has continued for about ten minutes, Fipak's technical manager Erja joins the meeting.

The meeting does not seem to have any formal agenda, but both Markku and the men from the Engineering Company bring up that they have prepared a list of issues they want to discuss. The talk seems to change from one topic to another quite haphazardly and then return back to an issue that has already been addressed. One of the topics which the participants keep returning to is the sharing of documentation between Fipak and the Engineering Company. The men from the Engineering Company inquire about the software used for product and tool design in Fipak; they discuss with Markku how to ensure the compatibility of the files between the companies when the designers are using different CAD software. They also talk about the files that tool design will produce to be used in the tool manufacture; the men from the Engineering Company ask to get some example files from Markku to use them as models. None of the participants has a computer, so the files they are talking about are not examined together. Later Erja notes she will need a picture of the mould in case she needs to order appropriate grippers for the robot; Markku advices the men which picture they need to send. Erja reminds that Markku needs to provide the tool designer a picture of the paperboard blank as well; Markku tells the men how a model of the blank can be used in the tool design to determine an important surface of the mould. He notes that the area of the blank is marked in the mould with polishing; it can be used in the trial runs for the correct positioning of the paperboard blank if done manually.

During the discussion, it comes up that the cooling of the mould is a current concern in Fipak, for which Markku hopes to get help from the collaboration with the Engineering Company. He inquires the men's experiences of cooling technology; Erja elaborates that currently Fipak's way of using the mould is unfavourable and therefore they would like to get more information about cooling and heating techniques for moulds. The men tell generally about considerations when using such techniques and inquire about Fipak's concerns in the development of the manufacturing technology. Erja and Markku tell that the unfavourable conditions of injection moulding materialise in the end use of the package if the package is heated in a microwave or oven; Fipak needs to find a compromise between the efficiency of the manufacturing and the quality of the packages. Markku returns to the cooling question later and illustrates the difficulties with mould design by referring to a sample package which the men brought from the factory. However, no concrete solution to the cooling question comes up in the meeting.

From time to time, the participants discuss the details of the tool design in the meeting. Markku states that the Engineering Company can use the construction of the Pilot mould as a basis for the design of the Module mould.[23] Erja reminds them about the standards of the heating part of the mould, which need to be taken account in the tool design. Markku continues that this means the attachment places of the parts: The tool designer can take them from the Pilot mould because they follow the manufacturer's standard. Markku tells that he will send the men a model file from which it is easy to start the design, including hints for design decisions for the Module mould.

> Tool designer: Actually if we agree, I can send a model with two parts and then a model that is kind of your tool, that is the rim and the paperboard are already united there, because you need both parts for the cavity construction. Then it's clearer to start off with one whole solid [3D file for mechanical design].

> Manager of the Engineering Company: Yes. And then we'll learn that connection there too.

> Tool designer: And I'll try to advise as to where the injections could be placed in the product [the mould], because you need to decide them already in the product design phase, from where to take the space for the nozzle and how the rim will be formed.

Markku also tells the men about the phase of the Module project: Fipak is making a 3D print of the package and he is going to visit the customer to check the dimensions of the packing lines. He notes that the provider of the packing lines does not give any pictures of the equipment, which complicates the design process in Fipak. When talking about the trial runs, Erja and Markku bring up a wish that somebody from the Engineering Company would come to see the mould being tested; they could also have a feedback discussion at the same time. The men from the Engineering Company agree and inquire if the tool manufac-

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[23] Here, the Pilot mould refers to the two-cavity production mould of the Pilot package.

turer also takes part in the trial runs; Markku says they aim to have a representative from the manufacturer present. When discussing the delivery of the tool design, the men suggest to Markku that they could arrange a review meeting by using software for virtual meetings. Markku thinks it would be better to have the first review face-to-face and arrange virtual reviews in subsequent commissions.

Markku concludes the meeting by stating that they are not supposed to design the mould in this meeting, more details will follow. The meeting has taken over an hour and Markku proposes a lunch in the factory cafeteria.

6.5.2 Analysis of the functions of the boundary objects

Even though the assignment of the Engineering Company was to design a moulding tool for the Module package, the package or its end use was not discussed in the meeting with the company representatives. The interaction centred on the properties of the mould and the requirements of the manufacturing method in Fipak. There was no representation of the Module package itself in the meeting, but in the factory the men were introduced to the manufacturing technology of Fipak as well as to some of the concerns associated with the behaviour of the moulds and paperboard and plastic materials in the manufacturing equipment.

To familiarise the new partners with the technology in whose design they would be involved, Fipak's tool designer pointed to the functioning of the moulds and the equipment that the men could observe and make sense together in the factory, using them as representations to illustrate the important issues (see Table 11). However, he used the Pilot mould and the production equipment merely to explain the properties of the manufacturing technology; these artefacts were not open for collaboration. Furthermore, he used sample packages to demonstrate the problems with the behaviour of artefacts that Fipak has faced. Instead, when observing the functioning of the mould in trial runs and the sample packages produced, the tool designer invited the representatives of the new partner to contribute to the resolution of the problems with the technology and inquired alternative solutions from them. The developed solutions would not affect the artefacts at hand but possibly future moulds and packages. The representatives of the Engineering Company were experts of the same field as the tool designer and they were able to identify differences between the artefacts they were observing and others with which they had earlier experience. Through this engagement, the new partners were confided some aspects of Fipak's production concept, for example the importance of experimentation in the determination of the final design of the package.

When discussing the work related to the design of the Module mould in the Engineering Company, the participants referred to CAD files of previous moulds that could be used as models for the design. The files can communicate the design decisions inherent in the mould concept and exemplify the information that the tool design needed to produce for the tool manufacture; the CAD files and the parts list served as the documentation of tool design while they also organised the work tasks. The participants agreed that the design of the Pilot mould

would serve as a model for the Module mould design. Interestingly, the moulding tool concept appeared to be open for suggestions at times while closed at other points of the conversation. On one hand, the tool designer emphasised his wish that collaboration in the tool design would produce suggestions for developing the mould technology. On the other hand, he talked of the design assignment as if it was a very simple task, because the basic mould construction already existed and the design of the Pilot mould was available as a model. Thus the Module mould to be designed did not appear as an open and negotiable artefact in the meeting; it had quite clearly defined boundaries. At the same time, the tool designer was outlining the Engineering Office a prospect where their engagement in the design of this mould would lead to a continuous collaboration between them and Fipak.

Table 11. Mediating functions of central boundary objects in the meeting about tool design.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
Pilot mould in production runs	Closed Physical	Representation of Fipak's mould concept	Explanation
Production equipment	Closed Physical	Representation of Fipak's manufacturing method	Communication Explanation
Mould in trial runs	Intermediate Physical	Discussion of Fipak's challenges with the manufacturing method	Explanation Problem solving
Sample packages in trial runs	Intermediate Physical	Representation of Fipak's challenges with the manufacturing method	Explanation Evaluation
CAD files and parts list	Closed Verbal	Representation of the moulding tool concept, documentation of the future tool design and organisation of the work	Communication Documentation Organisation
Moulding tool concept	Open - closed Verbal	Discussion of alternative solutions to cooling and heating the moulds	Communication Explanation Problem solving

6.6   Event 4: Meeting with the tool manufacturers

The primary source of data for the phase of tool manufacture was a meeting between Fipak's tool designer Markku and representatives of the manufacturer of the Module mould. Additionally, tool manufacture was addressed in various conversations, which we observed and sometimes also participated in when studying the Module project. During my visit to interview the product designer Niina, I met almost the whole development team in Fipak and learnt how the Module project was progressing. The sales manager Janne had visited the Cus-

tomer 2 a couple of days earlier to discuss the timetable of the project. The Engineering Office had just finished the tool design and the tool designer Markku had reviewed the design with them in a virtual meeting; the design had gone well. The next phases of the Module project had to do with the manufacture of the mould and the paperboard blanks. Fipak had selected Tool Manufacturer 4 as the producer of the Module mould. Markku had visited the manufacturer a couple of days earlier and they had proposed some adjustments to the mould, which the Engineering Office had added to the design. Meanwhile, Markku had made specifications for the injection part of the mould, which had been ordered from Tool Manufacturer 5 to be delivered to the Tool Manufacturer 4 for assembly.

The meeting at the Tool Manufacturer 4 took place about three months after the Module project had begun at the instigation of the manager of the manufacturer. The aim of the meeting was to review the Module mould together before it would proceed to assembly. The participants included Markku, the manager, the foreman of the production and three workers from different production phases. Anneli from our research group travelled to the manufacturer to observe the meeting;[24] the description is based on the transcribed recording of the meeting discussion.

6.6.1 Examining the moulding tool with the tool manufacturers

In the meeting, the participants discussed the design and manufacture of two moulds: One which was currently tested in trial runs in Fipak and the Module mould, which was going to proceed to assembly at the manufacturer. The meeting had no formal agenda, but first the men started discussing the experiences with the mould which was in trial runs in Fipak (this mould was nameless in the meeting); later they fetched documentation of the Module mould (to which Markku referred with its module name) and discussed what the workers would need to take into account in its manufacture. The interaction centred on problems the workers had encountered with the mould manufacture; the men tried to solve them by discussing alternative design solutions and manufacturing methods. Oftentimes they could not develop a solution to the problems because an alternative design could compromise other properties of the mould. During the discussion, Markku explained the complexities of Fipak's manufacturing technology and other requirements, including properties of the hybrid package, which needed to be taken into account in the tool design and manufacture.

When Markku and Anneli arrived, the manager of the Tool Manufacturer 4 received them. While they were waiting for the rest of the participants, Markku and the manager started discussing the ongoing trial runs in Fipak with the mould which the Tool Manufacturer 4 had produced. Markku had brought sample packages made with this mould and he used them to point out problems which had been solved and others which were still to be tackled. When the other men arrived, the manager introduced them to Markku. The manager told the

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[24] The appointed meeting day coincided with a two-day analysis seminar of our research group and we were invited to participate on a couple of days notice. Attending the meeting required two days of travel: Anneli left the previous afternoon to participate in the meeting the next morning.

employees they were going to discuss the problems encountered in Fipak (with the nameless mould in trial runs) and possible suggestions for improvement in order to deepen the collaboration. Markku continued that the purpose was to "take into account everything that eases the making of the tool, we'll make all necessary things already in the starting design if we can."

Markku had brought with him parts of the nameless mould to be made more round; the manager promised they would do that during his visit. Markku told the problem was that the surface the paperboard blank touched when entering into the mould tended to peel off the printed colour from the blank. Markku said the measurements could be doubled to make the parts more round; the worker who had manufactured the parts remarked that he would have done it already in the first place. Markku admitted the design of the parts was a compromise; it had to do with the handling of the package on the production lines of customers of which he did not have precise information. Unlike the Module mould, the nameless mould was not designed for a certain customer – it was Fipak's own development project to create a package that many different customers could use.

Between the discussions on problems, the manager pointed out that Markku had brought up how the package had improved; Markku told the workers the rim was very good due to changes in the mould. He had brought two kinds of sample packages with him: good ones with a smooth rim and worse ones with a rougher rim. Markku prompted the participants to touch the rim to feel the difference (see Figure 16); he explained that the smoothness of the rim was very important because the package was sealed with a very thin plastic film, which easily broke if the surface of the package was even a bit rough.

Figure 16. The tool manufacturers examining sample packages.

The discussion proceeded to other technical problems with the mould; one of the workers pointed out manufacturing and assembly problems with a certain part of the mould. He suggested the part could be made of a different shape

which would make it easier to attach to the mould. The manager and Markku remarked that the current shape had other strengths. Markku stated that this suggestion belonged to the kinds of issues that could be taken into account in the future development of the moulding tool concept. He noted that the design followed the needs of certain customers; he would rather have left it out because it caused troubles in the manufacture of the mould.

The manager asked the workers if they had faced other serious problems in the manufacturing of the nameless mould. The workers discussed the mounting problems of one part but noted that adding some screws helped it; Markku pointed out that in the Module mould there would be additional fastenings. Furthermore, one of the workers noted the mould was very complicated to assembly; it had to be done in a certain order and therefore required diligence. Markku acknowledged the assembly was difficult – the design was affected by restrictions that a key part of the mould set to the manufacture. The worker continued that the placement of the hoses for compressed air was very complicated in the current design; he suggested them to be placed in a different way between the plates. Markku recalled that the hoses would be placed a bit differently in the Module mould. The worker added that they had faced a problem with the measurements of the surface plates that were on top of each other. They had had to grind all the plates again even though they were within the required tolerances; because the tolerances of the plates had multiplied, other dimensionings did not hold any more. The manager stated that there was no other way than to have each of them properly fit with each other.

> Worker: See here, this plate, we had to redo everything in the machining, mill it again, because there was plus one hundred so all these immersions had to be machined again, because errors get multiplied there very fast, there are many plates inside each other here.

After the participants had discussed the nameless mould for almost 40 minutes, the manager suggested going through the pictures of the Module mould to check the tolerances; he asked the foreman to fetch the documentation of the critical parts. Meanwhile, one of the workers inquired Markku how the compressed air circulated in the mould and Markku explained to him by referring to the documents. He told Fipak was getting a new machine where the water hoses would be on the operator's side because the automation was located on the other side of the equipment. The worker continued and asked about the screws of a part of the mould; he noted that the screws were usually of different measurements. Markku told him the measurement was not a precise one, the main thing was that the screws were of the same length.

When the foreman came with the pictures of the Module mould, the men spread them on the table and started going through the tolerances of critical parts of the mould. The documents they examined were mechanical drawings of the different parts of the mould: They were projections of the shapes and included measurement information. While they discussed, Markku explained how the conditions of Fipak's production affected the requirements of the mould

manufacture: Due to the plastic materials they used, the optimal "process window" of the manufacturing technology was narrow. The men from the Tool Manufacturer 4 compared Markku's descriptions with their experiences with other moulds. One of the workers suggested wire cutting of some parts instead of machining them to improve the precision of shapes; especially spare parts for Fipak's mould would be better to be manufactured with wire cutting because it was a more precise method. The others doubted the change of method and brought up potential problems with it; the worker insisted on trying the method because the spare parts of the nameless mould had had many faults. The manager argued the problems were related to the lacking mounting of the parts; he believed the problem would be solved with the better fastening that was included in the design of the Module mould. Markku acknowledged that the current solution could be further improved and required more pondering. The worker suggested making a test by wire cutting the same material to see how the method would work; the manager reminded that such testing would take 30 to 40 hours. The manager concluded that in this case they would still use machining. Another worker suggested they could manufacture two parts at the same time so that a spare part would be available; both Markku and the manager thought it was a good idea. Later on, a worker suggested that the manufacture of another part of the mould would also benefit from changing the method from machining to wire cutting: the quality of the surface would be better and they could avoid small measurement mistakes. Markku agreed there could be benefits but the manager stated they needed to consider the longer manufacturing time the method required as well.

The participants continued going through the drawings and while they were inspecting the documents, they made remarks on issues to be noticed. Once a worker even praised a new solution in the tool design, which could straighten possible twists in a part of the Module mould. Otherwise the workers' observations concerned problems or suggestions for improvement. One of the workers suggested machining one of the plates thinner to improve the functioning of the mould; Markku first thought it was a good idea but the manager suspected that the change could make the plate distort and suggested adding washers to the part as a cheaper solution. Both the worker and Markku questioned the use of washers; the worker told they easily loosened and required maintenance. Markku concluded the issue required further attention.

One concern of the workers was the polishing of the surface of the mould. One of them asked Markku whether they should leave some allowance for the polishing when machining the cavity and Markku instructed him not to leave the allowance; the clearance between the cavity and the core was very precise in the manufacture of the hybrid packages. Another worker inquired Markku whether the need for the surface was functional – Markku and the manager told polishing aimed to decrease the friction of the surface to make the paperboard slide on it. The worker suggested they could use shot blasting for polishing, which would make the surface very slick. Markku agreed they could test the polishing method for a previous mould.[25]

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[25] He referred to the first Pilot mould with one cavity, which was not in use any more.

> *Tool designer: Yes, we'd be glad if something like that can be found. The polishing really isn't any need for the product's properties but only for the functioning.*
>
> *Worker: That shot blasting also condenses the surface a bit. Then if it goes to coating I think the surface will be quite greasy [makes a laugh] that nothing really sticks on it.*

While the men were discussing the design and manufacture alternatives of the two moulds, they returned to the sample packages from time to time. The workers inquired about the end use of the packages and Markku told for what kind of use each was designed. One of the workers asked if the package withstood soup and Markku replied it could even be heated in an oven for half an hour; the workers made jokes about warming the package in a stove. Markku told Fipak was producing both ovenproof and microwave safe packages by using different plastic materials. The manager asked whether those products were already on the market and when Markku told they had not been launched yet, he stated the sample packages would be put "under the shelf" in the factory.

Markku had also brought sample paperboard blanks; he told they still had a lot of "training" to do with the blanks, because yet no one had studied what creasing patterns were optimal for those kinds of packages. The manager told the workers how the creases were carved on the paperboard and Markku continued that the height of the creases was important for the proper shaping of the package. The manager knew how Fipak's competitor was manufacturing similar packages and he compared the method with the one Fipak was using. The men compared the behaviour of paperboard with metal in moulding and concluded that metal was easier to work with; Markku told the fibre length of paperboard limited its shaping.

The meeting ended without concluding how the discussed issues would be taken into account in subsequent tool design; the workers returned to their work and the manager took Markku and Anneli for a factory visit. During their drive back, Markku only briefly commented the meeting to Anneli: He thought the workers' suggestions for improvement were not significant in the development of the moulding tool concept.

6.6.2 Analysis of the functions of the boundary objects

In this meeting, the two moulds – the nameless mould, which the Tool Manufacturer 4 had produced and which was in trial runs in Fipak, and the Module mould, which was currently under production – were clearly the object of all interactions. Technical details of the two moulds were often discussed without making reference to visual or physical representations; comprehensive documents of either mould were not present. Despite the lack of visual representations, the participants were able to discuss the design and the manufacturing methods of many parts of the mould (see Table 12).

This problem-based interaction mostly followed a similar pattern: First the workers explained a problem and the way it affected their work, then they proposed alternative design or manufacturing solutions, which the manager of the

tool manufacturer and Fipak's tool designer reacted to. In most cases, the discussion revealed new contingencies such as other parts of the mould or conditions of Fipak's manufacture, which compromised the solutions proposed by the workers. In this way, the participants of the meeting negotiated about the optimal properties and functioning of the mould and explained their concerns.

Table 12. Mediating functions of central boundary objects in the meeting with the manufacturers.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
Parts of the nameless mould	Intermediate Verbal, visual	Discussion about the optimal design and manufacturing methods of the mould; Explanation of Fipak's manufacturing requirements	Problem solving Explanation
Parts of the Module mould	Intermediate Verbal, visual	Discussion about the optimal design and manufacturing methods of the mould; Explanation of Fipak's manufacturing requirements	Problem solving Explanation Anticipation
Sample packages	Closed Physical	Representation of Fipak's quality requirements Representation of Fipak's challenges with the manufacturing method	Explanation Evaluation
Mechanical drawings of the Module mould	Intermediate Visual, symbolic	Representation of the manufacturing requirements of the mould; Construction of shared understanding about the requirements	Communication Problem solving Explanation
Measurements of the moulds	Intermediate Verbal, visual, symbolic	Discussion about the most important measurements to be considered in the mould manufacture	Problem solving Explanation
Moulding tool concept	Intermediate Verbal	Discussion of alternative design and manufacturing solutions	Problem solving Explanation Anticipation

When discussing the nameless mould, sample packages which Fipak's tool designer had brought with him represented the functioning of the mould and the requirements of Fipak's manufacturing technology. The tool designer used them to illustrate the quality requirements of Fipak's packages and the quality the different versions of the mould produced. He also used sample packages to explain the range of products and their properties that Fipak could produce.

When discussing the Module mould, the participants used mechanical drawings to point out parts and measurements that required special attention. The

mechanical drawings are a very specific type of representation because they rely on a symbolic, standardised notation of shapes and measurements. Hence, the drawings do not have an observable correspondence: They are projections of the parts they represent. Therefore, their reading requires vocational education and work experience, which the participants shared and were able to use the drawings as boundary objects in their communication.

At the beginning of the meeting, the manager of the Tool Manufacturer 4 and Fipak's tool designer set up the scene where the design of the moulds would be open for discussion and improvement, rendering the moulds as boundary objects open for negotiation. During the discussion, the workers gained insights of the factors that Fipak needed to consider when using the moulds in their package production; by justifying his design choices the tool designer translated Fipak's concerns into compromises that the workers needed to take into account when manufacturing the mould. Even though both the manager and the tool designer had told the worker's suggestions would be considered to simplify the manufacturability of the mould, it was unclear how the concerns of the workers would get translated into future designs through the moulding tool concept. The workers were also affected by the iterative nature of Fipak's development process. The previous mould they had manufactured had gone through demanding modifications, which caused extra work; some of the workers brought up these difficulties but their concerns were not seriously discussed.

6.7   Event 5: The first trial runs of the Module project

The practices of trial runs were studied in two phases, by observing the first trial runs of the Module project and the third trial runs of the Food project, to gain insight of the iterative nature of the trial runs and the evolving concerns in the process. The timing of the trial runs in Fipak depended on the arrival of the moulding tool and the paperboard blanks. As Fipak only had two pieces of manufacturing equipment, used both for trial runs and production, and several products were iterating between trial runs and modifications, the schedules of the trial runs were continuously changing. This was the case with the Module project as well: The planned delivery date of the mould and the paperboard blanks had been agreed, but a week before the scheduled trial runs their timing was shifting from day to day. Due to the delay in the mould's delivery, I got a chance to observe the complicated craft of the operators and their collaboration with a bunch of artefacts which the trial runs depended on.

6.7.1   The first trial runs as a vulnerable infrastructure

The day the mould was finally supposed to come, I agreed with Fipak's technical manager Erja to observe the trial runs the following day when the mould would be installed and the trial runs ready to begin. When I arrive to Fipak the next morning, the Module mould has not arrived and Erja and the production engineer Risto are making calls to find out where it is, without results. Nevertheless, they decide to hold a meeting to plan the trial runs so that I would not have come

there in vain. Two operators, Tero and Susanna, who will be in charge of the trial runs, take part in the meeting.

In the meeting, the participants discuss how the trial runs will be carried out after the mould arrives. A document called "trial runs order" is projected on the wall. According to my reading, it specifies the package under development, the goals of the trial runs (in this case, testing the functionality of the mould and determining the size of the paperboard blank) and gives details of the mould, the paperboard blank and the plastic rim. It also lists observations which the operators should document during the trial runs. Erja states that some details of the mould are lacking in the document because the tool designer Markku, who is on holiday, did not remember all of them when she called. She reminds the operators that in the first trial runs it is important to pay attention to the functioning of the mould, also by listening whether it makes unusual sounds.

> *Technical manager: So the first thing is the functioning of the mould, there are the main things. What I've really found in the testing of machines and devices is that you also need to listen. You often don't have time to watch, to see much but listening if you can hear a 'plop' from somewhere, which tells that ventings don't work or then some other fuzzy rattle, bustle or banging. And if it doesn't look like anything very alarming, then you can proceed to testing paperboard blanks. And it'd be good for starters, when it [paperboard blank] begins to be about in place, to make those tests to see whether they get squeezed and break. Because it's a bit like, it isn't worth continuing very long, because it has to be put to the workshop [the tool manufacturer] for changes anyway.*

Susanna asks how to find a more specific checklist about the functioning of the mould which she has seen the third operator, Pasi, using. Erja and Risto do not know about the document but they decide to ask Pasi for it. The participants decide to start the trial runs with the same parameters as the Food package, which have functioned well. They also discuss the documentation of the trial runs: Erja shows where the Module project files are located on the shared disk. She suggests creating folders for each mould, under which documentation of all trial runs of the mould can be stored.

When the meeting has lasted for about half an hour, Erja concludes: "So that's about it, let's hope that the mould is found, then we'll get many crosses in the ok spots on this ticket." She calls the transportation company while Risto and the operators plan the arrangements of the trials runs; Risto tells about the complications with the logistics that have occurred with different moulds. Erja informs the others that the mould is going to arrive at noon. Risto agrees with the operators that they will start working at six o'clock the following day by lifting the mould to the testing equipment; he will try to ensure that they will get the paperboard blanks, which have not arrived in Fipak either. We agree that I will arrive at eight with the first train in the morning. A couple of hours later when I'm already at my workplace, Erja calls me to confirm that I can come to observe the trial runs as agreed; the Module mould has arrived and a chauffeur has left to fetch the paperboard blanks from the Printing Company.

Next morning when I arrive to the factory with Erja, all three operators are occupied with preparing the Module mould for trial runs. The mould has already been installed in the testing equipment. Tero is cleaning it with cloth and spirit from grease, which has protected it against humidity during the transport. The other operators, Susanna and Pasi, are working on the floor, preparing hoses for water-cooling: Susanna cuts pieces from a big coil of hose and Pasi puts connectors into the hoses. The operators are wearing overalls, whereas the engineers only have a work coat on their usual clothes; I am required to wear a similar coat, a cap and protection glasses during observation in the factory due to Fipak's hygiene and safety policies. Erja explains to me that they need new hoses because the mould has been designed for new production equipment, in which the hoses will be attached to the other side of the equipment. In the current equipment, the hoses need to be longer than usual because their positioning is different. Erja laments not having warn the operators about the unusual hoses but thinks that they would not have been able to prepare the hoses in advance because their length was not known.

The testing equipment consists of an injection moulding machine, which produces the packages, and a robot, which feeds the machine with paperboard blanks. The mould is installed in the machine, which shapes the paperboard blanks into a package and injects the plastic material around the blanks. The robot places the paperboard blanks in the mould, removes the ready packages from it and places them on the line. A dosing feeder of plastic material is attached to the machine. The equipment includes an operation display for controlling the injection moulding parameters (see Figure 17) and a closet where the robot operates (see Figure 18). Next to the display is a surface on top of which Tero's notebook (open on a page titled "Module package trial run"), a laptop and a document called "trial run feedback" are lying. Beside the testing equipment, the Customer mould[26] – that looks like a big chunk of metal now that it is closed – stands on a wooden pallet; I think its size resembles a washing machine.

About half an hour after I have arrived, Tero and Pasi begin to install the hoses into the mould and the machine. Erja and Risto arrive to see how the installation is proceeding. Risto explains to me that injection moulding machines do not often include robots and due to the automation, hoses and other parts of the machine have required adjustments. Meanwhile, Pasi joins Susanna and helps her finish the hoses while Tero removes dried plastic filament coming out from hoses which hang from an opening below the mould. When the water hoses are ready, two young trainees arrive and Susanna advices them in the visual control of samples of the Customer package. Tero has brought three coils of thin hoses for air circulation, a red, blue and yellow one. Because these hoses are used for three different functions and there are three different colours of hose, Tero suggests they use colour coding to mark the hoses. Each hole in the mould is engraved with a sign for a hose (e.g. IN1, OUT1). Tero and Pasi install hoses of one colour at a time: They begin with the red ones and then proceed to the blue ones.

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[26] I infered that the mould was for the Customer project because the manufacturer's name was carved on it and I knew that the operators had been testing it in trial runs the previous day.

Tero installs the hoses on the robot side of the machine while Pasi works on the mould side; they need to remove the old hoses that had been attached to the machine in the preceding trial runs.

Figure 18. The control interface of an injection moulding machine in Fipak.
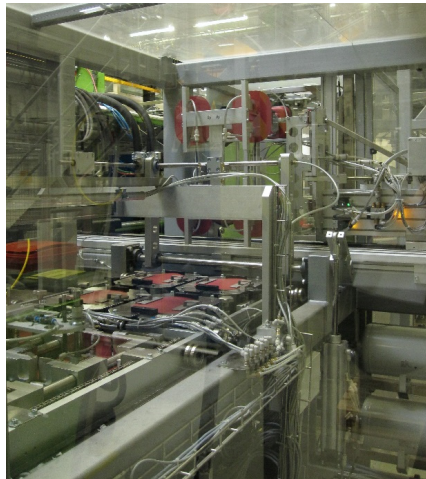
Figure 17. A robot handling paperboard blanks and produced packages (for a mould with four cavities) in Fipak.

While the operators continue the installation of the hoses, the development engineer Tommi arrives and shows me the paperboard blanks of the Module package. The paperboard blanks are in a big cardboard box next to the robot of the testing equipment. They are printed with the customer's design, which is the

same as in the current plastic package, but the product designer Niina has adjusted the positioning of the design to make it fit the shape of the package better. Tommi tells that four different sizes of the paperboard blank will be tested in these first trial runs. The blanks are still attached to a sheet of paperboard and the pile of sheets is ordered in the way that each size of blank makes its own pile. Later on, Niina and Susanna try to identify the four different blanks sizes by using a picture that has come with the blanks, but they cannot match the picture with the physical blanks because the picture does not indicate from which direction the sheets should be viewed. Niina thinks the blanks should be marked in the printing process to support the identification of the different versions. Finally Susanna manages to find out which blank is which one by measuring the actual blanks and comparing their proportions with the ones on the picture.

After having installed the hoses, Tero and Pasi observe that some of them are not in correct places. Susanna arrives and together they place the hoses in better positions to ensure that they will not be in the way when the mould starts moving. Susanna tells me that when the new equipment arrives and the operators can install the hoses in the proper way, it will be easier to fix the hoses if they break. The operators turn the injection moulding machine on. Immediately, one part of the mould drops because the air pressure does not hold it in place. Tero climbs on the machine; while he and Pasi are investigating the problem, they notice that a couple of water hoses are missing. Susanna and Pasi prepare two more hoses. The time is about half past ten in the morning when the operators decide to leave for lunch; they have started their workday already at six o'clock.

After lunch, the operators begin testing the mould by turning on the liquid circulation. Some of the hoses attached to the mould leak water. Pasi fixes them: He removes the leaking hoses and dries them with dry cloth; then he puts industrial cloth in them and attaches them into the mould. Meanwhile, Tero is taking notes in his notebook. Then Tero turns on the heating of the mould and the operators take a break. When Tero returns, he fetches paperboard blanks for the trial runs: He detaches them from the sheet and positions them on the magazine of the robot. Then he goes to the robot closet to determine the positioning of the robot's grippers. He starts testing the positioning of the paperboard blanks in the mould and adjusts the robot's grippers manually.

Finally Tero is ready to start testing the moulding of the packages. The robot picks the paperboard blanks from the magazine with the grippers and places them into the mould, which forms them by pressing. The first packages break. Tero adjusts the positions of the blanks on the magazine and decreases the pressure of the machine; the next packages break less. Then Tero begins to operate the injection moulding machine: He first injects old plastic out of the channels onto a big piece of paperboard, which he holds between the halves of the mould to protect the mould cavities from staining. Then he starts to run plastic rims with a fresh dose of plastic material, but the rims do not get filled properly. After these tests, Tero states that he dares to run full packages now by using the parameters of a tested package. When he runs the first packages with both paperboard and plastic, the packages break from the corners and their shape is distorted. In addition to Susanna, Tommi and Niina have come to see how the trial

runs are proceeding; they make jokes about the distorted packages and we laugh together.

Tero continues experimenting: At times he runs only paperboard, at times only plastic rims, while he keeps adjusting the parameters of the injection moulding. Then he returns to trials with whole packages. This time the machine manages to produce properly filled whole rims and the paperboard breaks less. The participants examine the packages: Susanna says the rim seems good because it does not break and Tommi anticipates that the package will make a good product.

At this point, also Risto arrives and they inspect the packages together. Risto says the size of the blank seems good; he suspects that the corners of the paperboard blank may have too many creases, which makes the packages break. Risto ponders that the shape of the Module package, which is again different from the other shapes they have been experimenting with, creates different tensions; every new package is a new experience. The time is almost two o'clock in the afternoon when Risto and the operators decide to end the trial runs for the day and continue after the weekend. I cannot take part in them the next week because I am having a holiday, so I ask Susanna if I can contact her afterwards about the trial runs. When I am about to leave I meet Erja who hopes that I got something out of my observations although it took time to install the machine before the trial runs could begin. I ensure her that the day has been very interesting and tell that I have asked Susanna for information about the continuation of the trial runs; Erja prefers that I contact Tommi who is in charge of the experiments.

When I later phoned Tommi, he told they continued the Module package trial runs on two days after the weekend. The packages were still breaking, so they had sent the mould to the Tool Manufacturer 4 for modification. A couple of the tested sizes of the paperboard blank seemed to be good. Tommi sent me a report of the trial runs Susanna had written, which documented the defects observed in the functioning of the mould and their consequences as they could be observed in the produced packages. The report also evaluated the properties of the paperboard blanks and described the measures taken to solve the observed problems. It concluded with further actions: The Tool Manufacturer 4 needed to make adjustments to the tool, after which the determination of the parameters of the equipment and the size of the paperboard blank would continue.

6.7.2   Analysis of the functions of the boundary objects

The first trial runs of the Module package thus focused on building the infrastructure that would enable the testing and evaluation of the mould and the paperboard blanks. This infrastructure consisted of an interdependent set of artefacts composing the functional components of the manufacturing equipment which the operators were working with. On the first day when the trial runs did not succeed because neither the mould nor the paperboard blanks had arrived, the participants of the meeting discussed the arrangements of the trial runs and possible problems that might be faced in the experiments. A document was used to inform the operators about the artefacts that they would be working with, but

there was no visual representation of these; the artefacts were only numbers on the document (see Table 13). The document itself was not modified during the meeting, but missing information was to be completed by absent members of the development team.

Table 13. Mediating functions of central boundary objects in the first trial runs of the Module project.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
Document setting the goals of the trial runs	Closed Visual	Informing the operators about the properties of the artefacts and their evaluation criteria	Communication
Hoses of the Module mould	Open Physical	Causing the operators unanticipated work and requiring them to reorganise their work The operators delegating the hoses the marking of different functionalities	Action Problem solving Organisation Delegation
Cascade of artefacts on the factory floor (robot, injection moulding machine, mould, paperboard blanks)	Intermediate Physical	Experimenting with and observing the behaviour of the different artefacts to create conditions for the production of packages	Action Evaluation Problem solving
Sample packages	Intermediate Physical	Evaluating the intermediary outcomes of experiments to determine further actions	Evaluation Problem solving

On the second day when the trial runs finally began, the changed placement of the hoses in the mould required significant manual work and revealed the complicated infrastructure of the trial runs. These were the second trial runs that I was observing (the trial runs of the Food package took place before these, see section 6.8) and only now I started to pay attention to the hoses and other artefacts which the testing equipment was composed of. Because the focus of the operators shifted to these otherwise mundane artefacts, I was able to understand the system-like interdependencies of the infrastructure better. The whole equipment required careful attention of the operators: First they needed to put all the artefacts, such as the hoses for water and air circulation, in place and connect them properly and only then could they proceed to testing the functioning of the mould. The artefacts thus affected the organisation of work among the operators: First all three were involved in building the infrastructure and when

it was finally in place, one of them took care of the actual trial runs. The installation of the hoses interfered in the usual unfolding of the operators' tasks in the preparation of the trial runs, delegating new tasks to the operators. The preparations also required collective problem solving, for example in the case of the leaking water hoses. However, the operators also used the properties of the artefacts, such as the colours of the hoses, to delegate the marking of different functionalities to the artefacts.

When the operators proceeded to the testing of the mould, they first manipulated the robot and the injection moulding machine separately to adjust their behaviour before beginning to operate the whole system. This allowed them a better control of the interdependencies between the artefacts the infrastructure was composed of, because they could observe their functioning separately. Here the operators and the artefacts carried out action together: The operators' actions depended on the behaviour of the artefacts. The operators evaluated the outcomes of the actions – plastic rims, paperboard packages and packages with both paperboard and plastic – and manipulated the artefacts to change their behaviour to see whether the changes improved the outcomes. These iterative actions led to small improvements in the produced packages, but the documentation of the trial runs showed that the mould needed to be modified before further development.

In the actions of the operators, the artefacts functioned as boundary objects in disciplinary use. The operators shared the embodied practice of conducting the trial runs, as well as a similar educational background and they could solve many of the problems encountered. When both the operators and other members of the Fipak team inspected together the first packages produced in the trial runs, these packages functioned as interdisciplinary boundary objects. They were the first material representations of the package under development, the intermediate outcomes of all the work carried out until this point. These representations were evaluated to determine next actions that the development of the Module package demanded to fulfil the requirements of the customer.

6.8 Event 6: The third trial runs of the Food project

The focus of the trial runs in Fipak evolved through the consecutive rounds of trial runs, between which the mould and the paperboard blanks were modified as their design could be made more accurate based on the outcomes of the experiments. This evolution can be observed in the following description, which is based on the observation of the third round of trial runs with a package whose development was proceeding towards a production phase.[27] Also this time we experienced a change of plans due to the delivery time of a moulding tool. We had agreed to follow the trial runs of the Customer package, whose design and production process we had studied in two workshops with Fipak team members

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[27] The observation of this third round of trial runs took place about a month before the first trial runs with the Module package, because the Food project had begun earlier than the Module project. To describe the unfolding of the development process, I discuss the observed events in the order of the process phases they represent.

some months earlier (see section 7.2). However, the Customer mould arrived early and the trial runs began before we got notice. Therefore the team suggested we follow the trial runs of the Food package, whose development was in a similar stage as the Customer package.

6.8.1 Evaluation of sample packages as intermediary representations

When I and my colleague Päivi arrive to Fipak, the development engineer Tommi comes to take us to the factory, where we meet the production engineer Risto and the tool designer Markku. They are supposed to hold a planning meeting of the trial runs, but it transforms into an introduction to us researchers of what the trial runs are all about. Actually the trial runs of the Food package have begun already the previous day and an operator is running experiments while we are having the meeting; if this was a real meeting, the operator should be present. The men tell us about the trial runs by going through a trial runs order, which is a document designed to serve two purposes: To give the operators the necessary information to conduct the required experiments and to collect the observations they make during the trial runs in a written form.

We discuss what has happened in the Food project before this round of trial runs. The men tell that the experiments in the trial runs have centred on the properties of the paperboard blank. The first trial runs had started with three sizes of the paperboard blank, one of which proved functional. After two rounds of trial runs within some four months, the blank size being tested now is already the seventh one in a row. Between the second round and this one, also the mould has been modified. Risto tells us that in the trial runs conducted the day before they have determined this size is correct; today they will investigate whether it is possible to produce air-tight packages. The participants use sample packages from the trial runs to demonstrate to us the previous changes to the design of the blank. Risto remarks that even though the package has a good appearance, it can still contain many faults – they will be wiser about it later in the afternoon. After the trial runs they will meet to discuss the observations and the next actions.

The men tell about the challenges of designing new kinds of hybrid packages. They describe how even small differences in the design of two packages can appear as huge differences in the way the packages behave in the manufacture. Fipak aims to reduce the number of iterations required before the packages can proceed to production by documenting the experiences of each product.

> *Tool designer: They have geometry differences, height mainly, and then dimension differences in the appearance. (...) There are totally different regularities when we run them. Even though we thought that we'll make the small one[28] first with the changes we saw necessary and they have been done, and we expected to make the same [changes] to this one, but this one doesn't need them. And still this one is working.*

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[28] The participants told they had two versions of the Food package, a smaller one and bigger one, whose shape and measurements differed only little.

Development engineer: We try to utilise the information we've got from previous products to estimate the size of the blank close to the correct one. So we would get the one right size already in the first round.

Production engineer: A year ago we only had a calculated estimate and now we can already leave some four five phases out based on documents. (...) And possibly in future Markku will calculate the correct [measurements] straight away. [gives a laugh]

The meeting ends after some 40 minutes of discussion and we leave for lunch with the men and the operator Tero. After lunch we join Tero in the factory; he is alone in charge of the trial runs of the Food package today. First he tells us about the functioning of the testing equipment, the injection moulding machine that produces the packages and the robot that feeds the machine.[29] Thereafter Tero starts the preparations of the trial run. First he empties the machine from old plastic that is left from the runs in the morning; this must be done each time the process is discontinued to ensure the quality of the injected plastic. Then Tero runs the machine with only plastic, producing plastic rims, after which he starts to use the robot for the moving of the paperboard blanks to produce whole packages. We follow Tero to the robot's side of the equipment where paperboard blanks are located. On the machine there is a drawing which represents the location of the flat paperboard blanks on the magazine, from which the robot picks them, and the packages on the line, to which the robot places them from the mould. The drawing helps in the adjustment of the positioning of the blanks on the magazine, because otherwise it would be difficult to remember that the order of the two piles of the blanks is different from the two lines of ready packages. From time to time, Tero carries out visual inspection of the ready packages, according to which he adjusts the positioning of the blanks and the parameters of injection moulding. Tero tells he searched for the correct positioning of the blanks already in the morning and adjusted the parameters of the injection moulding machine. Because the previous product which had been tested with the testing equipment before this Food package was very similar, the robot's settings were close to correct.[30]

The collaboration between Tero and the many artefacts participating in the production of the packages appears systemic: Tero evaluates the functioning of the different parts of the equipment by inspecting sample packages and uses his judgment to further optimise their functioning. He tells that he observes the positioning of the paperboard blank by inspecting the border between the plastic and the paperboard in the packages; the paperboard needs to be in the centre to make the package air-tight.

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[29] Even though I had visited the Fipak factory a couple of times earlier, this was the most profound explanation of the functioning of the manufacturing equipment I had heard.

[30] In Fipak, the moulds followed a standardised construction, which helped the positioning of the paperboard blanks with the robot when changing between products. Hence, the placement of the blanks in the mould was standardised even though the sizes and shapes of the blanks differed. Had that not been the case, the parameters determining the robot's movements to transport the blanks from the magazine to the mould would have needed to be resolved each time a mould changed.

Tommi comes to see what is going on in the trial runs and we discuss the aims of these runs with him and Tero. Now that the development team has found the correct size of the paperboard blank, they have a problem with the packages bending in the moulding. In these trial runs, they are experimenting with different patterns of creases on the paperboard blanks to see whether they can tackle the bending of the packages by changing the creasing pattern (see Figure 19 for an example of a paperboard blank with creases).

> Operator: In these trial runs we have different kinds of paperboard blanks. We're testing this form of the edge to get this straight to get rid of the tension in it.
> Development engineer: The paperboard blanks are of the same size but the blanks have creases here on the sides. Because we want to get rid of the problem that the rim is not even.

After having carried out the preparations for about half an hour, Tero is ready to begin the trial runs. I have mistakenly thought that we are already observing the trial runs. Two young trainees come to carry out visual inspection of the produced packages. For this Tero marks two packages as "test 1" under which piles of the inspected packages will be made: They correspond to the two piles of the blanks on the magazine and the two cavities in the mould.

After running the first version of the blanks for some half an hour, Tero switches to test another version. He tears the blanks loose from the paperboard sheets they are attached to with gloves on (for hygienic reasons, the blanks or the packages are not to be touched with bear hands). Then he stops the machine and removes the rest of pieces of version one and places the version two blanks on the magazine. Once again he inspects the first packages and adjusts the positioning of the blanks on the magazine. Then he makes new piles, marking two packages as "test 2." The creasing pattern is a bit different between the test 1 and 2 blanks. Tommi and Tero inspect sample packages to see how the paperboard is behaving; Tero thinks the current version of the blank produces straighter packages than the previous one.

While the machine is running, Tero shows us how the testing equipment can be used to follow the quality of the products: The equipment records the manufacture of each package and with the graph which it produces he can control that the equipment is following the programme exactly the same way every time. Tero explains that the equipment has 15,000 parameters which can be adjusted to optimise the manufacture;[31] when the correct parameters for a certain product are determined, the equipment can record them. Additionally, Tero makes notes to his notebook because the machine cannot record all parameters.

Soon Tommi comes and tells that the creasing patterns of the two first versions did not help with the bending problem. Therefore there is no need to test the three remaining versions of the paperboard blank; it is enough to run the tests with the second version of the blank. Tommi tells that the creasing patterns on

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[31] Process parameters of injection moulding include temperatures of the cylinder and the mould, speed of the movements of the mould, injection pressures and times of the injection phases (Höök & Nykänen 2009).

the paperboard blanks tested in these trial runs are not in an optimal place to straighten the bending of the packages. The pattern was decided after previous trial runs in a hurry to order new paperboard blanks for the next trial runs: Tommi had drawn the pattern on a blank and faxed it to the supplier of the blanks. Now the Fipak team have made different kinds of creases on some of the blanks with a manual tool to see if the placing of the creases would make a difference. Tommi demonstrates the differences between the blanks to us by showing example blanks. He shows that the creases made manually seem to straighten the package better.

Meanwhile, Markku arrives and we ask him about the design of the creases. He and Tommi tell there is no known regularity in the design of the creasing of the blanks: the Fipak team need to continue searching for new variations. This is the first package for which they need to study the creases in such detail; the bending problem seems to be connected with the flat and round form of the package. Markku characterizes the nature of development work as half of it being "a mystery."

When Tero has run the second version of the blanks for about half an hour, Risto has also come to the testing equipment; together they determine that these experiments are enough and they can hold the meeting. The trial runs have lasted some two hours, including the preparations, and have produced a couple of hundreds of packages. The men take samples of the produced packages with them and we follow them to the meeting room.

The participants of the meeting include the operator Tero, the production engineer Risto, the development engineer Tommi, the tool designer Markku and the sales manager Janne. All the men are examining the sample packages produced in the day's trial runs: They twiddle them and try to put their fingers through the corners to see whether the package breaks (see Figure 20 for an example of a hybrid package). This time the participants do not have a formal agenda or document that would guide the discussion. Tommi suggests that Tero first tells about the mould to inform Markku and then they can inspect the packages. Tero states the mould functions well; there was just a little problem with the forming part of the lower cavity. The men think there is no need to make more modifications to the mould.

Next the participants start talking about the size of the paperboard blank; Tommi thinks it could be one millimetre longer even though the current version behaves well when its positioning is exact. The men compare the Food package with the Customer package and think that its dimensions are now more balanced. They continue to discuss the width of the paperboard blank but conclude that they will make a decision about increasing the size of the blank later when the trial runs have proceeded.

> *Development engineer: And what about the width?*
>
> *Production engineer: Well the width would actually be, when this has, one millimetre there...*
>
> *Development engineer: If we could find one which is right in the middle and see it there.*

[The men are comparing different packages]

Development engineer: But in this sense also this one functions. So we could live with this one also, with this size.

Production engineer: But there, here you've got that kind of a piece, look at it, this one is in zero on that side. Look at that side...

Operator: It's right on the border.

Production engineer: Yes it's right on the border... But then when you take the millimetre there again...

Development engineer: I don't know. Maybe we'll decide that only after running a bit more of this.
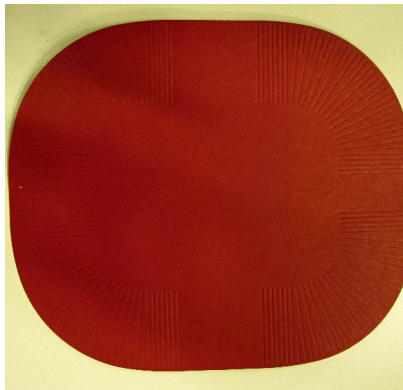
Figure 19. An example of a paperboard blank and its creases used for a customer's package in Fipak.

Figure 20. An example of a produced package in Fipak.

Tommi starts to talk about how the different measures taken in these trial runs influence the bending of the packages. While the men are talking, they refer to the packages in their hands. They compare these packages to samples produced

in previous trial runs but only verbally: They only have brought samples from the current runs to the meeting. Tero thinks the positioning of the paperboard blank in the mould influences the bending due to the flat form of the package. Risto and the others speculate whether the sealing with a plastic film, which is done on the customer's production line once the package has been filled, would help straightening the package. Tommi hopes the lid that is going to be placed on the film will not bend the whole thing again.

The men agree that the resistance of the package seems good: Neither the plastic rim nor the paperboard tray breaks. Tommi states "now the parameters of the injection moulding process are very good because there's no way you can break this rim". Risto thinks the same parameters could be tested with other packages as well. Tero tells the difference lies in the lower speed of the plastic injection, which might have an influence. Markku remarks that the parameters of the trial runs should not be far away from the mass production speed; otherwise they will have a problem when starting the production phase. Risto agrees they should test running the testing equipment with higher speed to see whether it affects the end results. Because Janne needs to bring samples of the packages to the customer, the men agree that the following day Tero will start by making good samples for the customer and then continue by experimenting with speeding up the machine.

6.8.2 Analysis of the functions of the boundary objects

Compared to the first round of trial runs of the Module package, these ones of the Food package, conducted after already two rounds of iterative experiments and modifications of the mould and the paperboard blank, appeared much smoother. The infrastructure was in its place in the background and the packages themselves were at the centre of attention.

Even though the planning meeting of the trial runs was a reconstructed one, it showed the function of the 'trial runs order' document, which defined what information was needed to carry out the trial runs and to evaluate their outcomes. At the same time, it also sought to make a translation between the concerns of design and manufacture (see Table 14).

In the actual trial runs, the operator collaborated with a multitude of artefacts to produce the packages. His actions depended on the behaviour of the artefacts, which he evaluated in order to optimise this behaviour towards the goals of the product development. He operated the manufacturing equipment through interfaces, the controls of the injection moulding machine and of the robot. Due to the sophisticated automation of the equipment, he was able to delegate part of the evaluation and documentation tasks to the testing equipment itself. Due to the standardisation of the elements of the equipment, his actions appeared quite routinized and he was able to devote his attention to the evaluation of the produced packages and the adjustment of the equipment parts. Like in the first trial runs of the Module package, the operator's actions in these trial runs were dependent on the behaviour of the artefacts.

Table 14. Mediating functions of central boundary objects in the third round of trial runs of the Food project.

Boundary object	Characteristics of the artefact	Use of the artefact	Function of the boundary object
Document setting the goals of the trial runs	Closed Visual	Translating the goals of product development into tasks and documenting the experiences in the trial runs	Communication Documentation
Cascade of arte-facts on the factory floor (robot, injection mould-ing machine, mould, drawing of the placement of blanks, paperboard blanks, sample packages)	Intermediate Physical / visual	Evaluation and adjustment of the artefacts to optimise the behaviour of the paper-board blanks in the testing equipment and to produce air-tight packages	Action Evaluation Problem solving Delegation Documentation Standardisation
Creasing patterns of paperboard blanks	Intermediate Physical	Experimentation with the behaviour of the paperboard blanks in the testing equipment	Problem solving Evaluation
Sample packages	Closed Physical	Evaluation of the intermediary outcomes of the manufacturing to determine further actions	Evaluation Problem solving Decision making Anticipation
Film and lid for sealing the packages	Closed Verbal	Speculation about the effects of the sealing methods on the bending of the packages	Anticipation

The starting point of the trial runs was the problem with the bending packages. The actions of the operator aimed to produce intermediary outcomes with different versions of the paperboard blank, sample packages, which could be compared to see what kind of creasing pattern could solve the bending problem. In addition to the creasing pattern, also the parameters of the injection moulding influenced the properties of the produced packages. Despite the additional creases carved on the paperboard blanks, the packages were still bending; the artefacts resisted the improvements the human actors were trying to accomplish.

In the meeting evaluating the trial runs, the sample packages were also at the centre of attention. They represented the intermediate outcomes of the package under development, which seemed to be getting closer to the final product. Evaluation of the properties of the packages concerned the size of the paperboard blank and the bending of the packages. A new concern emerged in the meeting when the participants began to speculate whether the sealing technologies that the customer would use in the production could cause new kinds of tensions in

the Food package. Interestingly, when the participants made comparisons between these trial runs and previous ones of the Food package and of other packages under development, they relied on their cognitive representations of the other packages, even though samples of them probably would have been available. They were able to recall the properties of the packages without their physical representation.

6.9 Event 7: Production runs of the Customer project

Practices in the production phase of product development projects were studied by observing the production runs of the Customer project, which we had studied in its earlier phases (see section 7.2). The Module project did not proceed to production before the development phase of the LPC project began; over the course of our research collaboration, it came out that the Module package did not reach a product launch with the Customer 2. The timing of the production runs of the Customer project was also uncertain, because the customer had not set a specific launching date for the new package. Finally they took place at the end of summer during my holiday week and therefore another researcher from our group, Päivi, travelled to Fipak to observe one day of the production runs. My analysis is based on a transcription of recordings and field notes that she produced by shadowing the operators' work.

6.9.1 The quality of packages as a primary concern

When Päivi arrived to Fipak in the morning of the fourth day of the production runs, the development engineer Tommi took her first to the cafeteria and they talked about what was going on. Tommi told the production runs aimed to manufacture the first production lot of the packages for Customer 1. The production had started three days earlier and would last two weeks because the operators were working on other projects at the same time. Later Päivi heard from Tero that the preparations of the production runs had taken place some weeks earlier so the equipment was ready for the production runs when they had started. Tero told the preparations included the installation of the mould and the determination of the parameters, because the robot of the production equipment was different from the testing equipment.

Tommi told that samples of the produced packages would be delivered to the customer to be filled and sent further to be tested by a commercial laboratory. Because the food product the package was used for was susceptible to spoil, both the customer and Fipak wanted to ensure that everything was alright before the product launch. The packages Fipak would produce before the test results were thus in danger of going to waste, but Tommi said the volume of the first lot was low and would not be an important economic loss.

Around ten o'clock Tommi took Päivi to the factory; on the way to the production equipment they passed by devices whose installation was taking place. The devices were designed for quality inspection of the packages and for their packing into boxes for transportation. They would increase the level of automation in the factory and reduce operators' craft work, thus decreasing the number of

operators needed in full production. Tommi and Päivi met the operator Tero by the production equipment, Tommi told they were in the start-up phase of the day's production. Päivi asked what was needed for the start-up and Tero explained the preparations that needed to be made with the plastic material, the mould and the cylinder that injects the plastic before the production could begin. Tero estimated that the start-up of the production took half an hour with the equipment but a couple of hours when considering all the required tasks. Tommi told the aim was to carry out production in three shifts to get rid of the start-up and shut-down phases to reduce the time they took away from production. Päivi asked the men about the different parts of the equipment and Tero explained to her the operational principles of injection moulding: Inside the cylinder there was a spinning screw, which melted the plastic and prepared the shot to be injected into the mould. Now Tero was observing the functioning of the cylinder and controlling it with a button. Then he injected the plastic through the mould on a piece of paperboard before running only plastic rims with the mould. He told Päivi he was doing this to ensure the plastic was of uniform quality in terms of dryness and colour before starting the actual production of the packages.

After some 20 minutes of preparations Tero started to run the equipment with both paperboard and plastic to produce packages. The first packages were put aside for disposal because their quality was not sufficient: Tero told Päivi it took a while for the process to stabilise. He showed to Päivi a pile of produced packages and explained that one could observe that the positioning of the paperboard blanks in the mould had succeeded but the plastic rim was not of adequate quality. Because the positioning of each blank was the same he could see the process was in order for the robot's part. Tommi said the team were going to increase the size of the blank still a bit because then it would not matter that much if the positioning of the blanks was not precise in the mould. Later Päivi inquired Tero about when the need to increase the size of the blank had been noticed and Tero told it was known already in the trial runs. Tero explained that they had wanted to test the paperboard blanks in the production equipment before changing the size, because the robot of the testing equipment used in the trial runs functioned in a different way. In the production equipment the robot functioned better and each blank was placed in the correct place. However, a bit larger paperboard blank would require less precision in its positioning in the mould.

Next Tero took two samples of the packages, one produced by each mould cavity, and brought them to an office space in the factory to test their air-tightness; Päivi and Tommi followed him. Tests for air-tightness were conducted six times a day. Tommi explained to Päivi the quality control system in Fipak, which enabled the team to trace from which paperboard batch a package had been produced. In the office, Tero was filling in a form of quality inspection on a computer that listed the features to be inspected when controlling the quality of the packages. He was marking in the form the features he had checked in the manual inspection of the packages; only the test for air-tightness remained. Tero wrote the time of the test on the form and filled the two packages with a special

liquid, which would reveal if the packages leaked air. They left the two packages in the office space and returned to the equipment.

While Tero was waiting for the air-tightness test to finish, he inspected the produced packages manually. He was wearing gloves and took a bundle of packages in his hands, spread them like a fan and inspected how the plastic and the paperboard had been seamed. Then he picked one of the packages and inspected it more carefully. After working like this for a while, Tero returned to the testing room with Päivi. He checked from the timer how long the testing liquid had been in the packages and removed the liquid, rinsed the packages with water and inspected that they had no leaks. He showed Päivi another package where leaks could be seen; he explained that when they observed a leak, they looked for the reason that caused the defect and tried to fix the process to avoid further defects. Now he could mark on the quality inspection document that the test for air-tightness was in order.

When Tero and Päivi returned to the equipment, the other operator Pasi was there. Pasi said he had guessed from Tero's calmness that the test was alright. Pasi and Tommi discussed the defects in the paperboard – black points on the printed side – that had been spotted and Tommi speculated where the colour had come from. He picked defective sample packages from the garbage container and took them with him to send them to the Paper Company's Testing Centre for examination. Tero and Pasi were now both inspecting the packages manually: This way they "double-checked" the packages before packing them in a big box. The box was covered with a thin plastic bag to protect the hybrid packages during their storage and delivery to the customer. The men told Päivi that they had optimised the number of packages piled above each other in the box as well as the size of the box; they ensured the filling of each box with the same number of packages by working together.

After a short while Tero took two new packages and went to the testing room with Päivi. When Tero was filling in the quality control document, Päivi observed that 20 minutes had passed from the previous test. Tero explained that it was good to make the tests more frequently at the beginning of the production runs and later about once an hour. He left the new packages in the liquid and returned to the equipment where he met Pasi. Päivi noticed a notebook on the table where the operators were inspecting the packages; Tero told he used it for taking notes of the trial runs so that he could set the process to the same state when the same product returned.

> The operator: When we're running many products, there's no way you can remember everything, you need to write them down. Of course we're reporting it on the computer, you can see it from there but still I've used this style.

Soon Tero returned to the testing room with Päivi to inspect the tested packages. When they came back to the equipment, Pasi and Tero discussed what was wrong with the cycle when the robot failed to bring the paperboard blanks in the mould. Then Pasi went to make coffee and Tero continued the manual inspection of the packages. Päivi asked him about the inspection and Tero explained

how he checked the positioning of the paperboard and the seaming of the plastic rim.

> *The operator: You look at the positioning in the corners because it's important to have enough paperboard in each corner of this product. Then you check a couple of pieces to see how the plastic has filled in the inside. Then you can already tell pretty well that it's a good bundle.*

Tero continued that when the new inspection device was installed, the team would need to teach the device to "look in the same way" to carry out the visual inspection. The device had a camera which it would use to compare the inspected packages with model pictures. Tero told they would need to define the places of the package from which the device would take pictures and to control that it could distinguish between proper and defective packages. Tero expected that when all new equipment would "come to life," the packages would be piled in bundles and packed in boxes automatically. The aim was that an operator could run several machines due to the automation when there would be more products.

After a coffee break Tero returned to the equipment. Päivi asked him how often the container, which fed the injection moulding machine with plastic material, needed to be filled. Tero told it lasted for a day; the plastic got dried according to the consumption of the injection moulding machine. Then Tero and Päivi left to make the third tests of the day. On the way they met Tommi who asked them for lunch; Pasi could take care of the running of the production in the meanwhile. Tero told he first needed to put the packages to the test.

After lunch, Tero and Päivi went to check the results of the third test, which had been a longer one. This time Tero found a miniature fracture in the junction of the plastic and paperboard parts of the package; he said this still did not mean the package would be defective. They returned to the equipment and Tero showed Päivi an example of a bigger fracture which leaked. Pasi was inspecting the packages; he had found samples where the printing was not in a proper place. This meant that a whole sheet of paperboard had been printed incorrectly. Päivi observed that the way the operators spread the bundles of packages like a fan allowed them to detect these kinds of defects in the manual inspection. Pasi confirmed that they observed whether the junction of paperboard and plastic was identical and whether the printing was in proper place in each package of the bundle.

Pasi had finished inspecting and packing a full box of packages. Päivi asked how many they had made altogether in the production runs and Pasi counted there were over 12,000 packages already. Tero lifted the box on a pallet, which now was filled with a maximum amount of boxes that needed to be covered with film.

When Pasi left for lunch, Tero filled the magazines of the robot with new paperboard blanks; this needed to be done two or three times during a shift. He explained to Päivi that they optimised the filling in order to leave as few blanks over as possible when shutting down the production at the end of the day. Otherwise the unused blanks needed to be returned to a "moisture room" because

paperboard dried quickly. The summer had been hot and the air humidity was high even in the factory, but especially in winter they needed to take only a currently required amount of blanks out from the moisture room.

Tero noted that after adding new blanks on the magazine "one had better see even more carefully that positioning has stayed in the right place." He added that when these kinds of changes occurred, it was sensible to test the packages for air-tightness as well. So he took one package from each pile and left to the testing room, Päivi followed. This was the day's fourth test for air-tightness.

When they returned to the equipment, Pasi had come from lunch, so he and Tero started to cover with film the pallet filled with boxes. Then they brought the pallet with the boxes to storage behind the wall. Next the men went to the moisture room to fetch 1,000 pieces of paperboard blanks for the production. The blanks were attached to paperboard sheets and they needed to be detached manually; Pasi was first cutting them with a tool away from the production to avoid making "a mess" there. Then he brought the partly detached blanks to the production equipment where he and Tero continued detaching them by hand with gloves on. While they were doing this, they inspected the blanks quickly by making a fan out of a bundle of them to find possible defects in the printing. Pasi and Tero piled the single blanks into two piles. Tero explained to Päivi that the paperboard was cut with two pieces of die-cutting tools, and by piling the blanks according to the tools they were made with, they could observe if there were differences between the blanks. The blanks not used in the day's production were covered with a plastic film to avoid letting them dry.

Later Tero left again to bring two new packages to the fifth test of the day; this time Päivi did not follow him. When Tero returned, he and Pasi worked on a device, which was not part of "normal production." Päivi inquired what they meant by "normal" and Pasi explained that usually all devices were ready when they were running production; their installation was not part of the operators' daily routine. Earlier Tero had told Päivi that their work included many other activities; she had seen only a fraction of them.

When Tero left to check the results of the tests, Päivi stayed with Pasi. She asked him about the remaining tasks of the day and Pasi explained there was a certain order for turning the different devices off. If this order was not followed or the shutting down was too quick, there was a danger of damaging certain parts of the mould. The damage could remain unnoticed long because it would be located inside the mould. Pasi noted that the more plastic was left inside the machine in the evening, the more work the operators had in the morning.

When Tero returned from the testing room, Tommi arrived. He and the operators speculated how the new device, which they had just turned on, would influence the production. Päivi asked Tommi whether there were further activities in the production that she should follow. Tommi did not think she would miss anything important so they agreed that Päivi could leave. It was about two o'clock in the afternoon; the operators' workday lasted some two hours more.

The Customer package was launched to the market about one month after the observed production runs (see Figure 21). At this point, our research project had proceeded to the development phase, which included workshop discussions

about the different product development projects. These discussions helped me to deepen my understanding of Fipak's products and product development processes, including why the Food and the Customer package succeeded but the Module package failed to proceed to production (see Chapter 7).

Figure 21. Customer packages filled with the food product.

6.9.2   Analysis of the functions of the boundary objects

Compared to the observed trial runs, the production runs of the Customer package seemed quite routinized. The operators encountered only a few problems with the quality of the paperboard blanks and thus their work concentrated on the maintenance of the production process instead of problem solving. The actions which the start-up and maintenance of the production consisted of were the same as in the trial runs, but they required less effort and attention in the production runs. Furthermore, efficiency of manufacture was emphasised in the production runs: Whereas in the trial runs the operators stopped the equipment for a lunch break, in the production phase the process was required to run throughout the day to minimise setting times and to maximise production times. It seemed that most of the work the operators carried out focused on ensuring the quality of the packages the equipment was producing. The handling of the different artefacts, especially the paperboard blanks, was planned in a way that enabled the tracing of possible quality problems in the production process.

   In the production runs, the Customer package was an outcome of the development process, a product whose behaviour in the manufacture was under control. The properties of the package finally fulfilled the requirements of the customer and thus the artefacts had acquired the status of closure (see Table 15). There was a plan to modify the size of the paperboard blank once more to grant the manufacture more leeway, but this decision had been made already during the trial runs. Visual inspection and tests for air-tightness were used to ensure the quality of the produced packages before their delivery to the customer, whereas in the trial runs sample packages were evaluated to detect needs to

change the production process. Now the operators were working autonomously and needed to consult other Fipak team members only in problematic situations that required interaction with the network partners.

Table 15. Mediating functions of central boundary objects in the production runs of the Customer project.

Boundary object	Character-istics of the artefact	Use of the artefact	Function of the boundary object
Cascade of artefacts on the factory floor (cylinder, mould, paperboard sheet)	Intermediate Physical	Adjustment of the artefacts to optimise the quality of plastic in the production of hybrid packages	Action
Cascade of artefacts on the factory floor (robot, injection moulding machine, mould, paperboard blanks, produced packages)	Closed Physical	Maintenance of optimal behaviour of the paperboard blanks in the production equipment to produce packages of proper quality	Evaluation Action Delegation
Paperboard blanks	Closed Physical	Evaluation of the quality of the blanks to avoid the production of defective packages	Evaluation
Cascade of artefacts on the factory floor (paper-board blanks, gloves, film, moisture room)	Closed Physical	Maintenance of hygiene and proper moisture level of the paperboard blanks in the production	Action
Cascade of artefacts in the testing room (sample packages, testing liquid, quality control document)	Closed Physical	Evaluation and documen-tation of the outcomes of the manufacturing to ensure the quality of the packages Tracing the sources of quality problems in the production process	Evaluation Action Documentation Delegation Standardisation
Produced packages	Closed Physical	Evaluation of the outcomes of the manufac-turing to ensure the quality of the packages	Evaluation
New device for visual quality control	Open Physical	Teaching the device to distinguish between proper and defective packages	Delegation

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Boundary object	Character-istics of the artefact	Use of the artefact	Function of the boundary object
Piles of paperboard blanks, piles of pro-duced packages	Closed Physical	Dividing the artefacts according to their source of production to trace the sources of quality problems in the production process	Documentation

Like in the trial runs, in the production runs the operators were working in interaction with a multitude of artefacts, but here the focus was on the produced packages and their quality. The operators needed to take care of the paperboard blanks whose properties could suffer if they stayed too long in the factory space; the blanks delegated maintenance tasks to the operators. The concern for qual-ity appeared in all the actions of the operators: They needed to be extremely systematic in the handling of the paperboard blanks and the produced packages to maintain traceability of possible defects. The use of artefacts for documenta-tion supported the detection of possible quality problems. For example, the tests for air-tightness of sample packages and the quality control document were used as parts of the quality control system. Systematic documentation – sup-ported by the standardisation of the testing procedure and the participating ar-tefacts – served the traceability of observed defects. The concern for quality made evaluation a key function of the boundary objects in the production phase: The visual inspection of the paperboard blanks and the produced packages to detect deviations of quality were central tasks of the operators.

During the couple of months between the observed trial runs and the produc-tion runs, the automation of the equipment had proceeded and was envisioned to reach an even higher level in near future. The dosing of plastic material was delegated to the equipment, whereas the maintenance of an appropriate amount of paperboard blanks remained the operators' responsibility. The installation of new devices for quality control and handling of produced packages predicted changes in the current sociomaterial system of operators and artefacts: The in-troduction of such a high level of automation would change the division of work between the operators and the artefacts.

6.10 The refined typology of the mediating functions of boundary objects

The preceding analysis demonstrates that various kinds of artefacts can perform the same mediating function in different situations. Furthermore, a comparison of the frequencies of the mediating functions across the observed events (see Table 21 in Attachment 1) illustrates that some functions feature across all phases of the product development process while others are more prevalent in particular process phases or tasks. Table 16 summarises the identified mediat-ing functions according to the frequency of the functions in the data and sums

up the characteristics of the boundary objects that performed the functions in the observed episodes.

Table 16. Summary of the mediating functions of boundary objects identified in the data.

Mediating function identified in the analysis	Characteristics of the boundary objects	Frequency of the function across the data
Problem solving	Open / intermediate / closed Verbal / visual / physical	57
Evaluation	Intermediate / closed Visual / physical	54
Explanation	Intermediate / closed Verbal / visual / physical	46
Communication	Open / intermediate / closed Verbal / visual / physical	33
Anticipation	Open / intermediate / closed Verbal / visual / physical	29
Action	Open / intermediate / closed Visual / physical	27
Documentation	Intermediate / closed Verbal / visual / physical	26
Decision making	Intermediate / closed Visual / physical	18
Delegation	Open / intermediate / closed Visual / physical	13
Organisation	Open / closed Verbal / physical	9
Standardisation	Intermediate / closed Visual / physical	2

Problem solving was the most frequently observed mediating function of boundary objects. Table 16 shows that various kinds of artefacts triggered problem solving in the different episodes. Problem solving featured as a key function in all phases of the product development process except for the production phase. The centrality of the function is related to the openness of product design early in the process, emphasising experimentation in Fipak's product development practices.

Evaluation appeared almost as frequently as problem solving in the data. Artefacts representing the intermediate or closed outcomes of the package performed this function. These boundary objects were used for comparing the outcomes with the properties of the designed package and to make adjustments to the artefacts to improve their properties and behaviour. Evaluation gained importance over the course of the product development process: It was particularly central in the phases of trial runs and production.

Explanation was a central function of boundary objects especially in the interorganisational encounters between members of Fipak and their partners. Various kinds of intermediate and closed boundary objects were used to familiarise

the partners with Fipak's manufacturing technology and the specifications they required; explanation hardly occurred between Fipak team members.

All kinds of boundary objects performed the *communication* function of sharing information between communities. Communication appeared central in the early phases of the development process both among the Fipak team members and between them and their partners.

Similarly, various kinds of boundary objects mediated *anticipation* across the observed events. The future-oriented use of the boundary objects laid out promises or challenges that the artefact and its use proposed. Anticipation featured mostly in the early phases of the product development process.

Action represented the most intensive mode of participation of artefacts in the practices, where humans and artefacts worked together to produce outcomes in order to reach a goal – in this case the production of packages that would correspond to the requirements of the customer. In these practices the artefacts comprised a system of boundary objects (cf. Rehm & Goel, 2015), which mediated action collectively. When the artefacts behaved in a way that did not produce satisfactory outcomes or refused to carry out any action, the humans involved needed to turn to problem solving and adjusting their own as well as the artefact's behaviour. In the trial runs, the episodes often followed a pattern of action, evaluation and problem solving, mediated by the participating artefacts.

Different kinds of intermediate and closed boundary objects performed the *documentation* function, which appeared central in the trial runs and production of the hybrid packages. These artefacts served the memorising of reoccurring routines.

Both visual and physical boundary objects of an intermediate or closed status mediated *decision making*. The decisions typically concerned the future actions, for example, the resizing of paperboard blanks to improve their behaviour in manufacturing. Decision making featured in almost all phases of the product development process.

Delegation of tasks between humans and artefacts occurred during the trial runs and the production runs of the packages. Various kinds of visual and physical boundary objects mediated delegation; in most cases, humans delegated tasks to intermediate and closed artefacts through the automation of the production. Open artefacts delegated tasks to humans when they acted in surprising ways and caused extra work, as in the case of the installation of the mould in the first trial runs. Delegation of tasks to artefacts occurred when the production infrastructure was in place – it featured in the third trial runs and the production runs.

Organisation was performed by open and closed boundary objects, which appeared in a verbal form in the early phases of the development process but in a closed form in the later phases. These artefacts mediated the division of labour particularly between the operators in the first trial runs.

The *standardisation* function was observed only twice during the observed events. Standardisation occurred when the artefacts reached sufficient closure, establishing the production infrastructure and the quality control system. This function was solely observed in the third trial runs and the production runs.

The summary of the mediating functions and the characteristics of the boundary objects confirms the assumption of the relational approach that *the mediating functions performed by boundary objects relate more to the nature of situated actions than to the characteristics of the artefacts themselves.* Table 16 shows that the forms of the artefacts – whether verbal, visual or physical – vary to some extent between the 11 functions. With regard to the manipulability of the artefacts, some mediating functions – evaluation, explanation, documentation, decision making and standardisation – were performed by artefacts with an intermediary or closed status only. The interpretation of these artefacts was thus restricted to a certain extent and their meaning was not open for negotiation. Many other functions – problem solving, communication, anticipation, action and delegation were performed by artefacts of any status. Whereas the previous literature has associated the organisation function with open and intermediate artefacts (Henderson, 1991; Nicolini et al., 2012), I found also closed artefacts mediating the organisation of work. These observations support the assumption about the situatedness of the role of artefacts in collaborative work.

The analysis also sheds light on the tacking between strong and weak meanings of boundary objects. Some of the mediating functions featured in actions that people carried out as solitary work, without collaboration with other human actors. I interpret these situations as representing autonomous work in which boundary objects appear in their strongly structured form (Star & Griesemer, 1989); the same artefacts mediated the collaborative work between communities in other situations. For example, on the shop floor the operators formed their own community, responsible for the production of the hybrid packages and the maintenance of the production infrastructure. The operators collaborated with each other and with the artefacts within their community, but in the trial runs they worked with other members of the Fipak team. In addition to supporting the autonomous work of the operators, the central boundary objects – the mould, the paperboard blanks, the sample packages – mediated actions in meetings before and after the trial runs. In these episodes that engaged members of different professional domains, the boundary objects appeared in their weakly structured form, mediating collaborative work.

6.11 Shifting functions of boundary objects during the product development process

In the construction of the typology of the mediating functions which boundary objects perform in different situations, I suggested that the same artefact can play different roles in different collaborative situations. This suggestion follows the relational view on the role of artefacts in human–world relations in general (Verbeek, 2005) and in organisational collaboration in particular (Scarbrough et al., 2015). My analysis of the mediating functions of boundary objects in the product development process demonstrates shifts between their functions across events. Sometimes I observed a boundary object performing various functions during a single interactive episode.

To examine shifts between the mediating functions across the events and thus across the different project phases, I analysed boundary objects that mediated actions in at least two events (see Table 17).[32] These include the 3D model, the mould, the paperboard blank, the production equipment and sample packages. I consider the artefacts developed in the three product development projects to correspond to each other in the functional sense to enable a comparison across the observed events, as I do with the testing and production equipment.

Some artefacts, such as *the 3D model*, served as boundary objects only in the early stages of the product development process. The 3D model mediated communication in both the negotiation and product design phases; its use did not significantly change between the phases. The four other boundary objects played a central role in several process phases.

The mould acted as a boundary object in all events after the phases of negotiation and product design. In the tool design, the moulds mediated explanation and problem solving. In the tool manufacture, the focus was on the different parts of the mould to identify and solve problems affecting their manufacture; the parts were also used to explain the specifications that the manufacturers needed to comply with so that the mould would function properly in Fipak's production. In the trial runs of both the Module and the Food projects as well as in the production runs of the Customer project, the mould took part in the actions of producing packages with a number of other artefacts as part of the production infrastructure. In the trial runs, the functioning of the mould required problem solving, but in the production runs the mould was a well-working, necessary part of the production equipment. The various functions that the mould performed in the interactions between different participants indicate that the mediating function an artefact acquires in a certain situation may depend on the relationships between the human actors in addition to the relationships between the participating artefacts (cf. Scarbrough et al., 2015).

The paperboard blank served as a boundary object in the phases of product design, trial runs and production. In product design, the paperboard blank was a model whose proper dimensions and creasing patterns were a concern: Even though the model documented the measurements of the blank and mediated communication between Fipak and the printing house, the product designer acknowledged that the model was only a best guess of the proper dimensions. In the trial runs and the production runs, the paperboard blanks participated in the actions of producing packages as part of the production infrastructure. In the trial runs, different versions of the paperboard blank took part in the experiments and their dimensions were evaluated through the inspection of sample packages. In the production runs, the quality of the paperboard blanks was under the operators' evaluation; the proper behaviour of the blanks required the care of the operators, to whom these artefacts thus delegated tasks.

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[32] In the previous sections, the tables combined some of the boundary objects in one cell because they worked together as a system with the human actors. However, not all the boundary objects of the system performed the same mediating functions. To simplify the analysis, Table 17 includes only the mediating functions of the boundary objects in question, although some of these functions were realised by a set of artefacts.

Table 17. Different mediating functions of the central boundary objects across the phases of the product development projects.

	3D model of the Module package	Module / Food / Customer mould[33]	Module / Food / Customer paper-board blank	Testing / Production equipment	Samples of Module / Food / Customer packages
Negotia-tion	Problem solving				
Product design	Communic-ation Organisation		Communic-ation		
Tool design		Explanation Problem solving		Communic-ation Explanation	Explanation Evaluation
Tool manufac-ture		Problem solving Explanation Anticipation			Explanation Evaluation
First trial runs		Action Evaluation Problem solving	Action Evaluation Problem solving	Action Evaluation Problem solving	Evaluation Problem solving
Third trial runs		Action Evaluation Problem solving	Action Evaluation Problem solving	Action Evaluation Problem solving Del-egation Standardi-sation	Action Evaluation Problem solving Document-ation Decision making Anticipation
Produc-tion		Evaluation Action Delegation	Evaluation Action Delegation Document-ation	Evaluation Action Delegation	Evaluation Action Document-ation Standardi-sation

The manufacturing equipment functioned as a boundary object in the phases of trial runs and production: The equipment took part in the actions of produc-ing packages as part of the production infrastructure. In the trial runs, the col-laboration between the artefacts and the operators was often interrupted and required problem solving. In the production runs, the manufacturing equip-ment carried out the production tasks together with a set of other artefacts al-most without human intervention: The actions that produced the packages were

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[33] In the tool design meeting, the Pilot mould and another mould served as boundary objects on the fac-tory floor. In the tool manufacture meeting, the Module mould and the nameless mould served as bound-ary objects in the discussion. The functions of all these moulds are included in the analysis.

delegated to the set of artefacts compiling the infrastructure. This routinized accomplishment of the production tasks was supported by the standardisation of the components of the manufacturing equipment and their interfaces.

Sample packages acted as boundary objects in all events after the phases of negotiation and product design. In interactions with the partners responsible for tool design and manufacture, sample packages mediated the explanation of Fipak's quality requirements as well as challenges with the manufacturing method. In the trial runs, sample packages mediated the evaluation of the properties the experiments had produced: When they were not satisfactory, they called for problem solving. Furthermore, sample packages mediated decision making about changing the size of the paperboard blank and triggered anticipation of possible problems with the behaviour of the packages in the customer's production. In the production phase, sample packages acted as primary means of quality control when their properties were evaluated. Produced packages also served as documentation when their storage during the manufacturing was organised according to their source of production. In addition, the standardised interaction between the operators, the sample packages and other artefacts compiling the quality control system enabled the routinized testing for air-tightness of the packages.

The significance of sample packages for the development of the hybrid package seems to relate to the experimental, iterative nature of the development work, which proceeded through cycles of design and production of material artefacts (the mould and the paperboard blanks) and their testing in trial runs. The sample packages served as material representations of the only partially specified package, allowing comparisons with the design of the package. The iterative nature of the development process resembles the dialectic of resistance and accommodation described by Pickering (1993): When material artefacts do not behave according to human actors' expectations, the actors need to accommodate their experimental arrangements in a novel way to overcome the problems faced. The sample packages represented intermediate outcomes of the development process (Boujut & Blanco, 2003; Vinck & Jeantet, 1995): Further actions were planned based on the evaluation of their properties.

6.12 Evolution of boundary objects during the product development process

The central boundary objects appeared in various forms and performed different functions during the product development process. While the previous analyses focused on the situated mediating functions of single artefacts or systems of artefacts, the following analysis traces the evolution of boundary objects over the course of the development process. Table 18 summarises the evolution of four central boundary objects – the hybrid package, the moulding tool, the paperboard blanks and the production equipment – as various representations across the observed events. This interpretation of a particular artefact as a representation of an evolving artefact follows Rheinberger's (1997) understanding

of the dynamics between open epistemic objects and their closed instantiations, technical objects (see also Ewenstein & Whyte, 2009).

The hybrid package was the object of the product development process, but it featured as various kinds of representations in the different process phases. In the negotiation phase of the Module project, the hybrid package appeared as an open, conceptual artefact whose only representations were a visual 3D model and a document outlining its main properties and the phases of its design and production (see Table 9). However, the design of the package was discussed through limitations set by the requirements of the customer's production and the customer's existing package as well as by the consumers' potential ways of using the package (see Table 18). Expectations of the commercial potential of a standard package mobilised the development process: Based on an initial understanding of the efforts required to produce a corresponding product, both familiar and new partners were recruited to the development work. As the development process proceeded, many of the conceptual artefacts discussed in the negotiation phase obtained a material form and their correspondence to the design could be evaluated. For example, the measurements of the Module package were transformed into a rapid model to test the correctness of the dimensions. Further on, the shape and the dimensions of the package were materially experimented with in the trial runs, which produced sample packages. These packages allowed the evaluation of the measurements of the mould and the paperboard blanks as well as of the properties of the package. In the case of the Module package, the measurements did not reach closure because its dimensions were not suitable for Fipak's manufacturing technology.

Similarly, *the moulding tool* transformed from conceptual representations to a physical artefact, reaching closure through experimentation and adjustments. In the interactions between the representatives of Fipak and their partners – tool designers and tool manufacturers – the design and manufacture of the mould were discussed in terms of optimal solutions to Fipak's production requirements. Even though these partners were experts in moulding tools and injection moulding as manufacturing technology, the hybrid package set special requirements for the manufacturing method that needed to be taken into account in the design and manufacture of the moulds. For example, many of the design improvements and alternative manufacturing methods of the mould suggested by the tool manufacturers were discarded because they could have compromised the proper functioning of the mould in Fipak's manufacturing equipment. Once the mould materialised, its functioning was put to a test in the trial runs as part of the production infrastructure.

The measurements of *the paperboard blank* appeared as a concern both in product design and the iterative trial runs. In addition to the evaluation of the size of the paperboard blanks, the experiments in the trial runs aimed to determine a suitable creasing pattern. For example, the creases were a central concern in the trial runs of the Food project due to the bending of the sample packages. Finally, the quality of the paperboard blanks was a key focus of the quality control system in the production phase, for which different kinds of quality procedures had been designed.

The production equipment featured fewer instantiations during the product development process. It appeared as a representation of Fipak's manufacturing method for the partners in tool design, whereas the adjustment and optimisation of its components were a central concern of the trial runs. Finally in the production phase, the production equipment – together with a system of connected artefacts – performed manufacturing tasks as production infrastructure.

The next chapter continues the study of the intertwined evolution of artefacts and practices. It examines the artefacts present in the product development process as elements of Fipak's product concepts and production concepts. The analysis explores the interdependencies of the trajectories of the hybrid package, the manufacturing technology and production practices.

Table 18. Evolving representations of the central boundary objects over the course of the studied product development projects.

Boundary object	Event 1: Negotiation	Event 2: Product design	Event 3: Tool design	Event 4: Tool manufacture	Event 5: First trial runs	Event 6: Third trial runs	Event 7: Production runs
Hybrid package	Requirements of the customer's production lines Comparison to the customer's existing package Use of the package by consumers (food product to be packed) Precise measurements of the package to be determined Promise of a standard package	3D model as a basis for cost calculations and for tool design Rapid model to determine the measurements of the package	Sample packages as representations of Fipak's product requirements and challenges with manufacturing	Sample packages as representations of Fipak's quality requirements	Document translating the properties of the package into the technical properties of the mould, paperboard blanks etc. Sample packages as preliminary outcomes of the experiments	Bending packages as a difficult shape resisting improvement efforts Sample packages as preliminary outcomes of the experiments marking slight improvement	Product ready for delivery Product as representation of Fipak's work, whose quality needs to be ensured through visual inspection and tests for air-tightness

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Boundary object	Event 1: Negotiation	Event 2: Product design	Event 3: Tool design	Event 4: Tool manufacture	Event 5: First trial runs	Event 6: Third trial runs	Event 7: Production runs
Moulding tool	An artefact to be designed and manufactured		Moulds in factory and CAD files as representations of Fipak's moulding tool concept CAD files as documentation Promise of collaboration Mould cooling as a problem calling for collaboration	Measurements of the mould as compromises between optimal tool design and Fipak's production requirements Mechanical drawings of the mould mediating between design and manufacture	Physical mould with incompatible hoses to be tested for the evaluation of functionality	Part of the Infrastructure requiring routinized actions to maintain functionality	Part of the Infrastructure requiring routinized actions to maintain functionality
Paperboard blanks		Picture of the paperboard blank as a basis for production and tool design			Different sizes of blanks for experimentation requiring identification	Versions with different creasing patterns to solve the bending of the packages	Part of the infrastructure requiring care to maintain proper functionality Part of the quality control system requiring continuous evaluation
Production equipment			Representation of Fipak's manufacturing method		Adjustment of the machine and the robot through parameters and physical contact	Optimisation of the machine and the robot through parameters	Part of the infrastructure requiring care to maintain proper functionality

7. Evolution of Fipak's product concepts and production concepts through product development projects

To study the mutual development of products and their production practices in the creation of innovations, I have set out to study the evolution of product concepts and production concepts. A product concept defines the qualities of a range of products that embody a comparable use for customers (Jalonen et al., 2016). It reconciles the requirements of customers with the expertise of designers and producers as well as with the capacities of the production technology. A production concept represents the principles of organising the activities of producing products. This logic is translated into work practices by embedding them in the organisation of work and the artefacts used. It is manifested in the division of work within the company and between their partners, the kinds of relationships among them and the chosen production technology as well as the tools for the management of production activity.

In the development of the hybrid package, the product concept and the production concept were both at the centre of the development process, and their evolution was mutually dependent. The product concept was bounded by the production concept from the early stages of the development process: The starting point was a package that would be produced in high volumes with an effective production process. At the same time, the development of the production practices required the creation of specialised technologies that enabled the manufacture of the hybrid package combining paperboard and plastic with highly automated production infrastructure. Thus, neither the product concept of the hybrid package nor the production concept for its manufacture were known at the beginning of the development process but rather evolved through the experimental development of first prototypes and later commercial packages, as described in chapters 5 and 6.

In this chapter, I study the temporal evolution of Fipak's product and production concepts from the initial understanding guiding the beginning of the development process of the hybrid package to the established product concepts and project management practices as well as the constructed mass production infra-

structure at the end of our research collaboration. I analyse interactions between researchers and practitioners to study *how product concepts and production concepts evolve through the development of the product's properties and its production practices*. To identify changes along the trajectories of the concepts, I examine *what characteristics the product concepts and the production concepts had in different phases of the concept development process*.

7.1 Research design

For the analysis, I have chosen encounters between Fipak's development team and our research group in which Fipak's product and production concepts were discussed and evaluated. The understandings of the product and production concepts identified through the analysis of these encounters portray three phases in the evolution of Fipak's product and production concepts. These phases are distinguished by the clarity of the product concept's characteristics and the practices reflecting the production concepts. The first phase of concept development illustrates a shift from research-oriented product development to commercial-oriented production after the market launch of the first hybrid package. The second concept development phase illustrates the identification of the boundaries of the product concept and the simultaneous construction of an automated production infrastructure as well the creation of practices for product development projects. The third concept development phase illustrates the situation with established product and production concepts. Figure 22 locates the three phases of concept development and the analysed encounters on the timeline of the innovation process.
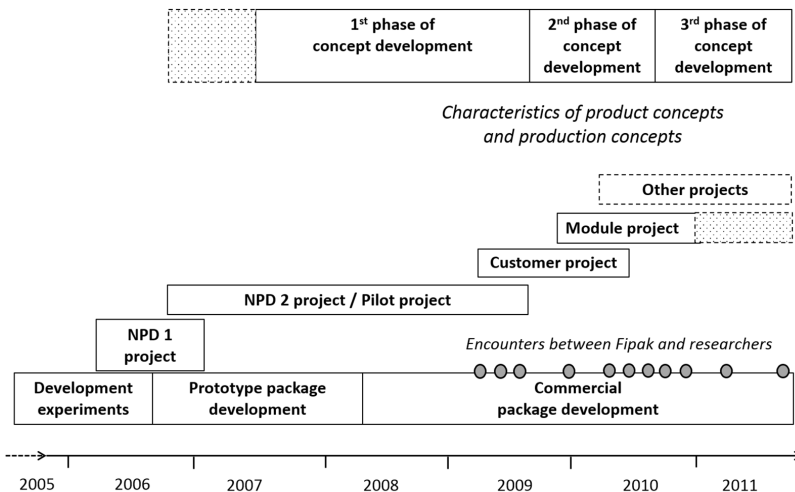
Figure 22. The concept development phases and the encounters with discussion on product and production concepts on the timeline of the innovation process.

The analysed data comprise mostly workshop discussions but also include meeting discussions and interviews from these three phases (see Table 19). The workshops were researcher-led interventions, for which we prepared a structure and used specific data and methods to facilitate the discussions about the chosen topic. The meetings were arranged to discuss the practices of research collaboration. The interviews were conversation-like but addressed topics according to a prepared interview protocol. The meetings and interviews were audio recorded, while the workshops were both audio and video recorded. For my analytical purposes, I mainly examined the transcribed audio recordings and used the video recordings as additional sources in cases where they helped me to verify indexical utterances that referred to certain artefacts at hand.

1. First phase: I analyse the conversations in the first encounters between Fipak's development team and our research group, *an introductory visit* to Fipak and *two process workshops*, which started the data collection phase of the LPC project in autumn 2009. During the introductory visit, representatives of Fipak described the current stage of development of the hybrid package and its production practices. In the process workshops, members of Fipak's development team described their work practices and topical concerns in different phases of an ongoing product development project for a particular customer. Additionally, the analysed data include *an interview* with Fipak's business manager conducted at the end of 2010.[34]

2. Second phase: I analyse the conversations in *a feedback workshop*, where our research group and Fipak's development team discussed the findings of the six-month data collection phase, and in *three concept workshops,* where our research group and members of the development team examined Fipak's product and production concepts. In the feedback workshop, the researchers presented their observations from the studied product development projects as mirror data; the discussions aimed to build a common understanding of the practices in the projects and to identify development targets for the development phase of the research collaboration. The feedback workshop took place in spring 2010. The concept workshops built on a cumulative study of the properties of Fipak's products and their development practices. The workshops aimed to identify Fipak's product and production concepts as well as needs for the development of tools that would support the activities in the product development projects, following the logic of the product and production concepts. The concept workshops took place in autumn 2010.

3. Third phase: I analyse *two factory visits* to Fipak, *a presentation by Fipak's representative in a public seminar* of the research project and *an interview* with two members of the development team. The seminar took place in spring 2011 and the interview was conducted in

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[34] This interview was also analysed in Chapter 5, but here the focus is on the initial understanding of the product and production concepts during the innovation process, leading to the commercialisation of the hybrid package.

spring 2012. By this point the research collaboration had officially ended, and Fipak's work practices followed established product concepts and production concepts.

Table 19. Encounters in which Fipak's product and production concepts were discussed.

Encounters with discussion on product and production concepts	Object of discussion	Participants
First phase of the concept development process		
Introductory visit (2009)	Aims of the research collaboration Fipak's product development process	Fipak's technical manager, tool designer and business manager Five researchers
Process workshops (2009)	Practices and concerns in different phases of the Customer project	Fipak's sales manager, salesperson, product designer, tool designer, technical manager and production engineer Four researchers
Interview (2010)	Development process of the hybrid package and earlier product development projects in the Paper Company	Fipak's business manager Two researchers
Second phase of the concept development process		
Feedback workshop (2010)	Products, production networks and practices in the studied product development projects Development needs of Fipak's activities	Fipak's sales manager, salesperson, product designer, tool designer, technical manager, production engineer, development engineer, operator, business manager Four researchers
Concept workshops (2010)	Fipak's product concepts, production concepts and tools in use	Fipak's sales manager, salesperson, product designer, tool designer, technical manager, production engineer, development engineer Three researchers

Third phase of the concept development process		
Public seminar (2011)	Fipak's experiences of the research collaboration	Fipak's technical manager
Factory visits (2011)	Fipak's production infrastructure	Fipak's technical manager, members of the research group and representatives of the steering group of the research project
Interview (2012)	Development of Fipak's product and production concepts	Fipak's technical manager and sales manager One researcher

An important challenge in the analysis of product concepts and production concepts lies in the fact that while I have defined these notions to serve as analytical tools, the notions initially constituted part of the research process under analysis in this chapter. The overall aim of the LPC project was to create practices that would encourage the continuous development of the participating companies' activity and their collaboration with partners as 'learning production concepts.' Exploring the meaning of production concepts and their manifestations in work practices was at the centre or at least in the background of all the studied encounters. At the beginning of the research collaboration with Fipak, our research group had only some preliminary understanding of what a production concept could mean or how it might be developed based on learning. Therefore, in the data of the first concept development phase, the notion of production concept was merely used as a vague theoretical concept by the researchers. In the second concept development phase, by contrast, the notions of production concept and product concept played a central role in the workshop conversations. Our research group was defining these concepts through the analysis of the collected data, and we used them to structure the mirror data that we used as the basis of the workshop dialogues. The participants of the workshops familiarised themselves with this thinking and began to refer to the terms in their talk. However, only some members of Fipak's development team used these concepts, while others continued using conventional terms, even when talking about the same phenomena. Our research group used the insights learnt from these encounters when constructing the model of the learning production concepts. At the same time, the practitioners were analysing their activity through the lenses of the concepts we had introduced. In the third concept development phase, the research collaboration between Fipak and us had ended, and the data were based on sporadic, organised encounters. At this point, our research group had explicated the model of learning production concepts, and the participants were familiar with the terminology and its background.

In the analysis, I try to portray these dynamics of the interactions between the Fipak development team and our research group by contextualising the conversation episodes. Oftentimes, the observations presented by us researchers led to

a dialogue between the workshop participants. I present many quotes from the data to illustrate the language the participants used and to examine how it reflected their understanding of the hybrid package and Fipak's production concept.

When conducting the analysis, I searched the transcripts for characterisations of Fipak's product and production concepts. For the analysis of product concepts, I identified episodes where the team members characterised the properties of the hybrid package as well as factors setting limitations to the properties. Furthermore, I identified requirements of customers and focus of product development as factors characterising the product concepts. For the analysis of production concepts, I identified episodes where the team members characterised the principles guiding their actions, the organisation of work and their relationships with customers and suppliers as well as the choice of manufacturing technology and management tools.

After identifying the episodes, which included characterisations of concepts, and coding the articulated characteristics, I extracted these episodes and examined them more carefully. This caused me to notice some overlaps in the codes and some inconsistencies between the coding of different encounters, which required the re-coding of part of the data. However, I did not develop the characteristics further into categories but rather my analysis relies on the dialogue episodes that articulate aspects of the concepts. I then wrote a narrative of each encounter, which highlighted the characteristics of the concepts. Based on the analysis, I distinguished between three different phases of concept development. I then began to examine the characteristics of the product concepts and production concepts within each concept development phase. I drew a picture highlighting the central characteristics of the concepts in each phase. Finally, I traced the trajectories of the concepts across the three development phases and studied their interaction.

7.2 First phase: Emerging product and production concept after the launch of the first commercial product

When we started the research collaboration with Fipak in autumn 2009, the first commercial product (developed in the Pilot project with the Pilot Customer) had just been launched and its production was on-going. We learnt about Fipak's product and its production process in our first visit to the factory in October 2009, which started our research collaboration as we agreed on the initiation of data collection about different product development projects. We met Fipak's technical manager Erja and tool designer Markku; the business manager Marianna took part in the meeting for a while. Our whole research group, Anneli, Hanna, Mika, I and a research assistant,[35] took part in the meeting. After the meeting we were introduced to Fipak's manufacturing technology on the shop floor.

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[35] Päivi joined our group at the beginning of 2010; the research assistant worked only a couple of months for the project.

The next occasion in which we discussed Fipak's product and its development process were two process workshops, which we organised in October and December 2009. At the same time with the production of the first commercial product, the Fipak team was working on a couple of products for new customers, which were in different phases of development. We took one of them, the Customer project (whose production phase was later observed, see section 6.9), under examination to study how the development process of the hybrid package was organised in the production network. The workshop discussions were structured according to the phases of the process that had taken place before the workshop. The first workshop dealt with the negotiation and design phases of the Customer project, while the second workshop proceeded until the trial runs phase (the phases of the development process are depicted in section 6.1, see Figure 11). The participants of the first workshop included the sales manager Janne, the product designer Niina, the tool designer Markku and the technical manager Erja. Two new participants, the salesperson Annika and the production engineer Risto, took part in the second workshop in addition to the aforementioned ones. Four members of our research team, Anneli, Mika, I and the research assistant Riitta, were arranging and documenting the workshops, which were both audio and video recorded.

The third occasion in which the initial product concept of the hybrid package and its production principles were discussed was an interview with Fipak's business manager Marianna. In the interview, she described the 15 years of development work in the Paper Company, which had contributed to the creation of the hybrid package and to its commercial success. Päivi and I conducted the interview in December 2010.

The following analysis focuses on the characteristics of the hybrid package as well the principles of its production and the concerns associated with its manufacture, as described by the participants in these three occasions. I interpret these conceptions as manifestations of initial product and production concepts, whose aspects can be evaluated against the subsequent evolution these concepts took.

7.2.1 Introductory visit

In the introductory visit, *the hybrid package appeared as a new product to be customised according to the requirements of each new customer*. The technical manager Erja told that the customer determined the shape and appearance of the package, while Fipak was responsible for fulfilling these requirements. The tool designer Markku told that Fipak did not have an "own concept" to be offered to customers but the design always followed the customers' needs. However, according to the understanding of product concept proposed here, Fipak did have an original product concept as the core of its business activity. The technical manager Erja told us: "We're developing and manufacturing these kinds of *paperboard trays that have a plastic rim*". Furthermore, package concepts designed as part of the NPD 2 project were on display on a wall, which we passed on the way to the factory (see Figure 23). During the meeting, Erja and Markku identified distinctive properties of the hybrid package, which included

stiffness, heat resistance and recyclability. They told us how the properties of the package depended on the combination of paperboard and plastic materials selected for the end use required by the customer. Still, the product concept as understood by Markku depended on the requirements of the customers.

Figure 23. Package concepts on display on Fipak's premises in 2009.

Determination of the properties of the hybrid package was the responsibility of the customer, who was supposed to study the preferences of the consumers. We got the understanding that central requirements of the customers included the filling process of the package on the customer's more or less automated production lines; all of the current customers operated in the food industry and their packages moved through different stages of the filling and packing process before their delivery. Markku told the production lines restricted the design of the hybrid packages because many customers wanted to use the new package on existing production lines.

> *Tool designer: The filling takes place in their [the customers'] facilities. There are quite many work phases that we should take into account here to make it [the package] fit. Because quite many customers of course want to continue with the production lines that they have; even though they'd get a new product there, it can't be different, deviant from it. (…) We don't have terribly freedom in the sense that we could do whatever we want, but that's why we need to discuss*

*what goes through in their production. Then we adapt that to our production,
to our way of making this tray.*[36]

*Fipak's production concept was described as customised according to each
product, which required the manufacturing technology to be flexible.* On the
other hand, Markku and the technical manager Erja told that the production of
the hybrid packages was restricted by the selected injection moulding machines.
The specification of the production equipment had started at the beginning of
the year 2009 when the team only knew about the Pilot package; Erja described
how the team needed to estimate sizes of possible future products to determine
what kind of a machine they would order. Markku told the team had developed
a kind of standardised moulding tool: "We've always got the same body in the
tool, we aim to change only the core parts according to the shape we need to
produce." Erja stated that the moulding tool was the core of Fipak's production;
tool design and manufacture were key elements of the development process.
Marianna opined that product design was the most critical phase of the process,
because it was a node that fed information about the product to the design and
manufacture of the mould, the paperboard blank and the automation compo-
nents.

Even though Fipak's first commercial product, the Pilot package, had already
been launched and its production was on-going, Erja characterised the current
stage of production practice as "pre-production." The Fipak team were not man-
ufacturing the packages with the production equipment yet. When the partici-
pants described the production process of the hybrid package, they referred to
collaboration with the customer to specify the requirements of the product, as
well as to selection of tool manufacturer for each product. We learnt more about
Fipak's collaboration with these and other partners in the process workshops.

7.2.2 Process workshops

In the two process workshops, we discussed the unfolding of the development
process of the Customer package, which was the second commercial product of
Fipak. First negotiations with the new customer had started some six months
earlier and the Customer 1 had soon decided to buy a new package for their food
product. In the first workshop, the development process of the Customer pack-
age had proceeded until tool design and by the second workshop, first trial runs
with the mould had begun. In the workshops, the participants compared their
experiences in the development process of the Pilot package and the Customer
package. These comparisons manifested some of the characteristics of Fipak's
product and production concepts.

The core difference between the two packages lied in the tailoring of the pack-
age to the customer's packing line. Whereas the Pilot package was a totally new
package for which a new production line was built, the Customer package would

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[36] In the previous chapters 5 and 6 I have translated the participants' references to the instantiations of
the hybrid package as "package" for comprehensibility even though the participants often used the Finn-
ish word "tray" in their talk. However, in this chapter I make a distinction between the terms which the par-
ticipants used to illustrate their understandings of the product concept.

merely replace an existing package that Customer 1 had been using. Hence, the hybrid package needed to fit the customer's existing production lines without significant modifications. This limited Fipak's possibilities to design an optimal package for their own manufacturing technology, as the tool designer Markku had explained already in the introductory visit. Furthermore, the end use of the new package posed challenges for the selection of proper materials: The Customer package needed to endure high temperatures because it would be cooked in an oven. The food product to be packed required good air-tightness from the new package, because it was raw and therefore riskier to be kept during logistics and sales.

The product concept of the hybrid package had not yet been expressed comprehensively; the workshop participants talked about the requirements that the end use and the production process of this customer set. Nevertheless, two material packages, the Prototype package and the Pilot package, manifested possible properties of the hybrid package. These properties were reflected in the moulds used to manufacture the packages. The Pilot mould 2, used for the mass production of the Pilot package, had become a standardised tool by autumn 2009, a "moulding tool concept" as Markku called it, which was used as a basis for new moulds. This mould had been tested in production and features limiting the production technology had been considered in its design. Markku told about the meaning of mould standardisation in the first workshop:

> Tool designer: We've been developing this thing at the same time (…) we had to start standardising some kind of a moulding tool concept for us so that we can live with the coming size range of the other trays with the same tool dimensioning (…) so of course there's been kind of guesswork, what'll be enough and will it hit the mark (…) it's important in the tool design that we'll standardise all those things on some level and will make use of the dimensionings in future.

Despite the development work done in the preceding development process, especially to launch the first commercial package, the effects of a huge number of features on the production process were still unknown. The members of the development team told how they sometimes felt overwhelmed by all the uncertainties: "There's such a terrible number of variables that it's kind of impossible to manage that in practice," the technical manager Erja sighed in the second workshop. Especially the behaviour of the paperboard blank in the manufacturing equipment still required considerable investigation and experimentation. The paperboard blank became the focus of development efforts in the Customer project, because the high temperatures the new package needed to endure set new requirements to its properties. Additionally, the development team had observed that the measurements of the paperboard blank calculated based on the 3D model in the product design phase did not give the correct size of the blank. In the first workshop, the participants described their struggles to find out how different features of materials and the production process interacted to determine the right size of the paperboard blank. Erja told the team had found out that factors influencing the size of the blank included the used printing colours

and the injected plastic materials. In the second workshop, the participants emphasised the need to find out patterns that would enable the team to calculate the correct size of the blank. However, the paperboard blank was only one concern in the development of the product concept of the hybrid package as the next excerpt illustrates.

> *Product designer: We're working on that it [the paperboard blank] should be sized now. In a way to think about the sizing to see if we can find some kind of a pattern from those existing models to see how it functions or if we can calculate it in some other way.*
>
> *Technical manager: And another is that first we're still looking for limits on the product side, on the design side as well, all the time. It's not enough to study this paperboard blank design still or its sizing but the product side is another area where we're going on a fishing expedition all the time to see where we can go.*
>
> *Sales manager: Can we make this size or this height or depth or...*
>
> *Technical manager: Will we make sharp edges for this one or not.*

When comparing their experiences in the Pilot project and in the Customer project, the workshop participants expressed ambiguous opinions about which project had been more difficult. On one hand, they thought the development of the Customer package was more straightforward. On the other, they opined that the restrictions of the existing production lines as well as the new requirements of the materials set by the end use were complicating the process. The product designer Niina told that such restrictions were typical of the packaging industry: "Because the machine line is already bound and that machine line is used the next ten years still, then you'll never get to make any product improvements let alone to bring a new product [package] to the market." The sales manager Janne pondered that for Fipak it would be best to collaborate with customers who are building new production lines.

> *Sales manager: An ideal situation is that either the customer's line happens to be in such a stage that it has come to the end of the road and they're investing in a new line anyway, it's kind of good luck if we get in between there right at that point. Or then the customer believes in the new product so much that they're putting up a new line anyway.*

While the trial runs with the Customer mould were beginning and the production runs of the Pilot package on-going, the construction of the production infrastructure was still in its initial steps. The team members pondered on Fipak's production concept in the workshops: They envisioned that they hardly would reach ideal cost-effective mass production that would require the continuous manufacture of same high-volume products with one production equipment in packaging industry. Instead, *the team were developing flexible production equipment allowing the manufacture of various products with the same equipment.* Moreover, they were struggling to find a suitable level of adjustability of the automation components, which would not compromise the speed of the equipment.

At the time, Fipak did not have a proper robot in the testing equipment. The development engineer Tommi described problems caused by the manual placement of the paperboard blanks in the mould in the trial runs: If the packages broke in the mould or had some other defects, the team members could not be sure if this was due to the inaccurate positioning of the blank, a defect in materials or unsuitable settings of the equipment. The development team was currently planning the automation of quality control and handling of the packages in the factory. Janne told they were considering the level of automation: "In this phase we're still looking for how much it's worth automating, but it's a question of if a robot is cheaper than a human."

In the workshops, we also discussed the tasks of the team members and Fipak's relationships with the partners whose work was needed in the design and production of the hybrid package. The division of work between the team members seemed to be established – for example, certain members were responsible for communication with customers or tool manufacturers. The members told that important decisions, such as the determination of the correct size of the paperboard blank, were made together. The salespeople addressed Fipak's relationships with the customers by comparing the differences between the two customers. Whereas the Pilot Customer was a big food company with a department dedicated to package design, the Customer 1 was a small company specialized in one type of food products. The team members had experience of close collaboration with the Pilot Customer, but Customer 1 expected Fipak to deliver a ready package without their own involvement. The Customer project thus gave the development team more freedom to tackle issues faced in the development process, but at the same time they felt the project lacked a clear goal and timetable. The Customer project also introduced some new partners, such as suppliers of printing ink to find printing colours that could stand heat, and new kind of collaboration including the outsourcing of tool design to the manufacturer of the Customer mould. In the tool design, the Pilot mould 2 (the production mould) functioned as a model for the new mould; the manufacturer designed the so-called inserts which give the specific shape of the product in the mould.[37]

The workshop participants agreed that the development process of the Customer package was an important learning experience, "a good exercise," because it brought up so many things which the team still needed to work with. The process had revealed new aspects to be considered in the design and production of future hybrid packages.

7.2.3 Interview about the development process of the hybrid package

In the interview with Fipak's business manager, we traced the history of the hybrid package by discussing both the NPD 2 project and preceding product development projects in the Paper Company which she had been involved in. Marianna told that from the beginning of the NPD 2 project it was clear that the

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[37] The outsourcing of the Module mould's design followed the same procedure, see section 6.5.

production of the hybrid package needed to be cost-effective. Therefore the experiments aimed to include both the moulding of the paperboard blank and the injection of the plastic rim in one manufacturing process; some competing packages made of paperboard had been made with a two-phased process. The significance of cost-effectiveness stemmed from the fact that the production of the hybrid package was more expensive than the production of convenient packages made of plastic and aluminium. Marianna told that the price of the hybrid package could be compensated by decreasing the overall packing costs. She noted that this would require the customers to rethink their production processes: "Cost-effectiveness comes from that the customer needs to simplify its packing processes."

Marianna also described the position of packages in the product concepts of Fipak's main customers, the food industry. *Fipak tried to sell the hybrid package to their customers as an opportunity to create distinctive products* but Marianna told this was a challenging task.

> *Business manager: Traditionally, in packaging industry you sell only what already exists. And now we're selling to them [the customers] the opportunity to develop, they can approach it in the way what they'd like it [the package] to be. But it's really difficult for the brand owners to understand that they've really got limitless opportunities to take whatever [they like].*

7.2.4 Characterisation of the product and production concepts in the first phase

At this stage of development of the hybrid package and its production practices – after the launch of the first commercial package when many new packages for customers were under development – it seemed the product concept existed but its boundaries were unknown to a large extent. Similarly, Fipak's development team was envisioning the production concept, but the construction of the production infrastructure was only beginning. Figure 24 illustrates the characteristics of the product concept and the production concept in this development phase.

The product concept appeared to be ambiguous among the development team: The team members talked about the different packages under development as tailored products. The team members seemed to view the hybrid package not as a product concept but rather considered the packages as single products; they saw that the packages were dependent on customers' preferences. This reflects a conventional understanding of product concept as a representation of a single concrete product, designed and produced independently in the company and offered to customers as a comprehensive product (cf. Clark & Fujimoto, 1990).

At the same time, the team members defined the hybrid package as *a paperboard tray with a plastic rim*; I take this as the definition of the product concept at the time. This definition suggests that the concept focused on materials rather than on the design or end use of the hybrid package. The concept was manifested in two packages – the Prototype package and the Pilot package – which illus-

trated the properties of possible products. The Pilot package was the only functional product suitable for food products to be heated in microwave. The development of the Customer package and some other new packages (analysed in Chapter 6) was underway, but the realisation of their required properties was still uncertain.

Although the customers had determined the design of the packages thus far, Fipak's manufacturing technology also played an important role in the realisation of the packages' required properties. However, the dependencies between different materials and their behaviour in the production equipment remained unclear at this point. Particularly the correct size of the paperboard blank seemed to be impossible to calculate in the design phase, but the team members were also concerned about their lack of knowledge regarding the kinds of shapes that could be made with the manufacturing technology. Nevertheless, the team had been able to design a standardised but customisable moulding tool based on their experiences from the development of the first packages. Due to standardisation, the different moulds were compatible with different injection moulding machines and hence paved the way toward a flexible production process.
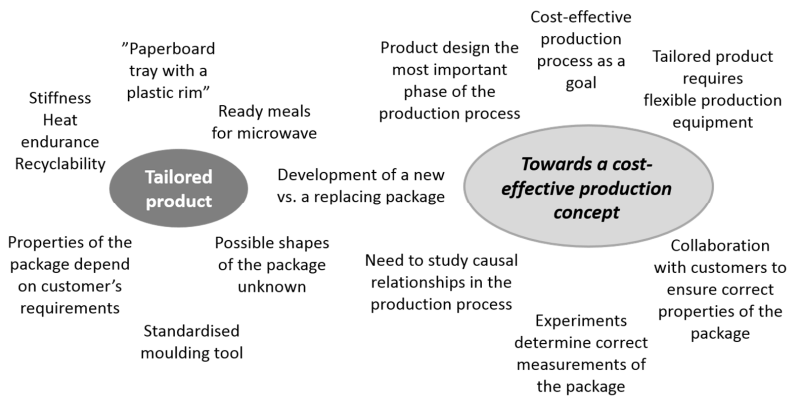
Figure 24. Characteristics of Fipak's product concept (left) and production concept (right) in the first phase of concept development.

The production concept was planned according to the requirement of cost-effectiveness, but the development team expected that only a few products could be manufactured as real mass production. Because the hybrid package was a tailored product, the production process also needed to be flexible; the mould was unique for each product but could be used in different injection moulding machines due to standardisation. The production of tailored products was seen as a transitional period on the way to real mass production; the construction of the production infrastructure had hardly begun.

The Fipak team had identified the phases of the development process of the hybrid package (they presented a model of the phases in the introductory visit;

Figure 11 in section 6.1 is a simplification of this model) and considered product design to be the key phase. Still, due to the experimental development of the properties of the packages, the determination of their exact measurements could only be accomplished through iterative trial runs. To enable systematic comparisons between experiments in trial runs, the team needed to acquire a robot for the testing equipment (this was soon realised, as the descriptions of the trial runs in Chapter 6 show). The number of iterations required to determine the correct size of the paperboard blank was costly, and the team members wanted to develop the practices of trial runs to make the phase more effective. The enormous number of factors that affected the behaviour of the materials in the manufacturing technology concerned the members, and they wanted to continue studying them.

The development work in Fipak required collaboration both between the development team members and their partners. In the NPD 1 and NPD 2 projects, collaboration with research partners had been important for the experimental development of the Prototype package and the manufacturing technology (see Chapter 5). In the development of tailored products for different customers, collaboration with the customers was essential. By comparing their experiences between the Pilot and the Customer projects, the team members drew distinctions between the development of new packages and replacing packages in terms of possibilities to design a product fulfilling the requirements of both customers and Fipak's manufacturing technology. These observations suggest that Fipak's production concept was not uniform but rather that the collaboration practices depended on key partners, especially customers.

7.3 Second phase: Searching for the limits of the product and production concepts in commercial product development projects

The most intensive discussions on Fipak's product and production concepts took place in the feedback workshop and the three concepts workshops. The feedback workshop gathered the observations of our research group concerning the three studied projects, the Pilot project (see chapter 5), the Module project (see Chapter 6) and the Customer project (see sections 6.9 and 7.2). We discussed our initial analysis with members of the development team with the aim of identifying development targets for the development phase of the research collaboration. The concept workshops were planned to enable the parallel development of Fipak's product and production concepts and tools that would support work practices in the product development projects. For the concept workshops, we continued analysing the data of the three product development projects, but also included the analysis of the preceding workshops to accumulate the data which the discussions could draw on.

We organised the feedback workshop in May 2010 to conclude the data collection phase and to introduce the Fipak team to the development phase. The feedback workshop aimed to identify learning needs based on the examination of current practices in product development projects. The workshop participants included Fipak's salespersons Janne and Annika, product designer Niina,

tool designer Markku, technical manager Erja, development engineer Tommi, production engineer Risto, operator Susanna and business manager Marianna. The researchers included Anneli, Päivi, Mika, a research assistant and myself.

The workshop discussions drew on mirror data, which our research group prepared from the data about the three product development projects. We structured the mirror data according to three themes we discovered during the analysis: conceptions of the product, network relationships and principles guiding actions in the production network. These perspectives seemed to describe the logic guiding the work practices in each product development project.

The workshop dialogues between the Fipak participants and the researchers consisted of two parts. The first dialogue of reflective character took place during the researchers' presentations of the mirror data: We discussed the three themes through our observations of the product development projects. Fipak participants not only responded to our observations but elaborated them in dialogue among themselves and with us. The second dialogue was of developmental character encouraging the participants to identify learning needs related to production concepts. This dialogue was facilitated by the researchers' questions addressing each of the three themes.

The three concept workshops aimed to identify product and production concepts, as well as to align the development of tools and work practices with the logic of the identified concepts. The concept workshops were arranged between September and December 2010. The workshop participants involved five to six members of Fipak's development team, including salespersons Janne and Annika, tool designer Markku, technical manager Erja, development engineer Tommi, production engineer Risto and development engineer Kaisa, who joined the team at the end of the year.[38] Päivi and I were in charge of organising the concept workshops and prepared their structure together with Anneli; Taru participated in the workshops as a note-taker. She was carrying out a study about the possible modularisation of Fipak's product and production, whose initial results were discussed in the third concept workshop.

In the first concept workshop, we examined Fipak's product concepts, in the second one Fipak's production concepts and in the third one we studied the evolution of both product and production concepts. Each workshop included two parts: First one during which we examined the logic of the concepts based on the mirror data and second one with a focus on information needed and tools used in the work of the Fipak team members. For the tool discussion, the team members carried out pre-assignments which they delivered to us before the workshop; Päivi and I preliminary analysed them to be used as the basis of the discussion.

The mirror data prepared for the concept workshops were structured according to our research group's developing understanding of the nature of product and production concepts. According to our analysis of the three product development projects and the dialogues of the feedback workshop, Fipak's product

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[38] The product designer Niina had changed jobs and was not working in Fipak anymore. The operator Tero was invited to participate in the workshops but his presence was not possible due to a lack of personnel in the production (only two operators were working in Fipak after Susanna had changed jobs). However, Tero carried out pre-assignments that were included in the discussed data.

concept embraced three artefacts that each organised development efforts: The package as an idea and outcome, the moulding tool and the paperboard blank. Hence, the discussion on the mirror data of the first workshop was structured to examine the properties of the artefacts from the perspectives of Fipak and their partners. According to our model of Fipak's production concepts, the development process of the hybrid package was organised around the development of the three artefacts that had their own, partly overlapping, production networks. Therefore the discussion on the mirror data of the second workshop was structured to examine the division of labour and the relationships in these production networks. The mirror data discussed in the third workshop examined the evolution of Fipak's product and production concepts through learning about the properties of the hybrid package and development of work practices.

7.3.1 Feedback workshop

In the first part of the feedback workshop, we discussed the properties of Fipak's products and the work practices in product development projects through the mirror data. Figure 25 exemplifies our way of presenting the mirror data: It portrays the collaborative development process of the Pilot package at Fipak and the Pilot Customer, highlighting the artefacts under development in each phase.[39] We used such illustrations to depict our observations of the conceptions of the product held by different partners and the relationships between the partners in the studied projects. During our presentation of the mirror data, we asked the participants to respond to the observations; often the mirror data led to a dialogue between the team members during which they reflected on their experiences. In the second part of the workshop, we directed the discussion to the identification of learning needs based on the preceding discussions. Our questions prompted the participants to discuss their current work practices and their logics; they identified tensions between the guiding logics. We also presented the first version of our model of learning production concepts, which included the notions of product concept, production concept and boundary tools (see Figure 26).

Discussion on the properties of the hybrid packages developed in the three projects showed *the product concept still lacked comprehensiveness that would have characterised Fipak's product offering*. The workshop participants stated that the hybrid package needed to fulfil the same requirements as any package for food products; additionally it provided benefits of the paperboard material, such as recyclability and printability. The product designer Niina noted that in practically all packages, different materials are combined because together they provide the required properties; the hybrid package appeared more compact because plastic and paperboard were united in it instead of appearing as distinct parts of the package. The participants lamented that their customers were not keen on utilising the distinctiveness that the printability could provide to make

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[39] All examples of mirror data presented in this chapter have been translated from Finnish and slightly modified for the use in the thesis.

the package stand out from its competitors. They thought the features providing uniqueness should be emphasised more in the marketing of the hybrid package.
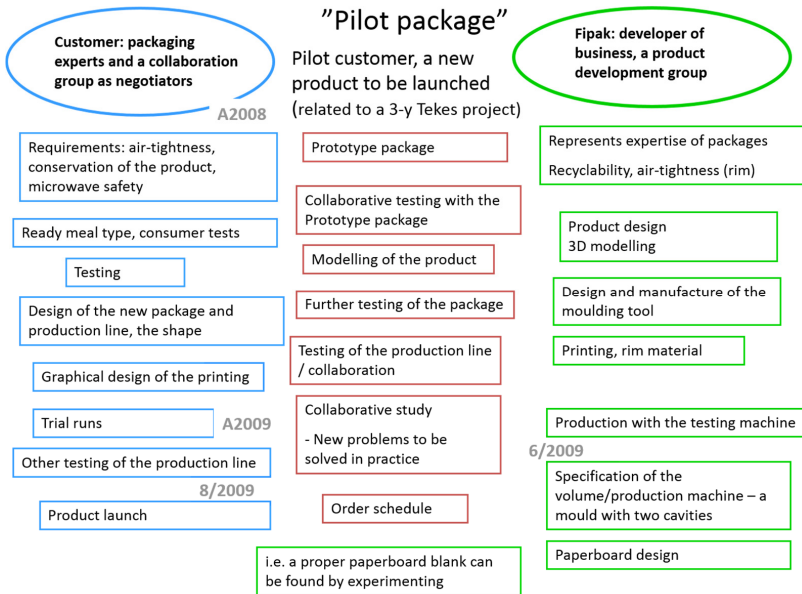
Figure 25. Example of mirror data about the development of the Pilot package discussed in the feedback workshop.
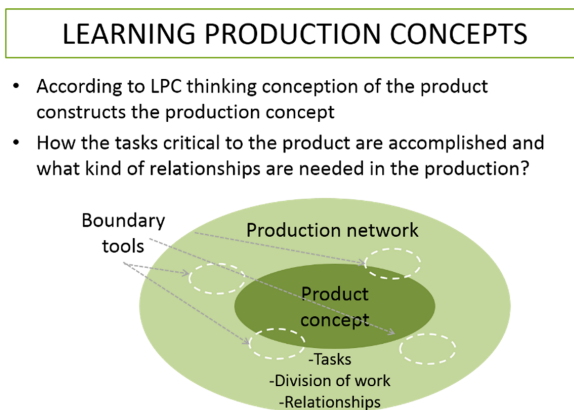
Figure 26. The initial model of learning production concepts presented in the feedback workshop.

The marketed uniqueness of the hybrid package was also problematized in the feedback workshop; the participants contrasted it with the requirements of mass production favouring standardisation of products to make their production cost-effective. The team members brought up that the food companies were problematic customers who did not put much weight on the package and were thus reluctant to invest in new production lines to improve the distinctiveness of their products with a new kind of package. Fipak's salespeople pointed out that the customers compared the price of the hybrid package with cheaper alternatives. Niina noted that in sectors such as electronics the package itself could be considered as part of the product experience, which could justify the price of the package. She pondered that the packages, which the hybrid package needed to replace, had once been designed on the terms favourable for the materials used in the original package. Niina thought it would be much easier to design and manufacture good packages if that could be done according to the requirements of Fipak's own technology.

> *Product designer: Now we're kind of trying to twist materials and techniques that don't necessarily function ideally in some case, exactly to the same size. (...) And then it happens that it [the package] won't fit the existing [production] lines and other [stuff]. If only we were allowed to design this product with this [our] technology and these materials uniquely into such a [thing] which would be good to make, then it would probably be much more gratifying to do.*

The fact that the properties of the hybrid package currently followed the requirements of food industry made the participants ponder potential requirements of alternative customers. The team members agreed that the limitations of the manufacturing technology had not been faced yet because the shapes of the developed packages had been quite conventional thus far. Niina envisioned that if Fipak got customers outside the food industry, the design of the packages could become more challenging because the requirements concerning the functionality of the hybrid package, such as opening mechanisms, would probably be higher. She suggested that for the food industry, the development of the hybrid package concentrated on materials development, which omitted more creative design of shapes. The product engineer Risto stated that the food industry set the standard for the hybrid package in terms of hygiene; if the package fulfilled them, it would serve other customers – perhaps with the exception of pharmaceutical industry.

In discussions about Fipak's production concept, two different logics were identified. In the mirror data, we suggested *a shift in logic over the consecutive product development projects: The Pilot project was characterised by the logic of research-oriented product development, while the Customer and the Module projects aimed towards commercial mass production*. The participants discussed the differences between these two logics on different occasions during the workshop, exemplified by the following excerpt; Risto concluded by summarising the dilemma between the two logics.

> *Researcher: Could we think that what appears as natural in a research project and [on the contrary] when thinking that everything should happen fast and be correct at once – so [it's not natural] when aiming at mass production. So it's not natural whereas...*
>
> *Sales manager: Yes, in a research project, it'd be extremely fruitful that you get something new to investigate each time.*
>
> *Product designer: And I think we have indeed been talking about this together too, that there's the problem that we're still somehow in between. We should also carry out research work, but at the same time, we should already be doing sheer manufacturing...*
>
> *Sales manager: Manufacturing for customers...*
>
> *Product designer ...where we should make it work at once.*
>
> *Production manager: Yes, they are two totally different things, research and [production]. They don't work when you always need to change something. When you go to production, then everything can be completely upside down, then it isn't the way we first thought.*

The properties of the hybrid package had been developed in projects for customers so far; the workshop participants called for anticipative study of new properties. The technical manager Erja emphasised that the development team needed to anticipate the possible requirements of customers by testing the behaviour of different materials on their own before those were used in commercial projects for customers. The team members agreed that documentation of the experiments was necessary for the further development of the properties of the hybrid package. The sales manager Janne summarised that Fipak's goals in the further development of the production concepts included both mass production and product development, in which collaboration with customers was essential.

> *Sales manager: We strive to have those standards [standard products] which we can freely offer. But still we want to keep the total innovation activity too, not only separated from product development. But we'd still have those kinds of projects where we develop something new with a customer.*

When talking about Fipak's take on mass production, the team members emphasised the criterion of cost-effectiveness, which meant the manufacture of the hybrid package should require only little human involvement. However, the current production volumes did not enable optimal cost-effectiveness because single products did not fulfil the capacity of one unit of production equipment. Thus *Fipak's production concept was characterised as flexible mass production: Various products were produced with the same production unit, requiring flexible automation and smooth change of moulds.*

The mirror data indicated that the work practices in product development projects depended on preferences of Fipak's customers. Especially the business manager and the salespersons made comparisons between the three different customers who had been involved in the studied projects. They pointed out that

the representatives of the customers who engaged in the negotiations influenced possible modes of collaboration: It was easier to get required information for product design when representatives of the customer's production were involved. They also reflected that the expectations of the customers differed between those ordering a new product and those ordering a replacing package. Janne pondered that they might need to tell to the customers that also the design of a replacing package required collaboration to obtain the necessary information from the customers.

> *Sales manager: The difference there is that, at the outset, [the Pilot Customer] has had the understanding that now we're developing a new package, this requires development. Then we have ourselves marketed to these two other customers that, okay, now we're doing a replacing package and this is a standard package. But should we have tried to emphasise more that this requires collaboration as well?*

In terms of collaboration with suppliers, the participants emphasised both the availability of services and the acquisition of knowledge. Erja told the team intended to have alternative suppliers of necessary components and materials. At the moment, this was the case with the design and manufacture of moulds, the provision of production equipment and the printing of paperboard blanks, but Fipak lacked options for the supply of plastic materials. The workshop participants compared the current suppliers in terms of the quality of their work and especially of their engagement in collaboration. Janne concluded that relationships, which enabled learning from the partner's expertise, would be beneficial to Fipak's development work: "We'd get those kinds of relationships where the opposing side would start to tell more on its own initiative, that it wouldn't remain a buyer-seller [relationship]."

7.3.2   First concept workshop

The first concept workshop aimed to identify product concepts based on requirements and characteristics of previous products; the discussions focused on the properties of Fipak's products. Through the analysis of the data accumulated so far, our research group had created a model of Fipak's product concept and production concept (Figure 27). We suggested *the product concept depended on the combination of the properties of three artefacts, the tray (the package), the moulding tool and the paperboard blank.* Furthermore, the model depicted production networks formed around the design and production of these central artefacts. Following the idea of the LPC project, we suggested the development of product concepts and production concepts was an on-going effort that could lead to a so-called learning production concept, where 'boundary tools' provided coherence in work practices at boundaries of work communities.[40] The model was modified after the first workshop based on feedback from the participants

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[40] The importance given to boundary tools in the model of learning production concepts followed the CHAT understanding of the mediating role of tools; we proposed the logic of the concepts could be embedded in the tools used in cross-boundary collaboration.

to include a fourth central artefact – the plastic rim – as an essential part of the product concept.

When Päivi and I presented the model for the first time in the workshop, *the participants brought up the plastic rim was missing from the picture*. They emphasised that *the rim was an important part of the hybrid package because customer's requirements influenced the choice of plastic material*. The technical manager Erja also pointed out that the development of plastic materials was part of Fipak's product development efforts. We noted that the rim as an artefact only came about in the manufacture of the package and thus did not form an own production network in the same way as the moulding tool and the paperboard blank. Erja suggested the rim was connected to the tray, because it related to the properties which the package should contain. We pondered on this feedback after the workshop and introduced the plastic rim into the model for the second concept workshop (see Figure 27).

The plastic rim played an important role in the discussion of the product concept, because new products that were under development for new customers had brought up a new design of the rim. Whereas the food products for which the hybrid packages had been used this far had required tight sealing due to packaging gases (modified atmosphere packaging, MAP), these new products did not require similar air-tightness. Instead of sealing the hybrid package with a plastic film, the new packages would use different kinds of lids and thus require a different form of rim. The salesperson Annika pointed out that the question of the new kind of rim and possible lids brought up the conception of what the hybrid package was all about.

> Salesperson: I think it's getting more and more emphasis that after all we need to offer the customer packages, not only trays. Where the lids will be got from, it doesn't mean that we necessarily need to make them ourselves, but they need to be taken into account already at the stage when we're offering the tray to them. It might be that in some cases we'll indeed make the lids, if it suits the customer's needs.

The question of whether the hybrid package should be thought as a tray (without a lid) or as a package (including different kinds of closing mechanisms) was a remarkable one from the perspective of Fipak's product concept. Until the first concept workshop, the team members had been referring to the different products as "trays" most of the time, sometimes as "products" and only occasionally as "packages." Still, the idea that the hybrid package could include a lid was not new: During the NPD 2 project before the launch of the Pilot package, different kinds of packages had been designed to portray possible uses of the hybrid package and some of them had already included lids (see Figure 23). However, it was at this point when Fipak was developing packages with a lid that questions about what the product actually contained surfaced. The product concept seemed to have become clearer in the sense that the team members were able to formulate how the hybrid package stood out from the competitors. As Annika put it: *"It's the first recyclable, packaging gas tight, ovenable package."*

LEARNING PRODUCTION CONCEPT: LEARNING FROM EXPERIENCES, CONTINUING DEVELOPMENT OF ACTIVITY

BOUNDARY TOOLS

BOUNDARY TOOLS

MARKETING

PRODUCT DEVELOPMENT

PRODUCTION

CUSTOMER

STORES

CONSUMERS

PRODUCTION LINE SUPPLIER

TRAY

PLASTIC RIM

TOOL DESIGNER

PRODUCT CONCEPT

ADVERTISING AGENCY

GRAPHICAL DESIGN

MOULDING TOOL

PAPERBOARD BLANK

PAPERBOARD PROVIDER

TOOL MANUFACTURERS

COMPONENT MANUFACTURERS

EQUIPMENT PROVIDERS

PRINTING HOUSES

PRINTING INK PROVIDER

PLASTIC MATERIAL PROVIDER

COATING PROVIDER

AUTOMATION PROVIDERS

DIE-CUTTING PROVIDER

DIE-CUTTING TOOL PROVIDER

BOUNDARY TOOLS

BOUNDARY TOOLS

Figure 27. Model of Fipak's product and production concepts discussed in the second concept workshop.

Fipak's product variety and the customisation of the hybrid packages was another important question concerning the product concept, which had already been raised in the feedback workshop. The tool designer Markku (who was in charge of the product design in addition to tool design now that Niina was not working in Fipak anymore) brought up how difficult it was to create initial designs of possible packages when customers gave very little information about their preferences. He suggested it would be easier if Fipak had its own repertoire of packages to be marketed to customers. Annika noted that according to chartings Fipak had made, the food companies did not use standard packages but each package manufacturer had their own offering. She and Erja reminded that Fipak had been marketing the versatility of their offering.

> Salesperson: It'd be easy if we had universal trays in use so we could make same kinds and offer them [to customers]. But unfortunately it feels like every manufacturer has own ones [package designs] and the customer has own wishes too. And of course we've also given that kind of a message to the markets that we can offer lots of different sizes and shapes etcetera. Surely we haven't started from 'here's our portfolio, take it or leave it'. But of course we'll need to see what will be sensible in the long run anyway, how we'll be able to operate.

> Technical manager: We've been banging about this innovativeness quite a lot now in the beginning. And maybe it's now connected with getting that kind of a box you're asking for. And of course we aim to be versatile.
> Salesperson: Yes we've been plugging that quite a lot indeed.

Päivi and I proposed that the question of whether the package to be developed was new or needed to replace an existing package, was decisive for Fipak's product and production concepts. Whereas some team members had regarded the replacing package as an easier case in the process workshops about one year earlier, now the workshop participants agreed that every new package required development efforts. Erja crystallised this understanding; the production engineer Risto continued that the development of a replacing package was actually more demanding for Fipak.

> *Technical manager: As you [researcher] said, this is always more or less a product to be developed. Whether it's new or replaces an old one, it's always a product to be developed, that holds up. If it does replace an old one, we need to take into account the production lines and thus design the product every time anyway.*

> *Production engineer: For us it's maybe more challenging to develop a product for existing [production] lines, because then there are clear limits we need to follow, clear measurements. If we're making a new product, completely our own product, then we're taking existing, easy and safe ways there. Now the heights and widths and all kinds of things are dictated to us. Then it's possible that so-called surprises appear, that paperboard doesn't necessarily bend with these existing systems immediately. That's pretty challenging.*

Even though the first workshop focused on the examination of Fipak's product concepts, aspects of the production concept were also touched upon. When discussing issues connected with the tray, the influence of the customer and the relationships between Fipak's and the customer's representatives were emphasised. The participants brought up Fipak was dependent on the customer's knowledge of the consumers' preferences. This was a current concern for the team because Pilot Customer's sales forecasts of the product packed with the Pilot package, Fipak's first commercial product, had not been met. The sales volumes of the product had fallen short of the Pilot Customer's forecasts, which made the team members speculate whether the Pilot Customer could market the product to new consumer groups to keep it on the market. Meanwhile, Fipak was marketing the hybrid package abroad and first contacts with potential international customers had already been established.

When discussing issues connected with the moulding tool, we touched upon the meaning of flexible automation in Fipak's production: Markku and Risto told the moulds were changeable between different injection moulding machines, but they envisioned that there would be more variety between the automation used for different products in future. Päivi, Taru and I had visited the factory the same morning and seen the current phase of automation. Päivi observed the development had been remarkable: New automatic devices, which had not been installed when she had followed the production runs of the Customer package only one month earlier, were now in use. Risto remarked the team were only at the beginning of the automation, because they were only starting to experiment with the new devices.

7.3.3 Second concept workshop

The second concept workshop aimed to identify the guiding logics of Fipak's production concepts. We first discussed the properties of Fipak's product concepts based on the previous workshop and then investigated the characteristics of their production concepts.

Like in the first concept workshop, we examined the production of the tray, the moulding tool and the paperboard blank separately according to the updated model (see Figure 27), to which we had added the plastic rim. While Päivi and I were summarising the issues related to Fipak's product concept which had been identified previously, the participants continued discussing what the repertoire of products could mean.

> Technical manager: On the other hand we could anticipate a bit the ready offering as well. I've been thinking that we must get this response time a bit shorter. If we'll get some inquiry, we should make shorter the time to really get some sample or product in our hands. In a way we should be able to study things that much in advance so we can shorten the response time, we'll have a little bit of repertoire. It might not be on the product level but it can be on the level of materials or shapes.

With the mirror data, we asked the participants what the expansion of Fipak's business abroad could mean from the perspective of the product concepts. Especially the significance of recyclability of the hybrid packages as a sales argument for foreign customers was uncertain due to the different recycling systems in different countries. Nevertheless, the participants told that for some potential customers the reduction of packaging material enabled by the hybrid package was an important factor in decision-making. Whereas conventional plastic packages were often wrapped with a paperboard sleeve containing product information and communicating the brand with graphics, the hybrid package combined the plastic and paperboard into one, seemingly unified product.

The discussion also returned to the question of product tailoring and the customers' understanding of what it meant. The sales manager Janne brought up that the customers were used to either buying a package from the manufacturer's standard offering or designing their own package which the manufacturer was to make according to their wishes. Although Fipak had been marketing customisability of the hybrid package, its customisation had boundaries due to the manufacturing technology.

> Sales manager: That's just that shown up there [on the slide], the customer's own product concept, do they themselves know what they want from the beginning. Of course there's the thing, we're in that kind of a position that we're giving a bit of leeway to the customer. They don't need to know what they want at the outset, because we're advertising this customisability. Maybe the customer is used to buying packages either off the shelf or then some packages can be modified just as the customer wants. Our model might be in the middle: We're tailoring but with certain limitations. It might make the customers [wonder] a bit like 'can we decide fully freely or not.'

Furthermore, the participants recognised the significance of feedback in the development of the hybrid package. In the mirror data, we addressed the significance of the customers' knowledge of consumer preferences to the development process and the commercial viability of the hybrid package. The participants noted that grocery shops were important stakeholders in the delivery process, because they were the ones selecting the products from which the consumers could choose what to buy.[41] Especially the product engineer Risto wished to receive feedback from customers about the hybrid package to get information about possible needs to improve the production process. He noted that the customers could get feedback from consumers and shops and when this feedback was about the package, it would be important to hear about it from the customers. Janne noted that they had held a meeting with the Pilot Customer some months after the launch of the Pilot package but had not received any important feedback on the package.

When talking about the role of the customer in the development process, the participants noted that in the Pilot project, the significance of the participation of the Pilot Customer stemmed from the sense of a concrete deadline in addition to the development work which had been carried out with them. The technical manager Erja pointed out that the involvement of the customer brought along "a driving force," a necessity to make things happen. Janne continued that a more autonomous, "basic product development project" did not necessarily have a pressing final point.

Once again the wish to decrease the time used for iterations between the trial runs and the modification of artefacts came up. Janne and Erja stated that shortening the experimental phase of the development process required learning from the experiences with the products under development.

> Sales manager: I suppose that kind of general level of knowledge has been rising all the time. With every new product, testing and trial runs will still remain, that's the crucial phase. But of course we hope that it would be as short as possible. But we'll hardly ever get rid of it.

> Technical manager: Right there we need learning, to make it shorter and shorter. We'll never get totally rid of it, but we should minimise it.

The naming of products indicated Fipak's aspiration to develop a range of standard product concepts. When going through the pre-assignment about open questions in Fipak's on-going product development projects for different customers, Päivi and I brought up that different team members had used different names for the projects in their assignments. The workshop participants pondered that naming practices reflected the task areas of the team members. They brought up a new practice of product codes, which were assigned to projects that passed to the phase of tool manufacture. However, new projects were still called with the customer's name because it was uncertain whether they would proceed

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[41] Finnish grocery trade is highly centralised: Two major chains hold a market share of almost 79 % (2014) and large supermarkets, which make 30 % of shops, account for 79 % of all grocery sales (Finnish Grocery Trade Association 2015).

to production, whereas old products were named according to the old conventions because the product codes had been introduced after these products were already in trial runs. Janne pointed out that when a package was not developed exclusively for one customer, it was not sensible to refer to the product with the name of the first customer. Thus *the product coding practice reflected Fipak's aim to develop a standardised repertoire of hybrid packages which could be offered to several customers.*

> *Technical manager: Actually, that's a fact, different people talk differently. Sometimes it's difficult to follow yourself, what are we actually talking about here. You [the salespeople] are maybe talking more with the customer's name and somebody has told me [the product code] at some point so that's what I'm sticking to. [laughs]*
>
> *Production engineer: Yeah, and there are so many of them [products] going at the same time that you always need to think a bit like which one is which one.*
>
> *Sales manager: Now we've got the [product] coding in use so that in the phase where a production mould is made, this kind of product code comes which we can use for all kinds of general [things]. Especially if we can sell it [the product] freely to anybody then it's no use to call it with the customer's name.*

In the mirror data, we suggested collaboration between Fipak and their suppliers as part of the production concept. We asked the workshop participants, what kinds of relationships with the suppliers the iterative development of the moulding tool and the paperboard blank required. Erja opined that the most important issue was that the suppliers needed to be able to commit to fast timetables. We suggested the mould manufacturers had participated in the development of the technology as well. The tool designer Markku pondered that the feedback of the manufacturers concentrated on issues related to techniques of the mould manufacture. He thought the manufacturers' suggestions were based on them comparing Fipak's moulds with other moulds they had manufactured. Markku noted that the participation of the manufacturers in the development of the moulds would require them getting more information about Fipak's requirements. Erja and Markku thought that in cases of outsourced tool design it would be good to have the designer present in the first trial rounds of the mould, but this would increase the costs of tool design.

The workshop participants noted that the manufacture of the hybrid packages in "production scale" required testing and implementing new automation equipment. The equipment included a device for visual quality control, a packing robot and a case erector for making the boxes in which the hybrid packages were packed for transportation. *The participants characterised Fipak's production as flexible but tied to production units*: The automation could be tailored by defining product-specific programmes but the robots were tied to certain injection moulding machines and the production units were thus fixed.

7.3.4 Third concept workshop

The third concept workshop aimed to identify phases in the evolution of Fipak's product and production concepts and to outline a future path for the continuous development of learning-based production concepts. We first discussed the characteristics of and open questions related to Fipak's production concepts based on the second workshop, then presented initial results of the modularisation study and finally moved to the evolution of product and production concepts.

Our model of learning production concepts proposed a focus on the meaning of learning in the development of product and production concepts: How the concepts could both encourage and embody learning of the team and their partners. When summarising the discussions of the second workshop, Päivi and I pointed out the role of customers in determining the work practices in product development projects. The extent of collaboration with the customer depended on relationships with the customer's representatives. We characterised a collaborative relationship with reference to a "co-configuration" type of work, made known by Victor and Boynton (1998) and further by Engeström (2004), whose meaning in Finnish is co-development (*yhteiskehittely*). The participants paid attention to the word, which they associated with independent product development without a clear goal: They thought that it characterised the early development phases of the hybrid package. They emphasised that in the current situation the team needed to concentrate on goal-oriented development instead.

> *Sales manager: To my mind, our product development is more based on these customer projects. I think [we] all agree that it'd be nice if we had more time and resources to do independent [development] which doesn't necessarily have that kind of customer pressure. But of course as a starting unit we don't want to sell 'we don't have it' much. If we get something from the customer, we try to see how we can work it out. If we had more time and resources for the independent [development] then it could be that there would be this kind of more informal development. Now it's this kind of frantic, maybe more goal-oriented.*

> *Researcher: We just met Marianna [the business manager] and went through the history a bit (...) behind it is a kind of product development phase during which there maybe has been more that kind of freer...*

> *Technical manager: Surely there was a bit of that kind of development to begin with, in the phase when we were looking at whether this paperboard could be moulded in the moulding tool and, at that point maybe there was a little...*

> *Sales manager: Yes, it shouldn't be [aimless] development [42] any more.*

> *Technical manager: Yes, after we discovered that it [the package] can be moulded in the mould and a rim can be injection moulded into it, maybe starting from that it has been more like [goal-oriented] development.[43] [makes a laugh]*

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[42] In Finnish language, there is a difference between verbs "kehitellä" and "kehittää" (as well as nouns deriving from these verbs): The first one can be understood as a dabbling-kind of activity that does not necessarily lead anywhere, whereas the second one has a more goal-oriented meaning, as exemplified in this dialogue.

[43] See previous note.

The preliminary outcomes of the modularisation study showed that different customers emphasised different requirements of the hybrid package. The modularisation study illustrated what properties of the hybrid package the Fipak team, their customers and suppliers regarded the most important in its development and use. The workshop participants found it interesting that the customers who had taken part in the survey did not emphasise one criterion of the hybrid package as the most decisive. They were positively surprised because the customers had given only little weight to the price of the package; this observation made them admit that price-sensitive companies would hardly become Fipak's customers. When we asked how the participants interpreted the equal distribution of factors (ranging from the appearance of the package to its logistics) the customers held important, they pointed out that such a distribution corresponded with the complexity of the product and its various ways of use, making the hybrid package potentially stand out from the competing alternatives.

> *Technical manager: It also describes how complex the product itself is and to what kind of end use it's going, because it has many requirements and with those come many things which are held important.*

> *Sales manager: Yes or if you turn it into that kind of positive marketing thinking then maybe we could think that we're a more diverse alternative compared with some competing products, because there are so many different factors.*

> *Technical manager: We respond to many needs.*

When discussing the evolution of Fipak's product and production concepts, we researchers suggested the concepts had evolved in parallel and their evolution had taken place through the development process of the hybrid package until these days. We had outlined different phases in the development of the product and production concepts with a picture which we presented to the workshop participants. The picture (Figure 28) included four phases in the evolution of the concepts; additionally, it characterised the production concepts according to product development projects belonging to each concept or marking transitions between the concepts.

Päivi and I proposed Fipak's product concept had evolved through learning from the different product development projects for customers. We described how the different products that revealed different factors affecting the design and production of the hybrid package both expanded and specified the properties of the product concept. However, we did not specify the phases of the development of the product concept in terms of the identified properties of the package. The workshop participants seemed to agree with our understanding of the accumulation of learning through different projects.

> *Researcher: We've talked here that in a way you've learnt more about the product in each project. On one hand what kinds of possibilities and on the other*

what kinds of limitations [the product has]. We think that on one hand it expands the concept and on the other it specifies it to a certain extent each time when a new kind of product and end use and customer comes.

Technical manager: With each one we're kind of defining more specifically the field where we can operate.
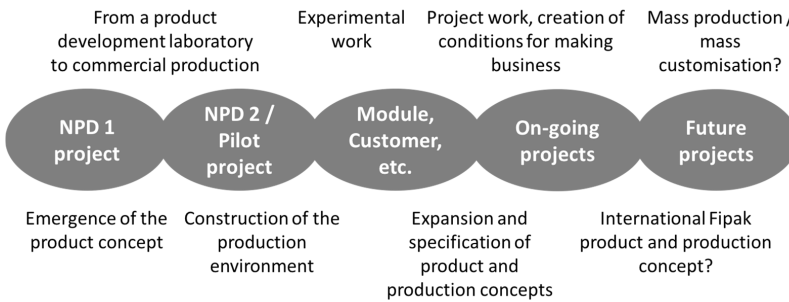
Figure 28. Evolution of Fipak's production concepts through product development projects.

Similarly, we suggested Fipak's production concepts had evolved through the product development projects, as depicted in Figure 28. We characterised the first product development projects leading to the production of the Pilot package as a transition from laboratory-like product development to commercial production. These projects (Module, Customer and Food), which we had followed in the data collection phase, were marked by iterative, experimental work, whereas the ongoing projects which were discussed in the concept workshops included more established practices, exemplifying project work. The sales manager Janne agreed that the basis for the production concept had been laid in the first product development projects. The technical manager Erja suggested the production concept was not final but could be redesigned to enable the production of different kinds of packages.

Researcher: We thought of them as kind of micro phases (...) when there's long-term product development even before the [NPD 2] project, which we went through with Marianna, then it's been quite a big leap from the product development activity to the first commercial [Pilot project]. You've been kind of creating the product concept but then questions about the production environment and requirements of production have appeared and then what the production concept could be. And then these later customer projects have been kind of smaller development.

Sales manager: Yes, the biggest frames have been discovered in those two first ones [projects]. The rest is a kind of specification of it. Although big things have of course appeared after it as well but...

Technical manager: Yeah. Then on the other hand you can put this totally, this was one field and then we can make this in a totally different way and then we'll

*make there that kind of a field where we can operate. We'll turn the moulds and
products and automation inside out.*

The picture of the phased of concept development (Figure 28) left the next steps
in the development of Fipak's product and production concepts open. Päivi and
I asked the participants, whether the product concept had been identified so
that the important question would be the expansion and internationalisation of
the production concept. Erja confirmed our understanding by returning back to
the question of phases in the development of the product and production con-
cepts and by emphasising the role of customer involvement in the successful
commercialisation of the hybrid package.

> *Technical manager: They'll probably be the next steps. Actually, the thing about
> the customer coming along with the [Pilot project] brought to my mind that, in
> a way, it has brought with it the necessity to work on the product until it's ready.
> (…) When there's no such necessity behind in this kind of a development project
> then it can be the job doesn't proceed very briskly. It's been kind of one own step
> that we've developed this production concept and product concept in the [NPD
> 2 project], but then the next big step to bring it fully to the end has maybe been
> the next phase there. And now how to bring it to the world is maybe one thing.
> And will we then do something in a totally different way, is a next step again.*

Now that Fipak was installing new production equipment and increasing the
level of automation, which required heavy investments, the unit needed to prove
its commercial viability by expanding the customer base. In our interview with
Fipak's business manager Marianna, she told the unit needed to have high turn-
over to stay within the Paper Company, not interested in niche businesses. The
workshop participants shared this understanding, as Erja put it: "When the best
charm of novelty disappears then we really need to prove that we're a viable unit
here." The participants described the pressure for commercial production
showed in the team's work: They needed to prioritise production runs over trial
runs because both were competing for the limited time of operators and the
same equipment.

Päivi and I suggested the development of the product and production concepts
could mean examining each potential customer project to see how it fitted the
existing concepts and whether it would bring new qualities to the product or
production concept. The participants told the team were already comparing in-
quiries about new products with hybrid packages which had been developed
earlier for other customers. Janne described how the team used to review exist-
ing products when a new one was proposed. Later Erja told they had chosen not
to start development projects for products that contained many uncertain fac-
tors that could make the project fail. The salesperson Annika added that the
team had learnt about the limitations of Fipak's technology with each project,
which helped them to turn down uncertain projects.

> *Sales manager: When a project comes we check if an existing product fits the
> production concept, for example if we can copy some of these current models, to*

> *act in the same way. Of course the mould will be new and some parts but [to see] if it's otherwise mainly something we've already made before.*

> *Salesperson: Of course our own limitations become clearer and clearer to us all the time, so that now it's easier to make this choice than it was in the beginning.*

> *Technical manager: The product concepts are getting more specific.*

During the discussion concerning tools that would support the development work in projects, Erja proposed a distinction between development projects of certain products for customers and independent development of materials, which potential project management software would provide. Erja suggested they could create general development projects in the software according to different kinds of plastic materials used in the packages. Janne saw that this would enable the accumulation of information from different customer projects as long as the team could identify what information was relevant for the development of materials. Erja continued that specific customer projects could also use the knowledge base of general development projects. The insight of using interconnections between Fipak's independent product development and development projects for customers to accumulate knowledge was elaborated in two tool development workshops, which took place in January and February 2011 and focused on the establishment of a project model and the development of project management tools.

7.3.5 Characterisation of the product and production concepts in the second phase

After having completed various commercial product development projects for different customers and having constructed a highly automated production infrastructure, Fipak's development team had quite a clear understanding of both the potentialities of the hybrid package and the requirements of its manufacturing technology. Fipak were facing pressure to take full advantage of these potentialities by generating profitable business with their products while the focus on commercial production decreased their opportunities for independent product development. Figure 29 illustrates the characteristics of the product concept and the production concept in this development phase.

The product concept had become more specific through the t product development projects that had brought forward different properties of the hybrid package. The product needed to fulfil the same requirements as any other package for food products, while paperboard material provided additional benefits, such as recyclability and printability. Even though most of the packages developed in these projects were still tailored according to the requirements of a specific customer, the development of the first standard packages, which could be offered to several customers, was on-going. An important question at this point was whether Fipak should refocus the development of the hybrid package towards a standardised offering of products to different end uses or continue to market the package as a customised product. Projects where a replacing package had been developed for a customer's existing production line had showed that

the customisability of the hybrid package had limits due to the manufacturing technology. Furthermore, uniqueness as a key characteristic of the product concept contradicted the cost-effectiveness requirement of mass production, because the current production volumes of the products did not enable the continuous manufacture of a single package in one unit of production equipment. The introduction of product codes also marked a step towards the standardisation of the product, because codes were given to hybrid packages with the expectation that a package could be offered to several customers once it had been created according to the requirements of the first customer ordering it.
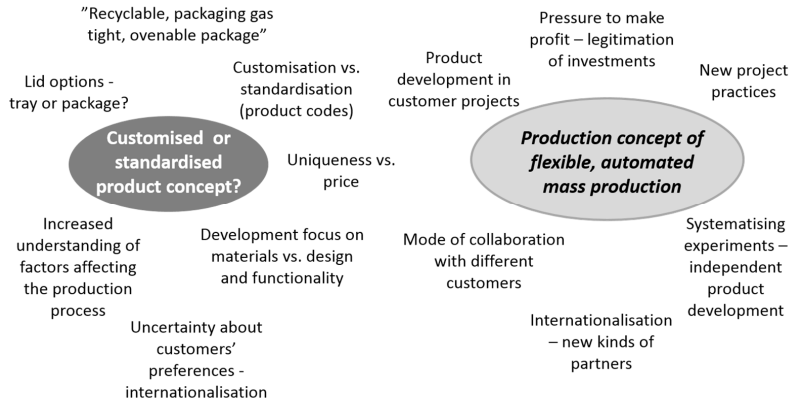
Figure 29. Characteristics of Fipak's product and production concept in the second phase of concept development.

During this phase of concept development, Fipak took the first steps towards the standardisation of product concepts. Due to an improved understanding of the effects of different factors on the production process which the team members had obtained through the development of different kinds of packages, they were better able to use existing designs in the modelling of a new product. However, the creation of standard products was difficult, because the team still lacked comprehensive knowledge about the preferences of potential customers.

Food companies as the primary customers also compromised the attractiveness of the uniqueness aspect as a key characteristic of the product concept. Investing in new production lines to put a new package into use was a threshold for many companies, because it was difficult to embed the price of an expensive package within the price of a food product. The target customers also influenced the focus of the development efforts, which had centred on the behaviour of different materials in the production equipment and the end use of the package. Meanwhile, the functionality of the hybrid package had received less attention because the customers had presented only modest requirements, but the question of possible lid models for new packages brought functionality to the centre stage. The possibility of considering lids as part of the product concept could potentially expand the team members' conceptions of the hybrid package, and

this materialised in the question of whether the product concept should be viewed as a tray or package.

Moreover, the expansion of Fipak's business abroad put the product concept to a more rigorous test; the salespeople were rethinking their sales pitches to address the requirements that customers operating in different markets held important. Experiences with the modest success of the Pilot package in the market[44] demonstrated the importance of customers' knowledge about consumers' preferences and emphasised the gatekeeper role of grocery chains. However, Fipak was dependent on their customers' knowledge of consumer preferences, because consumers had been out of Fipak's chartings concerning the potential requirements of the hybrid package.

The production concept of flexible, automated mass production was close to realisation on the shop floor. The production infrastructure was still under construction, and the testing of new automatic devices was only beginning; however, the development team could envision how the production system would work as a whole. At the same time, the significant investments in new equipment increased the commercial pressure for Fipak to demonstrate their viability as a business unit. Therefore, the development team concentrated on development projects for customers even though the members saw the need for independent product development to further study the potentialities and limits of the product concept. Nevertheless, the team members acknowledged that customer involvement could also act as a driving force in the product development process, contributing to its finalisation.

Commercial pressures were also reflected in the team members' aspirations to optimise the trial runs. While they acknowledged the experimental nature of the product development process, they aimed to decrease iteration in the product development process to reduce time and costs. They considered documentation of the experiments to be key for reaching these goals and for increasing the knowledge base that future development work could draw on. The team also planned to carry out systematic experiments with different materials and shapes to study their behaviour. Such independent product development work would enable the team to anticipate possible customer needs, although the commercial pressures made it difficult to arrange resources for these efforts.

The need to carry out several commercial development projects at the same time demanded that the development team establish new project practices, such as meetings and tools for collecting information, to keep up with how the projects were proceeding. Moreover, the team were planning to acquire project management software; our research collaboration in the definition of project phases and their information needs were part of this work.

Fipak had established supply networks for the production of the paperboard blank and the moulding tool (see Figure 27) and had laid out principles for choosing partners for a specific project. However, the internationalisation of Fipak's business called for collaboration with new partners. To reach customers in international markets, Fipak was negotiating with local distributors and re-organising sales efforts within the unit. The team members saw collaboration

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[44] The production of the Pilot package ended during 2010.

with customers as a necessary part of their production concept to ensure that essential information regarding the customers' requirements could be obtained and taken into account in the product design. However, they acknowledged that different kinds of customers engaged in collaboration to different extents, which required the team members to adjust their work practices accordingly.

7.4 Third phase: Establishing the boundaries of product and production concepts

Our research collaboration with Fipak ended in March 2011 with an evaluation workshop between the representatives of the two partner companies involved in the LPC project. After that, we remained in touch with Fipak when preparing a final report of the research process and its outcomes as well as a public seminar organised to disseminate the insights of the LPC project. In the seminar in May 2011 Fipak's representative gave a talk about the experiences of the development team of the research collaboration. In September 2011 the steering group of the research project visited Fipak's factory. Thereafter our research group concentrated on preparing a practical guide about the development of product and production concepts, which was published in a seminar in April 2012. Meanwhile, I began working on my dissertation and proposed an interview about the early phases of the development process of the hybrid package to complete the earlier interviews that had focused on the Pilot project. I conducted the interview with Fipak's technical manager and sales manager in March 2012.

7.4.1 Factory visits

While the LPC project continued with the writing of the guidebook, Fipak were expanding their production with new equipment and more automation. We could observe the speed of this development in two factory visits in 2011, first one in January and second one in September. The difference between the almost empty factory hall, which we had seen in our first visit to Fipak in October 2009, and the one filled with robots operating behind glass walls, which we observed only two years later, was incredible.

  The factory visit took place in January 2011 when we arranged the first tool development workshop in Fipak. The technical manager Erja showed Päivi and me around in the factory and we discussed the latest developments. The installation of new equipment was still ongoing but the level of automation of the equipment in use was already higher than what we had seen in our previous visit on the shop floor in September 2010. Meanwhile, the packing of the hybrid packages into boxes had been transferred from the operators to a packing robot, which placed piles of packages arriving on a conveyor belt into a box, closed the box when it was properly filled and printed a bar code that identified the product and production batch in question. A case erector made the boxes, in which the hybrid packages were packed for transportation, out of cardboard and placed a plastic bag inside each box. The boxes were transported between the robots on rails that circulated above the equipment (see Figure 30); there was a lift by the

robots that brought the boxes up and down when their turn came. Above the rails circulated a great number of pipes that transported plastic granules, cooling water and compressed air to the injection moulding machines. Erja stated that the proper installation of the pipes felt like her biggest personal achievement in the current phase of the construction process.

Figure 30. Transportation of empty and filled boxes to and from the packing robot in Fipak.

The factory visit in September 2011 took place as part of the penultimate meeting of the steering group of the LPC project. The members included representatives of the participating companies and universities as well as expert members from both academy and industry. The host of each meeting was one of the partner organisations and this time it was Fipak's turn. The technical manager Erja was Fipak's representative in the steering group and she took the group members to a factory visit, during which she explained the principles of Fipak's production concept. During the nine months between the two factory visits, the construction of the production lines had proceeded and now we were observing the operation of the machines and robots behind glass walls, whereas earlier we had been able to go around freely. Erja emphasised a high level of hygiene as a guiding factor in all Fipak's activity. The hybrid packages were produced and packed almost without a human touch: Only when the paperboard blanks were placed to the robot, an operator was handling them with gloves on. Erja told that all materials, which were in contact with the packages in the production, were certified as suitable for contact with food. Hygienic requirements had also influenced the choice and placement of the production equipment, which used electricity as their power source and were stilted above the floor to enable easy cleaning. Other guiding factors were energy efficiency and reliability of the production equipment.

The construction of the new production lines was still based on speculations about what Fipak's future products would require and how large volumes needed to be produced; as earlier, Erja characterised the experience as "looking into a crystal ball." She stated that the increase of production volumes of the packages simultaneously with the construction of new automation had been a challenging effort, because the development team had not been able to test the functionality of the new equipment. Päivi and I observed that the production equipment was operating much faster than the testing equipment we had seen in the trial runs and even faster than the production equipment in the production runs of the Customer package: It was not possible to follow the movements of the mould any more. Even though the device for visual inspection was now in use, we saw the operators carrying out visual inspection. Erja told to us that the device controlled the air-tightness of the packages while the human eye was needed to detect problems with the printing of the packages, such as colour errors.

One year earlier, the development team members had been concerned of the difficulty of carrying out both trial runs and production due to the lack of machines. Now Erja told that the capacity of the installed equipment exceeded the production volumes.

7.4.2 Presentation about the research and development process in Fipak

In her presentation in the public seminar of the LPC project, Fipak's technical manager Erja discussed the characteristics of Fipak's business activity and the engagement of the development team members in the research collaboration. She told about the starting point of Fipak's development work at the beginning of the LPC project and described the experiences of the team members during the different phases of the research collaboration. She pointed out that the activities of Fipak differed from the established units of the Paper Company; the need to develop work practices stemmed from the chaotic situation of the starting business unit. Erja described how the team members had expected a ready solution from the researchers after the data collection phase; after realising that our research group did not intend to provide it, they had first been "grumbling" about it. Erja continued that the team had understood little by little that the researchers could not tell them what to do but they needed to "determine just by ourselves what's wrong and what we'll start to develop." In her presentation slides she described this situation as "enlightenment." She told that the interventions arranged by the researchers had helped the Fipak team because they "forced us to think what we're going to do; otherwise we'd have continued in the same way and done what we had always done."

In her talk, Erja briefly presented the model of Fipak's product and production concepts (Figure 27) from the perspective of the composing artefacts and their production networks. The important outcome she discussed more in detail was the project model created in the tool development workshops. She showed the project phases identified and the list of tools associated with the phases. Erja told that the project model was still evolving while the team was learning in the

projects, but some of the new tools were already in use; she noted that the practices of the development team had changed due to the research collaboration.

7.4.3   Interview about the recent development of the product and production concepts

In the interview with Fipak's technical manager and sales manager in March 2012, we discussed the product development process of the hybrid package from the emergence of the idea until the launch of the Pilot package, as well as the development of Fipak's product and production concepts after the research collaboration. During the interview, Erja and Janne reflected on their experiences and identified critical turning points in the development of the hybrid package and its manufacturing technology. In the following description, I concentrate on illustrating their understanding of the product and production concepts.

Right at the beginning of the interview, Erja framed the development process of the hybrid package as one having the development of *"a tray with a plastic rim"* (in Finnish this is one word) as its starting point. However, she only used this term when talking about the first meetings during which such an idea was put forward; otherwise both she and Janne referred to the customary "tray" or "product." Still, I take the use of this new term – which I heard for the first time in the interview – as an indication of the crystallisation of Fipak's product concept. Even though Erja had defined the hybrid package as a tray made of paperboard with a plastic rim already in our first visit to Fipak (see section 7.2.1), the identification of the critical factors leading to the attainment of an air-tight package by her and Janne during our conversation showed that *the properties of the hybrid package as well as factors providing them had clarified as a result of knowledge accumulated from the previous product development projects.*

During the previous year, problems with some of Fipak's product development projects had made the team realise even more clearly that shapes of conventional packages could not be directly manufactured with Fipak's technology. One of these projects was the Module package which we had followed during the data collection phase. At the time of the concept workshops over one year earlier, the team members believed that the Module package could be realised by adjusting the mould and the paperboard blank. Now Erja and Janne told me that the collaboration with the Customer 2 had ended and the development of the Module package proceeded as Fipak's own development effort. Due to a more radical redesign of its shape and many rounds of trial runs, the Module package was finally attaining air-tightness. Looking back at the development process of the Pilot package, Erja and Janne concluded that the oval shape of the Pilot package had been a lucky coincidence because the shape happened to be "favourable" to Fipak's manufacturing technology. Instead, the shape of the Prototype package, with which lots of experiments had been carried out, was not as suitable for the technology and therefore it remained leaking.

An important breakthrough, which had improved the forming of the packages in the moulding tool, was the increasing ability of the tool manufacturers to adjust the dimensions of the moulds with more precision. Erja told that when the

Fipak team had proposed such adjustments in the earlier phases of the development process, the manufacturers had believed it was impossible. However, it had proven possible over time.

Fipak was still facing pressures to increase turnover: Janne told Fipak would need to sell the existing products to new customers to increase the production volumes. At the moment, the team was working with a couple of new customers in the development of new kinds of products, but each of them required investments in new technology. For the internationalisation of business, Fipak's sales organisation was going through changes and collaboration with external sales partners, international distributors, had been established. Erja told that their current aim in the development of the production concept was reduction of the production costs of the hybrid package.

Erja and Janne told that the Fipak team were now able to carry out some independent development work outside customer projects with a dedicated, although limited, budget. The team were currently testing the behaviour of different kinds of materials; Erja remarked that this was the second round of such testing after the first one which had taken place during the NPD 1 and the NPD 2 projects. She stated the testing was sensible because materials had developed in the meanwhile. Moreover, accumulating information about what end uses the potential customers found most interesting, as well as the costs of different materials could also be used in the selection of materials. In addition to the study of materials, the team had proceeded with experiments with different package shapes. Janne stated that nowadays the team could rely on their ability to produce packages with similar dimensions as products which they had made before. Erja continued that the team's development efforts currently focused on different kinds of lids. She concluded that the hybrid package as a product was continuously under development because Fipak needed to "act as a forerunner."
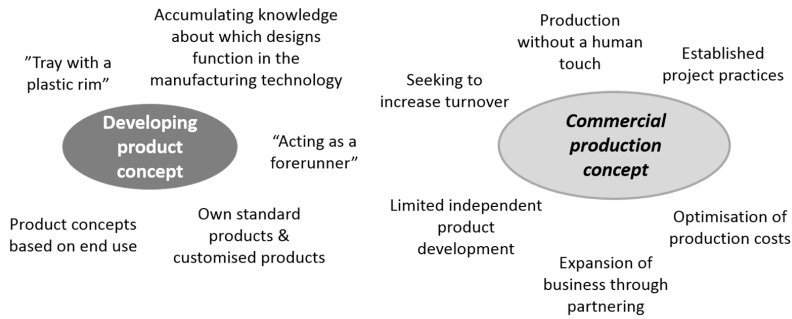
7.4.4 Characterisation of the product and production concepts in the third phase

After three years from the establishment of Fipak as a business unit of the Paper Company, their activities seemed to have settled down. Systematic experiments with different kinds of packages made of different materials and with different shapes had enabled the development team to accumulate knowledge about the boundaries of the hybrid package concept. The team had continued to organise their work in a way that enabled limited internal product development without customer involvement. Figure 31 illustrates the characteristics of the product concept and the production concept in this development phase.

The product concept appeared as a developing one, indicating that it was still becoming more specific while maintaining the possibility of expansion. The team members' understanding of the product concept at the time highlighted the properties enabled by the plastic rim; even though lid options were a development focus, the package was still called a "tray." Through the accumulation of experiences from different product development processes, the Fipak team had learnt about the factors that made some packages succeed and others fail, which enabled them to make critical adjustments in the design phase. The team

carried out experiments with different materials and shapes to develop a set of standard products to be offered to multiple customers, while they continued the development of tailored products with specific customers. A question remained as to whether standardised products could attract customer orders in volumes that would make the automated production process profitable. These development efforts were leading to the creation of multiple product concepts based on the end use of the hybrid package, such as heating in microwave or oven.


Figure 31. Characteristics of Fipak's product and production concept in the third phase of concept development.

The production concept emphasised a commercial orientation: Independent product development, even though limited, aimed to create products for high-volume mass production. The automation level aspired to had been achieved, and the optimisation of the production process now focused on the reduction of costs. The highly automated production lines and quality control enabled the maintenance of a high level of hygiene throughout the production process, which proceeded almost without the need for human intervention. The development team sought ways to increase turnover to make Fipak's business profitable, which required a significant increase in sales without investments in new equipment. This could be achieved by finding new customers for packages developed for previous customers, because moulds and optimised production parameters already existed for these products, whose production would therefore not entail development costs. The team also aimed to optimise the development process by improving the documentation of the experiments to reduce time and costs spent on the development of single products. The internationalisation of the business continued, and Fipak had established an international sales organisation, including relationships with external distributors. However, the collaboration with distributors had not resulted in significant customer orders thus far.

7.5 Trajectories of Fipak's product concepts and production concepts

The preceding sections have characterised Fipak's product and production concepts in three distinguishable phases. The description has emphasised the intertwining of the development of the concepts. In the following, I discuss the unfolding of the trajectories of the concepts and suggest a comprehensive view of how they can be brought together.

My overall interpretation of the development process of the hybrid package and Fipak's production concepts is one of experimentation and learning. Through the development of different versions of the hybrid package for different kinds of end uses with different customers, the team (and their partners) learnt about the properties of the product and the preferences of customers, which enabled them to specify the product concept (see Figure 32). Similarly, learning from the experiences gained in these product development processes had enabled the team to first construct and then optimise the automated mass production infrastructure and to establish collaborative relationships with customers and suppliers.
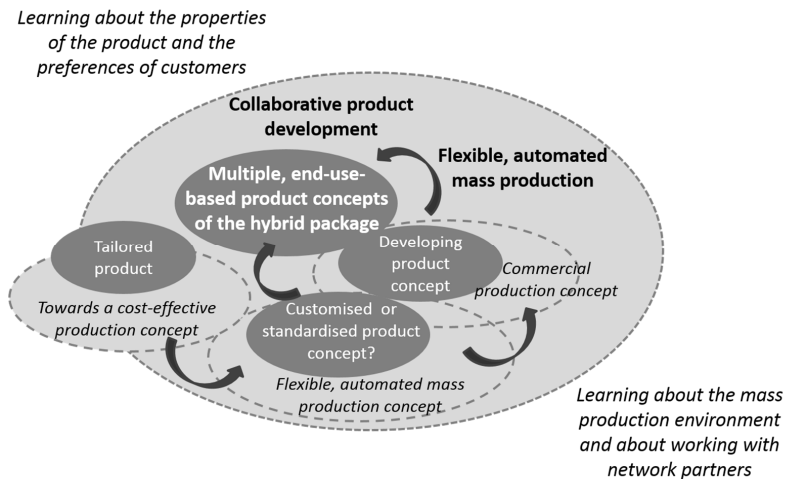
Figure 32. Evolution of Fipak's product and production concepts through the phases of the concept development process.

The product concept evolved through the three phases of concept development – from a tailored product to the dilemma between a customised or standardised product concept and finally to a developing product concept. Fipak moved *from viewing the hybrid package merely as a tailored product, which was their understanding of it in the first phase of concept development, to a comprehensive understanding of the hybrid package in terms of solutions to generalised end uses in the third concept development phase.*

The production concept evolved through the three phases of concept development – *from the aspiration of building a cost-effective production infrastructure to a flexible, automated mass production concept and finally to the distinction between two production concepts: collaborative product development and flexible, automated mass production.*

In the first concept development phase, the product concept appeared as a tailored product. The Fipak team considered the hybrid packages under development as single products whose properties depended on customers' preferences. Even though the team did not view the hybrid package as a comprehensive product concept, they defined it as "a paperboard tray with a plastic rim." The product concept focused on the development of materials, and the realisation of the different properties of the package was uncertain because the influence of an enormous number of factors in the behaviours of materials and the production equipment remained unknown.

Similarly, the production concept was only under construction in the first phase: The Fipak team worked to build a cost-effective production concept. However, the work practices in the product development projects were craft-like: The development of each new hybrid package took place through cycles of experiments and adjustments. The development efforts also required collaboration with both customers and suppliers, but the collaboration opportunities depended on the customers. However, the team regarded the production of customised products as a transitional period on the way to real mass production. At the same time, the selection of production equipment needed to be done without detailed information regarding the products which the equipment would be manufacturing in future.

In the second concept development phase, the product concept of the hybrid package had become more specific through the realisation of various product development projects in which the properties of the package had been realised. During this phase, questions concerning the type (customised or standardised) and scope (tray or package) of the product concept emerged. Thus far, the properties of the hybrid package had been tailored according to the requirements of specific customers, but Fipak's production technology set limits to the customisability of the package. Moreover, a customised product concept contradicted the cost-effectiveness requirement of mass production, because every tailored package required investments in the production of a new moulding tool and time-consuming iterative experiments. While the aspired-to production concept called for a standardised product offering, the creation of such offering seemed demanding due to the lack of standard package shapes in the food industry and the unwillingness of customers to invest in changes to their production lines according to a new package. The development projects to create new kinds of hybrid packages with a special rim design and corresponding lid made the team members question the scope of the current product concept. The inclusion of lid models in the product concept meant viewing the hybrid package as a comprehensive "package," whereas the team was used to thinking of the product concept merely as a "tray."

At the same time, the Fipak team was developing a flexible, automated mass production concept to answer to the calls for ensuring that the unit would generate profitable business in future. While the construction of the automated production infrastructure was still on-going, the team was able to envision the functioning of the production system as a whole. The team saw the independent development work of the properties of the hybrid package essential to the profitable production concept, but the commercial pressures hindered the organising of such development efforts. Together with our research group, the Fipak team identified these two production concepts, which seemed contradictory at the time, because they competed for the limited resources and called for different ways of working with customers and other partners. At the same time, Fipak's business began to expand to international markets, which brought new partners into the production network. The team had established a production network of domestic suppliers and work practices for product development projects.

In the third concept development phase, Fipak was establishing a set of product concepts according to different kinds of end use, which all represented the essential properties of the hybrid package. Because these concepts were developed according to materials and not shapes, they were still customisable according to specific customer preferences and hence do not necessarily correspond to the traditional understanding of the product concept. Furthermore, the Fipak team aimed to map the properties and experimental outcomes from existing, customised products to the identified types of product concepts. Thus, the team seemed to have solved the question about the customised or standardised product concept by opting for both. The general product concepts could be used as a basis for both standard products when an appropriate shape could be designed and for customised products because the end uses were universal.

By the third concept development phase, Fipak seemed to have developed two coexisting production concepts – collaborative product development with customers and flexible, automated mass production (which still included development efforts) – which together could ensure the profitability of the business. The team seemed to have found ways to employ these concepts in different projects, which enabled them to maintain and develop both of them. Whereas the parallel development of several products had been difficult in the previous phase, the capacity of the automated production system now exceeded the production volumes. Therefore, the team sought new customers for the standardised products to respond to the requirements of the Paper Company to generate commercially viable business with the hybrid package. The establishment of an international sales organisation and the collaboration with international distributors were beginning to produce results; the future of the hybrid package looked bright.

7.5.1 Observations about the characteristics and the evolution of product concepts

Whereas previous research has studied the creation of the product concept during the product development process, the present study extends the analysis beyond this and discusses the evolution of the product concept throughout consecutive product development projects.

Previous studies suggest that product concepts materialise during the product development process as three kinds of representations: stories, metaphors and prototypes (Seidel 2007, Seidel & Mahoney 2014). In the present study, prototypes of the moulding tool and samples of the hybrid package were central representations that recruited collaborators and organised development efforts (as analysed in chapters 5 and 6). The development centred on iterative experiments with the moulds and different versions of the paperboard blank, which produced sample packages whose properties could be evaluated. I presume that the importance of the material prototypes as representations of the product concept derives from the experimental nature of Fipak's product development and the significance of trial runs as fundamental part of the development process. Instead, the research participants made no references to stories or metaphors as part of the initial stages of the innovation process. This may be connected to the fact that the creation of the product concept was not an explicit part of the data collected concerning these stages. However, different metaphors seemed to reflect the team members' understandings of the product concept in different phases of the concept development process. The significance of metaphors is exemplified by the distinction between viewing the hybrid package either as a tray or package in the second concept development phase.

This study adds the final product as a new representation of the product concept, which previous studies have not identified. Viewing the outcomes of the development process as representations of the product concept results from my understanding of product concept: It defines the qualities of a range of products that embody a comparable use. Hence, single products do not necessarily embody all the properties the product concept embraces but act as its material manifestations. In Fipak, the Pilot package, the Customer package, the Food package and the Module package all represented the hybrid package concept and manifested some of its key properties. In the third concept development phase, the Fipak team began to define product concepts according to the end use of the package; the future packages of different shapes would be manifestations of these concepts.

My analysis identified the central characteristics of the product concept of the hybrid package in each development phase to study of the evolution of product concepts. In all concept development phases, the characteristics included metaphors describing the core of the concept. In the first concept development phase, the characteristics included known properties (e.g. stiffness, heat resistance and recyclability) and end uses of the of the hybrid package, as well as open factors (e.g. possible shapes of the package). In the second phase, while the team's understanding of the factors affecting the production process and thus the properties of the hybrid package had increased, the product concept

was characterised by different tensions: Questions concerned the scope (tray vs. package) and type (customised vs. standardised) of the concept. In the third phase, the product concept was established but viewed as a developing one through the accumulation of knowledge about possible and impossible designs; a repertoire of hybrid packages was emerging.

The analysis demonstrates that the properties of the hybrid package were valued in different ways over the course of the concept development process. This evolution follows the observation that "the qualities of the product are attributed, stabilized, objectified and arranged in relation to each other" as the product encounters various trials of strength on its way to the market (Reijonen & Tryggestad, 2012, p. 216). In their study of the dynamics of product qualities during a product development process, Reijonen and Tryggestad (2012) emphasise the significance of these encounters between the product, the producer and the consumer, in which the product properties are evaluated against the interests of both the producer and the consumer. In the case of the hybrid package, the product passed several in vitro trials before it entered the market. An initial trial was the establishment of the NPD 1 and NPD 2 projects, when the development of the package received funding from both the Paper Company and from a funding agency. Another trial was passed when the hybrid package attracted the Pilot Customer to join the project and a further one when its prototype gained support in consumer tests, which enabled its entrance to the market (see Chapter 5). Once the first commercial product had been launched, the hybrid package underwent in vivo trials on the market.[45] The first commercial product, the Pilot package and the new product for the Pilot Customer, seemed to pass the market test at the beginning, but eventually they failed. Nevertheless, despite the rocky beginning, new customers chose the hybrid package for their products (see chapters 6 and 7); the Food package seemed to succeed in the markets during the LPC project. The difficulties with the market test indicate that the hybrid package and the product it covers and presents make a unified whole; therefore, the customer's knowledge of the preferences of consumers is vital. This confirms that the success of an innovation is not only in the hands of the company developing it but depends on many other actors as well (Akrich et al., 2002a; Christiansen, Varnes, Gasparin, Storm-Nielsen, & Vinther, 2010).

7.5.2 Observations about the characteristics and the evolution of production concepts

The construction of Fipak's production concept was a long process; I have identified three phases of concept development during the three years covered in the analysis of this chapter. Experimentation represented a key feature of the production concept since the beginning of the development efforts of the hybrid package. Experimentation was required both in the development of the product's properties and the implementation of production technology. However, when the requirements of cost-effectiveness and profitability were emphasised

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[45] Before the products covered and presented by the hybrid package could compete for the consumers' attention, they needed to be selected by the selection managers of chains of stores and further by shopkeepers. However, information about these negotiations is not included in my data.

as Fipak's commercial activities were established, the team aspired to reduce iteration in the development of products.

In the first concept development phase, the development of tailored products according to the requirements of single customers relied on an experimental development process. In the second concept development phase, the team identified two kinds of contradictory logics guiding the product development projects, collaborative product development and mass production. According to the logic of mass production, experiments only belong to the product development phase, while production is to be straightforward once the product is "ready." In the third concept development phase, the development team seemed to have succeeded in resolving this tension by developing two distinct production concepts. The flexible mass production concept aimed to offer standard products, developed independently or based on previous customised products, to several customers. The collaborative product development concept produced tailored products according to the needs of a particular customer. These two concepts differed in terms of their guiding principles, cost-effectiveness and customer-centeredness, and in the division of work between Fipak and the customers. The relationships with the customer and the involvement of customer's representatives in product development distinguished the two concepts. The suppliers were mostly the same in both production concepts and so was the manufacturing technology. Nevertheless, product development in both concepts could lead to experiments with new materials, calling for collaboration with new partners.

Whereas the framework of Victor and Boynton (1998) and the notion of activity concept by Virkkunen (2006a, 2007) focus on the transformation between production concepts, the story of Fipak is about the construction of a local production concept. The team members repeatedly told how they had begun to build the production infrastructure based on vague guesses about what kind of products Fipak would produce in future. The guiding principle of the production concept was cost-effectiveness and automation was chosen as the means to achieve this. Even though the Paper Company had a long history of developing different kinds of paper products and their production technology, the production of the hybrid package differed from the existing business. Fipak's manufacturing technology and production process combined paperboard and plastics manufacture; the production concept may be regarded a hybrid like the product itself. Furthermore, the move from the NPD 2 project to the establishment of Fipak as a business unit required a reorientation of activity of the development team: The background of many team members was in research and development activities; they had not been involved in commercial production. Other team members had a production background but from different kind of production.

My findings suggest that production concepts evolve through experimentation and learning. The development of many kinds of hybrid packages had enabled the Fipak team to specify the product concept and to first construct and then optimise the flexible, automated mass production concept along with the collaborative product development concept. Previous research on the evolution of

production concepts has also emphasised learning as the enabler of change (Victor & Boynton, 1998; Virkkunen, 2007). However, this research focused on the historical transformation of production concepts, whereas the present study follows the emergence and development of production concepts. During the research collaboration, Fipak found itself in-between two production concepts, whose characteristics and hence guiding principles changed during the concept development process. These findings contrast with the tendency to raise one production concept at a time as universally applicable (cf. De Toni & Tonchia 2002) as well as the tendency to focus on the change of concepts (Victor & Boynton, 1998; Virkkunen, 2007). Fipak's concept development process illustrates that instead of establishing a coherent production concept, an organisation's activity may lie in-between multiple production concepts over lengthy periods (Jalonen et al., 2016). Furthermore, the study demonstrates that the parallel analysis of the evolution of production and product concepts reveals the situatedness of local production concepts, which general labels such as "mass production" neglect.

Fipak's concept development process also shows that the development of a production concept does not necessarily involve the implementation of management tools. In fact, there were very few formal tools in use. In Fipak, project management relied on sharing documents on a network disc and salespersons acting as project managers, while production management was carried out with spreadsheets and verbal interaction between the production engineers and the operators as no production control system was available. The team members had succeeded in establishing a shared orientation to their work and they appreciated each member's expertise and contribution to the joint development efforts. All of them also understood the commercial pressures that Fipak was facing from the Paper Company and were committed to doing their best to respond to the challenges.

7.5.3   The intertwined evolution of product and production concepts

The analysis shows how Fipak's product and production concepts developed in relation to each other. In the first phase concept development, the tailored product concept providing uniqueness constrained the development of a cost-effective mass production concept (see Figure 24). In the second phase, the production infrastructure was designed according to principles of flexible, automated mass production and efforts to design a repertoire of standard products were started (see Figure 29). In the third phase, the efforts to build coherence between the product and the production concept led to the creation of multiple, end-use based product concepts of the hybrid package and to the establishment of two parallel production concepts, collaborative product development and automated, flexible mass production (see Figure 31 and Figure 32). The intertwined processes of concept development demonstrate how the product influences the production practices and may challenge the chosen business model (cf. Deken & Lauche 2014).

The findings also suggest an intimate connection between the evolution of product and production concepts and the development of artefacts used as

product components and manufacturing technology. Through the development of different versions of the hybrid package, the Fipak team (and their suppliers) learnt about the properties of the product and the preferences of customers, which enabled them to specify the product concept. At the same time, experimenting with different moulds, paperboard blanks, plastic materials and automatic devices produced knowledge which allowed the Fipak team to construct and optimise a production infrastructure according to the principles of flexible mass production. Likewise, experiences gained from working with different customers and suppliers enabled the team members to identify the competences of the partners and to develop different kinds of relationships with them. The produced knowledge became embedded in work practices and the tools used in the product development projects, thus aligning them with the production concept. In the first product development projects after the market launch of the first commercial hybrid package, the project practices were under development, and the optimisation of the artefacts' behaviour required many experimental iterations. Through consecutive product development projects, Fipak's repertoire of both end products (different shapes and end uses of the hybrid package) and project practices (e.g. meetings and project management tools) had expanded and become clarified, which was manifested by the established product and production concepts. The different artefacts composing the production infrastructure had become part of the infrastructure: The introduction of a new mould did not require the modification of the other artefacts to as large an extent as before. Thus, the construction and further optimisation of the production infrastructure may be viewed as a standardisation process of artefacts and experimentation practices. The development of Fipak's activity had almost reached the aim presented to us during our first visit: It was possible to define the measurements of the hybrid package nearly accurately as early as in the product design phase, although trial runs were still required.

7.6 Epilogue: Product and production concepts three years later

I visited Fipak at the end of my thesis project in August 2015 to interview the technical manager Erja and the sales manager Janne about Fipak's activity after the research project ended. We also discussed my thesis manuscript, which Erja had read and commented on; I was able to fill in some gaps that I had discovered in my analyses.

Erja and Janne described the period from 2012 to 2013 as the "crazy years" involving many new product development projects. During these two years, Fipak had acquired important customers through their distributors in Europe, and the promotion of the hybrid package by the salespersons had created interest among potential customers. This had resulted in Fipak receiving inquiries almost weekly regarding possible packages; the team needed to hire a second tool designer to respond to the product design requests. Many new product development projects started with new customers, and even though not all of them resulted in commercial products, Fipak's product offerings had grown to almost 20 packages during those two years. The expansion of Fipak's product range

required important investments in new moulds and production equipment; in addition, new operators needed to be hired.

At the same time, the Paper Company were realigning their operations according to a reformulated strategy. Because Fipak and some other business units did not stand in the core strategic areas, the Paper Company sought potential acquirers of these operations. At the end of 2013, Fipak became an independent company when it was acquired by a group of investors, including Packaging Company 2. Despite the change of ownership, Fipak continued their operations on the established premises of the Paper Company. Erja and Janne opined that the most important consequences of the acquisition were a vanishing bureaucracy and "the turn-off of money tabs."

By 2015, Fipak's operations relied on the mass production of standard products. Because Fipak was now operating as an SME, the company had only limited resources to develop new products that required new moulds. Thus, the production concept of flexible, automated mass production prevailed, but independent product development had practically ended; the role of the production concept of collaborative product development was marginal. Moreover, the radical reduction in product development had shrunken Fipak's collaboration with the tool manufacturers. While Fipak's network had expanded to cover four tool manufacturers in 2012, the current collaboration was limited to the maintenance of the existing moulds by one of the manufacturers. In a similar vein, the collaboration with equipment providers was limited to the purchase of new parts for the existing equipment. However, the most important changes had occurred in the production of the paperboard blanks due to the restructuring of the paper industry in Finland. Fipak had needed to find new providers of the paperboard sheets as well as printing and die cutting providers. Fipak's own organisation had changed as well: Product design and tool design were outsourced while sales were handled by the salespeople of the Packaging Company 2 and by foreign distributors. Whereas the majority of customers had been domestic during our research collaboration, now Fipak was selling most of their products abroad: International sales represented some 90 per cent of the total sales.

Along with the focus on the mass production of standard products, Fipak's product concepts were established and now embraced a fixed repertoire of standard products. Unlike in the early years, Fipak were not producing exclusive products any longer; rather, all their products were available for all customers. The product concept was not a developing one anymore: The product repertoire eventually expanded if customers wanting a new kind of package were willing to invest in the development of a new mould. This standardisation of the range of products was possible because Fipak had learnt that customers from the food industry were able to adjust their production lines by changing only parts of the devices. In fact, acquiring a standard hybrid package required only minor investments by the customer compared to the ordering of a new mould for the package. *The package repertoire covered a range of shapes, which could be produced with different plastic materials according to the end use*; this differed from the third concept development phase, when the repertoire was based on end uses rather than shapes. *Most of the packages that Fipak sold were used*

for cooking or heating food either by the customer or the consumer; for such end use, the hybrid package could provide more added value. Thus, the hybrid package competed mainly with aluminium packages and heat-resistant plastic packages.

Even though the product launch of the hybrid package had taken place six years earlier, there was only one corresponding package – an air-tight paperboard package – on the market. Erja and Janne explained that even though the food industry showed interest in paperboard materials, other factors still played a significant role in the decision making, often favouring the use of plastic materials in packages. Nevertheless, they had observed a growing acknowledgement of the problems caused by the huge amount of plastic consumption, translated into concerns about marine ecosystems. Still, the use of paperboard in packaging was very marginal. Janne characterised the situation: "If the demand for fibre packages has doubled from 0.5 per mil to 1.0 per mil, then it doesn't necessarily show on the markets yet." Hence Erja and Janne did not expect significant growth of Fipak's business in the near future: Deals with important customers were sometimes made, but they might last only a relatively short time, and therefore new customers were constantly needed. Fipak had recently established their first licencing contract with a foreign distributor; time would show whether the hybrid package would be produced outside Fipak's premises.

8. Discussion and conclusions

Throughout the previous chapters, I have analysed how the hybrid package and its manufacturing technology emerged as well as how boundary objects mediated the collaborative development practices. This chapter summarises my findings and discusses these in relation to previous research. I begin with summing up the findings and answering the research questions. Then I discuss the contributions and implications of the study, after which I examine the limitations of the research and reflect on the research methodology. I conclude the dissertation by suggesting some avenues for further research.

8.1 Summary of the findings

The purpose of this study has been twofold. First, the study aimed to explore the engagements of human actors and artefacts in collaborative development efforts and the ways they shape the innovation process. Second, the study aimed to increase the understanding of interdependencies between product development and production in the innovation process by analysing the intertwined evolution of a product's properties and its production practices. The research adopted a practice-based perspective to the study of the innovation process and its outcomes. The data for the study were produced in a research collaboration with a recently founded business unit of a paper company – Fipak – which carried out the development of a package innovation, the hybrid package. I analysed sets of these data to examine the research questions and summarise the central findings of the study by answering these questions.

8.1.1 Boundary objects and the innovation process

My first research question explored the innovation process through the engagements of human actors and artefacts: How do boundary objects shape the unfolding of an innovation process and its outcomes? This question was studied in the analysis of the development process of the hybrid package in Chapter 5. This analysis traced the trajectory of the innovation from the early experiments until the launch of the first commercial product, which I call the Pilot package. In the analysis, I examined 18 retrospective interviews conducted with the participants of the development efforts.

According to my findings, boundary objects shaped the development process of the hybrid package in four ways. First, *boundary objects attracted partners*

to join the collaboration by generating expectations. In the first, experimental phase of the process, the moulding tool and the hybrid package acted as boundary objects that invited partners to join the development efforts. They shaped the development process by engaging new partners whose competences were crucial to advance the development of the hybrid package. Second, *boundary objects facilitated both autonomous, within-community and collaborative, cross-community experimental work*. In the first phase of the process, the moulding tool mediated the collaborative development efforts of the partners by allowing both autonomous and collaborative work. In the trial runs, all participants could observe the mould's behaviour and discuss it together. In domain-specific research and testing, the participants developed certain properties of the moulding tool and the materials autonomously. The properties of the hybrid package emerged from this experimental work, which proceeded through cycles of collaborative and autonomous work. Third, *boundary objects enabled the transfer of work tasks between people without direct communication between the individuals when the boundary objects themselves contained the documentation of the work*. In the second phase of the process, focused on the development of a tailored package for the pilot customer, the prototype mould became a model, a representation which the new tool designer could make use of in the design of the tailored mould. Here, the mould as a material artefact mediated the solutions that the previous tool designer had developed: The new tool designer investigated the structure and functioning of the prototype mould to infer how the mould was designed to compensate for the lack of documentation of the design. Fourth, *boundary objects transformed the course of action in the process through resistance by causing surprises and setbacks*. In the second phase of the development process, the problems that occurred with the Pilot mould in the trial runs inhibited the development efforts from proceeding before its functioning was improved. New expertise and new kinds of resources were needed to proceed with the development because the mould did not behave as the actors had expected, which called for collaboration with new partners. Even though such troubles slowed down the progress of the development efforts, each setback eventually took the project forward.

8.1.2 Transformations of boundary objects

My second research question focused on the ways boundary objects mediate collaborative work: How do boundary objects transform during a product development process? The development of the relational approach to the study of artefacts in collaborative work – including a typology of the mediating functions that boundary objects may situatedly perform – led to two sub-questions. Thus, in the analysis of the practices of the product development process in Chapter 6, I examined (1) what kinds of mediating functions boundary objects performed in product development practices during the process and (2) how the functions of the boundary objects changed during the process. I the analysis, I investigated observations of seven events that represented the phases of Fipak's product development process.

Through the analysis of the product development practices, *I identified 64 artefacts and 11 mediating functions: problem solving, evaluation, explanation, communication, anticipation, action, documentation, decision making, delegation, organisation and standardisation.* My findings demonstrate that the mediating functions, which the boundary objects performed, related more to the nature of situated actions than to the characteristics of the artefacts themselves. In addition, the analysis connected the mediating functions with the phase of the development process. Some mediating functions, such as communication, were central in the early phases of the development process, whereas others, such as evaluation, appeared significant in the later phases. Furthermore, the functions of communication and explanation seemed to play an important role in interactions between representatives of collaborating organisations. In work practices within the interdisciplinary development team, boundary objects performed the mediating functions of evaluation, problem solving and action most frequently. The functions of standardisation and organisation occurred only occasionally.

In addition to identifying the situated functions of the boundary objects, the analysis showed that the functions transformed across the phases of Fipak's product development process. I identified five artefacts that acted as boundary objects in several events during the development process. Each of these boundary objects performed various mediating functions in the events; typically, their functions were different in different stages of the development process, reflecting the objectives and concerns in each development phase. The conceptual boundary objects served as representations for communication and explanation in the early project phases, whereas material boundary objects mediated experimental actions during trial runs, triggering problem solving and serving as means of evaluation. The experiments in the trial runs seemed to follow an artefact-centred pattern of action depending on the collaboration of humans and artefacts, the evaluation of the outcomes of the experiments and problem solving if the experiments produced surprising or unwanted outcomes.

The analysis also illustrated the evolution of the boundary objects themselves by comparing the various representations of the central boundary objects over the course of the product development process. This indicates that artefacts evolve through their engagement in different practices that highlight and make use of their particular characteristics.

8.1.3 Evolution of product concepts and production concepts

My third research question explored the development of product concepts and production concepts over time: How do product concepts and production concepts evolve through the development of the product's properties and its production practices? The development of practice-based definitions of product and production concepts led me to formulate one sub-question. Hence, in the analysis of the encounters where understandings of product and production concepts were articulated in Chapter 7, I examined what characteristics the product concepts and production concepts had in different phases of the con-

cept development process. The analysis studied 12 encounters between members of the Fipak team and our research group, which represented different phases of concept development.

According to the findings, the concept development process had three phases during the research collaboration: Each phase was marked by different characteristics of the product concepts and the production concepts. The first phase of the process illustrated a shift in production concepts from research-oriented product development to commercial-oriented production after the market launch of the first hybrid package. The product concept was ambiguous: Different hybrid packages were viewed as distinct products, tailored according to the requirements of a specific customer. The second phase illustrated the identification of the boundaries of the product concept and the simultaneous construction of an automated production infrastructure. The Fipak team was struggling to decide whether they should develop a standardised product offering or continue with tailor-made products. This dilemma was related to the realisation of a flexible, automated mass production concept and the commercial pressures to demonstrate the viability of Fipak as a business unit. The third phase illustrated the establishment of product and production concepts. The Fipak team was creating various product concepts based on the end use of the hybrid package. They were developing a set of standard products while continuing the development of tailored products with specific customers. The team was following a commercial production concept, which allowed them to carry out independent product development to a limited extent, while they sought to optimise the production process and find customers for the existing products to reduce costs.

The findings suggest that Fipak's product concepts and production concepts evolved through experimentation and learning. The development of many kinds of hybrid packages had enabled the Fipak team to specify the product concept and to first construct and then optimise the flexible, automated mass production concept along with the collaborative product development concept.

8.2 Contributions and implications

This study makes theoretical contributions to the research on the role of artefacts in collaborative work and to the research on innovation, product development and operations management. The study develops a relational approach to the role of artefacts in collaboration and proposes boundary object as an umbrella term for artefacts that mediate collaborative work. The study suggests that artefacts perform as boundary objects through mediating functions, which artefacts acquire as part of a practice. Moreover, the typology of mediating functions developed in the study demonstrates that boundary objects are multifunctional and transformative because they can perform various mediating functions in different situations. The study bridges the innovation and operations management literature by demonstrating interdependencies of the trajectories of the product, production technology and production practices.

8.2.1 A relational approach to boundary objects

The study developed a relational approach to the analysis of the role that arte-facts play in collaborative work to depart from a substantialist approach, which associates these roles with the inherent characteristics of the artefact (cf. Øster-lund & Carlile, 2005). The relational approach draws on the notion of mediation from cultural–historical activity theory (Engeström, 1987) and postphenome-nology (Verbeek, 2005). This approach analyses the role of artefacts in collabo-ration as different forms of mediation carried out by artefacts depending on the situation and the relationships between the actors and the artefacts. Thus, the approach presumes that the mediating ability of an artefact is not its inherent property but rather depends on the kinds of relations in which the artefact is involved (Verbeek, 2005).

Following the relational approach, I propose that the notion of boundary ob-ject may be used as an umbrella term for various kinds of artefacts that mediate activity between different communities. Furthermore, my empirical findings that demonstrate the importance of artefact mediation of within-community and even solitary work remind us that the definition of boundary object includes the mediation of both collaborative and autonomous work (Star & Griesemer, 1989).

The relational approach answers the call for more nuanced research on the roles of artefacts in collaborative work (Ewenstein & Whyte, 2009; Nicolini et al., 2012). However, the approach takes an opposite stance from suggestions that the notion of boundary object should be reserved to relatively stable arte-facts which mediate collaborative work between communities (Ewenstein & Whyte, 2009) and that other roles of artefacts be studied in terms of other labels (Nicolini et al., 2012). I argue that labelling artefacts according to their situa-tional role may in fact entail a return to the substantialist approach from which the scholars strive to depart (cf. Østerlund & Carlile, 2005). I suggest that the relational approach enables a dynamic understanding of the role of artefacts as emergent and temporary functions that artefacts may acquire as part of a prac-tice. This follows previous work arguing that an artefact becomes a boundary object as the outcome of situated interaction, rather than due to the artefact's qualities (Nicolini et al., 2012; Scabrough et al., 2015; Zeiss & Groenewegen, 2009). The approach follows the situated understanding of how work is carried out through the actions of humans and non-humans, inherent in the practice-based view (Nicolini et al., 2003).

The analysis of the development process of the hybrid package in Chapter 5 illustrates the use of the relational approach to identifying boundary objects and their influence in the unfolding and outcomes of the innovation process. Through the analysis, I identified four ways in which boundary objects may shape an innovation process: attraction of partners, facilitation of both collabo-rative and autonomous work, transfer of information and resistance to manip-ulation.

The attraction or motivation of partners by artefacts to join collaboration has been acknowledged in the literature. However, previous organisational research has analysed such artefacts as epistemic objects (Ewenstein & Whyte, 2009;

Knorr Cetina, 2001; Miettinen & Virkkunen, 2005; Nicolini et al., 2012; Rheinberger, 1997). CHAT scholars have named them tertiary, imaginative artefacts that represent a potential future (Engeström, 1990; Miettinen, 1998, 1999; Wartofsky, 1979). According to the relational approach, motivation or anticipation is one of the mediating functions: Boundary objects generate expectations that potential collaboration partners may find attractive.

The facilitation of autonomous, within-community and collaborative, cross-community work is the original essence of boundary objects. Facilitation refers to tacking between the strong and weak forms of the boundary object (Star & Griesemer, 1989). This tacking can also be interpreted as the transfer between a clearly defined artefact, a technical object (Ewenstein & Whyte, 2009; Rheinberger, 1997), and a more open artefact, an intermediary object (Vinck & Jeantet, 1995) or even an open, partly imaginary artefact (Ewenstein & Whyte, 2009; Knorr Cetina, 2001; Wartofsky, 1979). However, over time, boundary objects may lose their ability to move between the well-structured and ill-structured forms of the artefact and become standardised parts of the taken-for-granted infrastructure (Star, 2010). Despite the increasing interest in the sociomaterial nature of work, organisation studies on boundary objects continue to emphasise the facilitation of collaborative work across community boundaries without examining how the same artefact is used in autonomous work within a community. The present study improves our understanding of the tacking between collaborative and autonomous work through the use of artefacts by demonstrating how the same boundary object mediates both kinds of work practices.

The transfer of information without direct communication between individuals also belongs to the essence of boundary objects; their interpretive flexibility has been the focus of many studies (Star, 2010). Some scholars have problematized this ability of boundary objects to "pass from one community of practice to another with little or no explanation" (Lee, 2007, p. 312-313), arguing that artefacts also mediate negotiation between communities. This study suggests that viewing boundary objects as representations – or secondary artefacts – that embody a mode of practice by symbolic means (Wartofsky, 1979) – helps us to understand the way artefacts enable the transfer of knowledge and skills. Hence, an artefact itself contains the documentation of the work practice in a way that instructs the human actor regarding how to carry out the action. Such work on behalf of humans is an example of the mediating function of delegation (Latour, 1994).

The transformation of the course of action in collaborative work through the resistance of boundary objects has hardly been studied in organisation research. Even though some studies have analysed the inability of artefacts to facilitate collaboration (e.g. Sapsed & Salter, 2004), few have addressed the question of the ways artefacts may change the direction of collaboration. However, resistance by artefacts and its influence in the unfolding of scientific work have been addressed by Pickering (1993), who referred to this dynamic as the "dialectical process of resistance and accommodation." The identification of the source of the problem manifested by a malfunctioning artefact and the creation

of a solution requires that the behaviour of the artefact is observable and comparable to the planned course of action: The boundary object is used as a closed artefact (Rheinberger, 1997). Situations in which artefacts do not behave as the actors expect them to may lead to the manipulation of the artefact in question, to its replacement with another artefact or to collaboration with new partners who can provide the knowledge necessary to identify and solve the problem.

In addition, the relational approach demonstrates the benefits of using the notion of artefact instead of object in the analysis of collaborative work. The term artefact allows us to distinguish the particular kinds of objects that participate in activity in particular ways: Artefacts are human-made, simultaneously conceptual and material constructions, which serve specific purposes (Cole, 1996; Kallinikos, 2012). This study has illustrated the different purposes that artefacts may serve in the development of products and production practices as well as the possible consequences of the participation of artefacts in these practices. The findings of the study show that opening up the role artefacts play in human activity enables the exploration of human–artefact relations in ways that a priori definitions do not allow. Thus, the study suggests that cultural–historical activity theory could revisit the fundamental distinction between the object and the mediational means of activity and empirically explore the participation of the artefacts in the activity. Some CHAT scholars have already argued that some artefacts, such as complex simulation models, do not fall into either of these categories (Kerosuo et al., 2015; Paavola & Miettinen, 2013). However, the present study suggests that even simple-looking artefacts may engage in the practice in different ways that enable a more nuanced analysis of their mediating ability. Furthermore, artefacts in contemporary work settings tend to construct complex infrastructures on whose functioning human activity is highly dependent (Edwards et al., 2009). Thus, the study suggests that CHAT scholars could gain insights from other practice-based approaches that explore new takes on the sociomateriality of practices.

In addition to demonstrating the different ways in which an artefact may perform as a boundary object, these findings indicate that the same artefact may serve various purposes in different situations. I further explored these performances as mediating functions of boundary objects.

8.2.2 The typology of mediating functions: Multifunctionality and transformations of boundary objects

The study constructed a literature-based typology of the mediating functions that boundary objects may perform in collaborative work. The notion of mediating function refers to the ways in which a boundary object encourages some ways of actions or discourages others (Verbeek, 2015); it enables us to distinguish between the different purposes that artefacts fulfil in a certain situation (Kallinikos, 2012). The typology was refined during empirical analysis of product development practices in Chapter 6, resulting in the identification of 11 mediating functions performed by various boundary objects. As illustrated in Table 20, the functions included in the typology differ to some extent from the ones

discussed in previous literature. Most of these functions correspond or bear resemblance to purposes associated with collaboration artefacts in the literature. Nevertheless, my analysis discerned one new mediating function – evaluation – that has not been examined in previous studies. Table 20 is ordered according to the frequency of the functions in the data to highlight the situated nature of mediation: In another research setting, some of the functions identified in this study might be absent while it is possible that further functions still remain to be discovered.

The typology of mediating functions elaborates on previous research on collaboration artefacts and mediation by artefacts. With regard to studies on the role of artefacts in collaborative work, the typology turns the characteristics of artefacts into situated performances of mediation. With regard to research on mediation, it seeks to create a more nuanced understanding of mediation than previous research in cultural–historical activity theory and makes further distinctions between types of mediation identified within actor–network theory by Latour (1994) and postphenomenology by Verbeek (2005).

Table 20. The refined typology of the mediating functions of boundary objects in comparison to previously identified functions.

Mediating function used in the empirical analysis	Corresponding / similar function in the literature
Problem solving	Transformation
	Negotiation
Evaluation	
Explanation	Communication
	Translation
Communication	Communication
	Transfer
	Representation
Anticipation	Motivation
Action	Composition
Documentation	Delegation
Decision making	Negotiation
Delegation	Delegation
	Translation
Organisation	Organisation
Standardisation	Standardisation
	Reversible black-boxing

Previous studies have mostly analysed boundary objects as means of representing and sharing knowledge across community boundaries (e.g. Bechky, 2003; Carlile, 2002, 2004), named *communication* in the typology of the mediating functions. The present study demonstrates that in a process marked by uncertainty of the outcomes of collaborative work, artefacts may perform a variety of other functions in addition to communication.

Problem solving was the most prominent mediating function of boundary objects in the study. Problem solving resembles the transformation of knowledge

to solve problems outlined by Carlile (2002, 2004) and it sometimes included negotiation of alternative solutions between actors (Lee, 2007). However, problem solving stood out as a function because it often required the use and evaluation of several artefacts to detect the source of the problem and to create a solution.

The second most prominent function in the study was *evaluation*. Such functionality of artefacts has previously been studied with the notion of intermediary object (Vinck & Jeantet, 1995; Boujut & Blanco, 2003), but this study suggests evaluation as a key mediating function of boundary objects in product development practices. The significance of boundary objects – such as intermediary instantiations of the hybrid package – for the evaluation of the correctness of the design or the functioning of the production technology is probably related to the experimental nature of product development in the studied setting (cf. Rheinberger, 1997).

In the present study, mediation by artefacts to illustrate actions or principles guiding the actions to an actor from another community is called *explanation*. Boundary objects served as means of translation to communicate concerns of one community to another and establish a shared understanding, which resembles Carlile's (2004) understanding of translation of knowledge and can be interpreted as a special case of communication. The actions in which translation occurred were discursive and did not always succeed in persuading the target actors to follow a certain programme of action, which distinguishes explanation from translation as understood by ANT scholars (see Callon, 2007).

Another key function of boundary objects was the *anticipation* of future actions and the proposing of alternative ways of carrying out actions. Sometimes the speculations broadened the horizon of actions – for example, concerning the actions of the future users of the products to be designed. Anticipation thus bears some resemblance to the motivation function identified in the previous literature (see Henderson, 1991), but it did not play a key role in the discussion with a new partner – it seemed that the partner had been enrolled in the collaboration already earlier. Instead, anticipation was often connected to efforts to avoid future problems based on experiences with similar products.

The present study labels the collaboration of artefacts and human actors as *action*, because the actions of the participating actors are mutually interdependent. The previous literature on collaboration artefacts has not identified such human–artefact collaboration. However, Latour (1994) outlined composition as a form of mediation for cases in which "action is a property of associated entities" (p. 35) and the engaged human and non-human actors exchange competencies. The interdependence of the work of human actors and the systems of artefacts in the experimental trial runs and the automated production illustrates the importance of a system of boundary objects (Rehm & Goehl, 2015) to carry out actions. The mediation of action was often a distributed accomplishment.

The study suggests *documentation* of the conditions and the outcomes of actions as a mediating function. Documentation by artefacts enabled human actors to remember how to carry out similar actions later or to collect information

on different alternatives for future decision making. Documentation may be interpreted as a special case of delegation by humans to artefacts (Latour, 1994; Verbeek, 2005).

The study identified *decision making* about further actions as a mediating function. Boundary objects triggered a discussion about the actions in the artefact's development process; the decisions often included the scheduling of actions. Decision making may also involve negotiation (Lee, 2007).

Delegation of tasks may occur both (1) from artefacts to humans by requiring them to act in a certain way and (2) from humans to artefacts. The first mode of delegation actually corresponds to Verbeek's (2005) understanding of the translation function, which refers to artefacts inviting and discouraging particular actions. The second mode of delegation resembles Latour's (1994) understanding of delegation that comprises of the inscription of humans goals in artefacts, which in turn influences other actors' actions.

In the present study, *organisation* of the division of work between human actors did not belong to one of the most central functions of boundary objects. However, the identified episodes of organisation indicate that even artefacts with a closed status may influence the division of work; earlier studies have associated this function with artefacts allowing manipulation (see Henderson, 1991; Nicolini et al., 2012).

In the study, *standardisation* was the least prominent mediating function of boundary objects. However, standardisation seemed to become more central due to the increasing automation of the manufacture. The emergence of systems of boundary objects mediating actions together indicates the development of infrastructure, in which operations of and relationships between artefacts become routinized (Mongili & Pellegrino, 2014a). Latour (1994) called 'reversible blackboxing' the process that stabilises and naturalises artefacts, because such a system of artefacts becomes visible only upon breakdown – which opens the blackbox. Due to the inherent standardising of actions and knowledge brought by the use of boundary objects (Bowker & Star, 1999; Star, 2010), the standardisation function calls for further research and can be informed by studies on infrastructure (e.g. Edwards et al., 2009; Mongili & Pellegrino, 2014b).

While insisting that mediating functions are situated in practices, the relational approach proposes that the notion of mediating function as an emergent and temporary capability of artefacts is a general one, as suggested by theories of mediation (Cole, 1996; Verbeek, 2005). Studying the ways in which artefacts participate in practices in different collaboration settings can be expected to expand the identified mediating functions while deepening the understanding of mediation. Moreover, the further elaboration of the typology of functions may replace the existing characteristic-based labels which have been used to distinguish between the different roles of collaboration artefacts. For example, Nicolini and colleagues (2012) employed the notions of boundary object, epistemic object, object of activity and infrastructure as analytical categories to discern what roles certain artefacts performed during a research collaboration to construct a bioreactor for growing cells. Referring to the hierarchy of artefacts in-

troduced by Wartofsky (1979), they proposed a three-level hierarchical framework to distinguish between the roles of objects in cross-disciplinary collaboration (Nicolini et al., 2012, p. 625). This framework associates functions with the roles that different kinds of artefacts play in collaborative work, but the suggested mediating functions remain at a very general level (motivation, facilitation, support).

The findings of the study suggest that *boundary objects are multifunctional in nature*. Due to the analysis of artefacts' roles with different characteristics-based labels, the previous studies have only focused on one function of an artefact at a time (e.g. Ewenstein & Whyte, 2009; Nicolini et al., 2012; Scarbrough et al., 2015). The relational approach enables the identification of the mediating functions that a boundary object performs across situations: The present study demonstrates how an artefact acquires various mediating functions in different situations. Furthermore, the findings illustrate patterns of mediated actions – action, evaluation and problem solving – which the experimental product development practice relied on. Hence, the study proposes that *the mediating functions artefacts perform depend on the sociomaterial constitution of the situated practice*.

The findings also demonstrate *the transformative nature of boundary objects*: The artefacts acquired different mediating functions over the course of the development process. I propose the analysis of mediating functions as a potential method to study the dynamic status of artefacts by exploring how artefacts transition in terms of their functions and what impact these transitions have on collaboration (Nicolini et al., 2012; Scarbrough et al., 2015). Previous studies have analysed such transitions as transformations from one type of collaboration artefact to another (e.g. Ewenstein & Whyte, 2009; Miettinen, 1998). Scarbrough and colleagues (2015) found that the artefacts performed different functions in coordinating collaborative tasks over the course of an innovation process. Additionally, Star (2010) argued that boundary objects have a temporal status in collaboration, because people try to make the ill-structured and well-structured forms of the artefact equivalent; when the movement between these forms becomes standardised, the boundary object becomes immersed in the infrastructure. The present study illustrates how the mediating function performed by a boundary object transforms from one situation to the other and over time.

The transformative nature of boundary objects raises the question, to what extent the artefacts themselves transform. Drawing on Kallinikos (2012), I analysed the boundary objects in terms of their form, manipulability and function. When tracing the artefacts across the phases of the product development process, I observed that the central boundary objects appeared in the form of different kinds of representations. These representations tended to be conceptual and open at the beginning of the process, while later they appeared in a material form and finally reached closure at the end of the process. Similarly, the mediating functions evolved from conceptual mediation (e.g. communication and explanation) to material mediation (e.g. action and delegation) of actions, reflecting the central concerns of the actors in each development phase. This compares

with the different levels of mediation suggested by Béguin and Rabardel (2000), which may range from temporary, situation-based mediation to the stabilisation of the link between an artefact and its function and further to the transformation of the artefact to perform new functions. However, the relational approach emphasises that *the stabilisation of the mediating function of an artefact is related to the evolution of the practice in which the artefact participates*; the function may become inscribed in the artefact in the practitioners' eyes through reification (cf. Wenger, 1999).

In addition to allowing the tracing of the temporal trajectory of artefacts, the relational approach enables the exploration of the interdependences of trajectories. Figure 33 relates the evolution of product and production concepts to the ways in which boundary objects participate in the shaping of the innovation process. The mediating functions of boundary objects are connected with the purpose of the practice and the relationships between the actors in each situation. For example, in the early development phases, the boundary objects participated in the formation of the network that constructed the product and process innovation (see Figure 9 in section 5.3), which produced the initial characteristics of the product concept and the principles of the production concept. Furthermore, within the practices that evolved throughout the innovation process, some of the boundary objects performed several functions, which shifted across situations (see Table 17 in section 6.11).
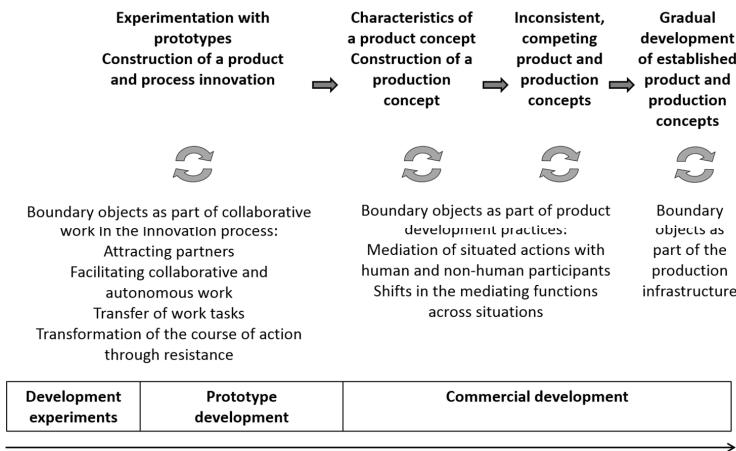
Figure 33. The use of the relational approach in the study of boundary objects in the innovation process.

The study of situated mediation of actions as part of the relational approach differs to some extent from previous research on mediation by artefacts in terms of the temporal dimension. The typology of mediating functions relies on the activity–theoretical and the postphenomenological understanding of media-

tion, combined with situated analyses of previous empirical studies of the purposes that artefacts fulfil in collaborative work. Despite being based on the situated study of actions, the analysis of mediating artefacts as part of activity systems within CHAT tends to portray a generalised picture of the use of artefacts in a particular phase of the development of an activity. In addition, ANT scholars understand translation as a process – possibly unfolding over several years, which consists of many displacements that construct a network of actors under a common interest (Callon, 2007). Hence, the situated and processual understandings of mediation call for further research.

8.2.3 Interdependencies of product development and production

This study suggests the practice-based approach as one way to integrate insights from the innovation and operations management literatures. The study demonstrates that the use of practice-based definitions of product concept and production concept in the analysis of the innovation process and its outcomes reveals the interconnections between the development of products, production technology and production practices.

My findings highlight the interdependencies between the development of products and production. Despite the acknowledgement of the significance of integrated product and process development to innovation (e.g. Ettlie, 1995; Tatikonda & Montoya-Weiss, 2001), the understanding of the interaction between product innovation and the development of production remains limited. Recent attempts to bring these streams of research together have included concepts of customisation (Spring & Dalrymple, 2000) and modularisation (Campagnolo & Camuffo, 2009), calling for the alignment of marketing, product design, production systems and organisational structure. Furthermore, in engineering design, a so-called DFMA approach has promoted the design of products for improved manufacturability and assembly (Boothroyd, Dewhurst, & Knight, 1994). Despite these developments, the innovation and operations management literatures have remained separated.

The present study demonstrates that the adoption of the practice-based approach to innovation may bridge these research streams and improve our understanding of the relationships between product innovation and production. The practice-based understanding of the innovation process views it as a bundle of sociomaterial practices that contribute to the development of a product, which eventually meets the requirements of both customers and effective manufacturing. My findings illustrate how new product and production concepts emerge from the innovation process, which integrates the development of the product and production technology. Furthermore, the findings show how the logics of the product and production concepts evolved over time through the development of variations of the product and the construction of the production infrastructure. Hence, the study demonstrates the interaction between the development of innovation practices and the evolution of product and production concepts.

My literature review on production concepts demonstrated that the research is scattered in different disciplinary literature streams. Thus far, the literature

has not defined a coherent set of dimensions of production which a production concept comprises. The present study suggests production concept as principles of organising the activities of producing products; it represents the logic of production activity (Jalonen et al., 2016). The logic is manifested in the division of work within the organisation and between the organisation's partners, the kinds of relationships among the partners, the chosen production technology and the tools for the management of production activity. The definition includes an understanding of production as a collection of practices to create a product.

The previous literature has associated the creation of a product concept with the early phases of the product development process, resulting in a coherent representation of the goals of the process. This study proposes a novel definition: A product concept defines the qualities of products that embody a comparable use for customers (Jalonen et al., 2016). Hence, products are material manifestations of the product concept but do not necessarily embody all the properties that the concept embraces.

Whereas the previous literature in the fields of innovation management, product development and operations management strives to minimise the changes to product design during the product development process, the present study proposes that changing product qualities are characteristic of flexible production concepts. Previous studies on shifting product concepts suggest that the ability to develop flexible product concepts and to master a repertoire of changing concept representations may be important, particularly in radical product development processes (Seidel, 2007; Seidel & Mahoney, 2014). Furthermore, constructivist market studies demonstrate that the significance of certain product qualities is not the same for all stakeholders, and their significance tends to change during the product development process (Reijonen & Tryggestad, 2012).

The findings of the present study about the reception of the hybrid package in the market follow the science and technology studies insights on the serendipity of the innovation process. The package passed through various trials during the development process and was selected by various food companies (cf. Akrich et al., 2002b; Reijonen & Tryggestad, 2012). However, some of the hybrid packages – together with the food product that they represented and covered – had difficulties in passing the market test. The grocery shop chains appeared as important gatekeepers between the product and the consumers; it was the shops and not the hybrid package that formed an obligatory point of passage between products and potential consumers (cf. Law & Callon, 1992). The hybrid nature of the package as an industrial and consumer product made it difficult for Fipak, the developer organisation, to establish a strong network promoting the innovation (Akrich et al., 2002a; Law & Callon, 1992). Nevertheless, as the epilogue suggests, the developers of the hybrid package learnt the strengths of the product over time and were able to promote these features through their distributors in a way that attracted customers – and eventually consumers – to adopt the product.

My findings about the intertwinement of the development of products, production technology and production practices imply that organisations may in-

tegrate these in their innovation processes. Conventional innovation management and product development literature emphasises the coordination of the various phases of new product development through project management practices and the integration of competencies through cross-functional project teams (e.g. Brown & Eisenhardt, 1995; Crossan & Apaydin, 2010; Krishnan & Ulrich, 2001). The practice-based approach suggests that the integration of product development, production and other competencies, such as marketing, takes place in everyday activities of the participants of the innovation process. The study illustrates that an organisation is able to carry out continuous development of the product and related production practices in a development team that is not dispersed after one development project. Over time, the members of the organisation managed to develop practices that enabled them to carry out both the commercial production of existing products and the development of new products.

Furthermore, the notions of product concept and production concept may bridge the organisation's strategy and everyday activities. In the research project, the concepts were identified based on the examination of product development practices. In the workshops, the members of the organisation established connections between the organisation's goals and the daily practices. Moreover, the research collaboration produced a model of product development projects, which enabled the members to see links between their activities and develop tools for information sharing. This collaborative work aimed to embed the logics of the product and production concepts in artefacts used in the product development practices (Virkkunen, 2006a). This suggests that product concepts and production concepts may coordinate the work in innovation processes.

The study reveals the situated and local nature of production concepts by demonstrating the relationships between them and product concepts (Jalonen et al., 2016). The organisation's production concept displayed characteristics of various production concepts, which previous research has discussed on a general level, in each phase of the concept development process. The characteristics of the production concepts were related to the organisation's understanding of the product concept of the period. This suggests that organisations should evaluate the implementation of a production concept by examining their products and production practices. Moreover, my findings indicate that experimentation may be a fruitful way to develop product and production concepts in an integrated way. Scholars of cultural–historical activity theory have suggested experiments and their evaluation as important ways to develop the activity as part of the expansive learning cycle, carried out as interventions (Engeström, 2004; Miettinen & Virkkunen, 2005; Virkkunen, 2006a). However, this research has not addressed the experimental development of practices by the members of an organisation themselves.

8.3 Evaluation of the study

Evaluation of research generally assesses the trustworthiness of the findings of a study. It is the research process that produces the results of a qualitative study:

The research design is an interacting and integrated whole of the goals, the conceptual framework, the research questions, the methods and the validity of the study (Maxwell, 2005). Hence, evaluation of the validity of the findings relates to the entire research design of the study.

Maxwell (2005) understands validity as "the correctness or credibility of a description, conclusion, explanation, interpretation, or other sort of account" (p. 106) whose assessment requires the testing of the account in relation to the world, against possible alternative explanations. In the present study, validity threats concern not only the empirical accounts of the unfolding of the innovation process and the product development practices but also the theoretical interpretations.

My strategies to avoid compromising the validity of the empirical accounts include rich data, triangulation, comparison, respondent validation and long-term involvement (Maxwell, 2005). I have analysed large sets of different kinds of data that provide both details of the practices and information about long-term processes, including the participants' changing conceptions of their practices. The diverse data sets also allow the triangulation of the data and comparison among descriptions of the participants about the same practice from different perspectives. Validation by the participants took place throughout the research collaboration: They responded to the researchers' interpretations in the various workshops. Furthermore, over the course of the workshops, the researchers were able to observe how the participants gradually began to use the analytical concepts introduced by the researchers to make sense of their activity. Moreover, two participants have read the manuscript of the dissertation: They opined that the accounts give an "embarrassingly" detailed picture of their attempts to develop the product development practices. The longitudinal research design demonstrates that interpretations are situated and limited to the observations that the researcher is able to make during the field study. The epilogue illustrates that the product and production concepts may change over a relatively short period. This suggests that longitudinal studies are important to improve our understanding of organisational processes.

The validity of the theoretical claims of the research is a challenging question. The data about the innovation process, product development practices and the participants' understandings of their activity would have allowed many kinds of theoretical interpretations. I chose to focus on the materiality of the innovation practices due to the observation that the practitioners were struggling to understand the behaviour of a vast number of artefacts, whose functioning was crucial to the product innovation. Furthermore, the need to collaborate with experts from different organisations to develop ways to deal with these artefacts became obvious during the research collaboration. In addition, I was intrigued by practice theories and the notion of sociomateriality to study the role of artefacts.

These observations and theoretical interests made me turn to the analysis of boundary objects. However, during the research process I have considered the use of other analytical concepts due to the critique that the widespread use of boundary objects has raised. I believe that it is necessary to distinguish between a mere artefact and a mediating artefact, because I understand the mediating

ability as a function related to interaction between humans and artefacts (Béguin & Rabardel, 2000). I find boundary object a useful analytical tool for studying innovation practices that include both autonomous and collaborative work (Star & Griesemer, 1989). Furthermore, the literature demonstrates that various kinds of artefacts perform mediation in collaborative practices; the question is, what concept allows their analysis when employing the relational approach. I am aware of the fact that my definition of boundary objects is a broad one; many scholars have emphasised that the use of boundary objects in work practice brings along durability and standardisation (Bowker & Star, 1999; Star & Griesemer, 1989; Trompette & Vinck, 2009). However, Mongili and Pellegrino (2014a) note that the focus on standardisation in the STS research on boundary objects and infrastructures have shadowed the boundary character of both. The exploration of the mediating functions of boundary objects thus emphasises the situated dynamics of the actions of these artefacts, which both enable the crossing and the establishing of boundaries. The assessment of the value of the relational approach to research on artefacts and their mediating ability calls for further studies in different kinds of settings.

Actor–network theory would have offered an alternative lens to study the unfolding and outcomes of the innovation process. Even though I have used insights from the STS and ANT research on innovation in the analysis, the account produced on the development process of the hybrid package is not a full-fledged narrative of a translation process (see Nicolini, 2010 for an example). Due to the activity–theoretical orientation of the research group, we were interested in the collaboration of the actors brought together in the development efforts and in the hybrid package as the object of these efforts. Like Deken and Lauche (2014), we observed temporal networks and changes in their composition over the course of the innovation process. ANT accounts of innovation processes emphasise the role of politics and power in the alignment of interests and the enrolment of the network (Nicolini, 2010). Due to the research design for tracing the development of the hybrid package, the interests of the actors did not gain such emphasis in our data. Furthermore, the research design also excluded some actors – whose interest may have played a part in the unfolding of the innovation process and its outcomes – from our informants, as discussed in the limitations of the study.

The ways in which the researcher's presence in the research setting may influence the participants' practices and hence the research findings is part the evaluation of validity in qualitative research (Maxwell, 2005). I have tried to make the research process, including the researchers' interactions with the participants, transparent and open for evaluation throughout the dissertation. As discussed in Chapter 4, the action research approach adopted in the research project included the engagement of our research group in the development of Fipak's activity together with the practitioners (Greenwood & Levin, 2007). I reflect on the nature of my engagements in section 8.3.2.

8.3.1   Limitations of the study

Qualitative researchers have been reluctant to evaluate the generalizability of their findings, opposing the quest for universal applicability (Lincoln & Guba, 2009). However, debates on generalizability have resulted in new understandings of the concept, which many social scientist employing qualitative research methods are willing to accept. Hence, the extent to which the findings of a qualitative study may be generalizable are evaluated in terms of the comparability of settings (Schofield, 2009). For example, Lincoln and Guba (2009) discuss generalizability in terms of transferability of insights with their definition of 'fittingness' of the findings, which is assessed as the congruence of two settings and thus requires information of both of the settings. This understanding of generalizability as a relativistic rather than universal phenomenon (Lincoln & Guba, 2009) realigns the responsibility of its evaluation from the researcher toward the reader (Ruddin, 2006). Thus, the researcher is liable to afford sufficient information for the reader's judgment as to whether the findings of the particular study can be applied in another setting or field of practice (Ruddin, 2006; Schofield, 2009). To enable the evaluation of the insights of this study to other settings, I reflect on the limits of the claims developed in this study.

The evaluation of limitations relates to both the generalizability of the theoretical inferences of the study and the empirical generalizability of the findings to other settings (Davies, 1999). I have argued that the relational approach to the study of artefacts in collaboration and the typology of mediating functions are theoretical constructions, applicable across settings. This claim stems from my discussion of previous research on collaboration artefacts and mediation. However, the boundaries of these theoretical inferences are also subject to further empirical studies.

The limitations of empirical generalizability of my findings are related to the comprehensiveness of the data, the conduct of the analysis and the characteristics of the studied setting. I discuss the limitations with respect to the focus of analysis – the innovation process, the mediating functions as well as the product and production concepts.

With regards to the innovation process and its outcomes, the data have certain limitations. For one, early research partners were not included in the interviews; their participation is discerned based on Fipak members' memories and conceptions. Second, important actors – shops and consumers – were not part of the study although their actions proved crucial to the commercial success of the hybrid package in the market. Third, the marketing efforts of Fipak's salespersons were not part of the data; we were not invited to meetings with the customers in the projects we followed nor to the trade shows that the salespersons attended. Fourth, despite learning some insights concerning the relationship between the hybrid package and the product portfolio of the paper company or the position of the business unit within the company from the informants, we did not have access to the management making decisions about the investments in the development and commercialisation of the innovation.

Furthermore, the data represents the different phases of the innovation process with different levels of detail. The research design enabled a longitudinal

study of the development of the properties of the hybrid package and the characteristics of its production practices. Even though the data cover an eight-year time span, the data production was condensed during the 18-month research collaboration. Because the beginning and the end of the innovation process are covered through retrospective interviews, these data allow a less detailed analysis than the observation and workshop data.

With regards to the analysis of mediating functions, there are also limitations. For one, the lack of repetitive data is a challenge: My analysis of the product development practices relies on one-time observations of single events (cf. Knoblauch, 2005; Pink & Morgan, 2013). The limited amount of data describing a particular practice – or phase of the product development process – makes it difficult to infer to what extent the functions I discerned based on the observations are representative of each practice. In addition, the analysis possibly misses some distinctions between the mundane and the particular aspects of the observed practices. Furthermore, the identified functions are not mutually exclusive: Due to the various artefacts that typically were present in the observed work practices and the duration of actions in which mediation took place, I often identified several mediating functions during an episode.

Second, the lack of video data and other visual records proved challenging. Even though we video recorded the workshops, we were not allowed to take even photographs of the activities on the factory floor. I drew some details of the artefacts in my field notes during the observations, but during the research collaboration, I did not envision that the visual recollections would fade over the course of time. The importance of visual records only emerged during the analysis of the data once the research collaboration had ended.

Third, the experimental nature of the work in the development practices probably emphasises the mediating functions of problem solving, evaluation and action. I expect that the analysis of artefacts' mediating functions across different settings will reveal different patterns in the occurrence of different functions due to the situated nature of practice. Hence, I propose the mediating functions to be used in further empirical analyses to evaluate the generalizability of the analytical framework.

These limitations of the analysis may relate to the problem of overcoming the 'humanist' perspective when examining sociomaterial practices (Lather & St. Pierre, 2013). My accounts of the product development practices in Chapter 6 tend to centre on human actions and the analyses often portray the "use" of artefacts in these practices. Despite my attempt to investigate the participation of artefacts in the performance of the practices, these accounts remain limited in the description of the entanglement of humans and non-humans (Gherardi, 2015). Besides, my intention was not to produce a fully symmetrical account of the acts of humans and artefacts as I took an asymmetrical position to non-human agency.

With regards to the development of product and production concepts, there are also limitations to generalize the findings to other settings. For one, these are connected to the particular characteristics of the studied setting. It is possible that the intertwined development of product and the production concepts is

more typical of small companies. The Fipak team consisted of fewer than 15 members, who were all knowledgeable of the entire development process. However, the team had established clear responsibilities for each member as well as communication practices, including meetings and shared documents, to coordinate the work within the team and with their partners. The product development literature recommends the use of cross-functional teams in product development projects (Brown & Eisenhardt, 1995), but typically such teams are temporary structures that dissolve after the completion of the project or after its hand-over to production. Therefore, the parallel development of product and production concepts may be a trickier business for large companies, calling for new kinds of collaboration practices across product development projects. This calls for further explorations on the interdependencies between the development of products and production (Tatikonda & Montoya-Weiss, 2001). Even though the problems of developing the properties of the hybrid package and its manufacturing technology are particular to packaging industry, the studied setting as an example of an innovation resulting from the combination of two different fields may lend insights to other settings. The hybrid package was not a case of a disruptive technology to neither the company nor the industry: It did not challenge the existing products of the paper company and fibre as a packaging material of food packages has remained marginal despite the innovation. However, the business of producing the hybrid packages differed from the existing production of the company and finally the management decided to sell the business. These findings thus connect with studies on the development of business models (e.g. Günzel & Holm, 2013).

Second, the research collaboration between Fipak and our research group – particularly the opportunities for collective reflection and the researchers' aid in analysing the activity – may have contributed to the development of the shared orientation. The notions of product concept and production concept became boundary objects in the encounters between the development team and our research group, especially in the second phase of concept development. However, it is difficult to discern the possible influence of the research collaboration in the activities of Fipak, because the product development practices in the unit were still under construction.

8.3.2 Reflections on practice-based methodology and the relevance of the study

The discussion about the production of theories relevant to practice arises from time to time among scholars of social sciences. In organisation and management studies, there has been a growing concern that the theories produced by academics hardly inform organisational practices (e.g. Nicolai & Seidl, 2010; Sandberg & Tsoukas, 2011). In recent years, practice-based studies and theorising have been proposed as a means to bridge between organisational theories and practitioners' practices (Räsänen, 2015; Sandberg & Tsoukas, 2011). However, Eikeland and Nicolini (2011) have argued that the production of practice-based theories that would be relevant for practitioners requires researchers to change their practices of conducting research and theorising.

Based on my experiences in research collaboration with practitioners, I suggest that research may produce relevant knowledge to practitioners through both participation and outcomes. The majority of debates on relevance concern the outcome aspect of relevance, assuming that practitioners may acquire academic knowledge that informs organisational activities (Nicolai & Seidl, 2010) or their understandings of work (Räsänen, 2015). The research collaboration discussed in this study dealt with the participation type of relevance, which inspires me to ponder on practice-based methodology employed in the collaboration. I suggest that this research offers one account of "how researchers and practitioners can engage in a dialogue capable of nurturing knowledge of relevance to practice and of facilitating change" (Ripamonti, Galuppo, Gorli, Scaratti, & Cunliffe, 2015, p. 55).

Eikeland and Nicolini (2011) identify four different kinds of research orientations to conducting practice research in the social sciences in terms of the researcher's theoretical or practical interest and her relationship with the practitioners and their practice. 'Normal science' is theoretically orientated and examines the practice "from a spectator position" outside the observed action to gather data and produce theoretical contributions. 'Applied research,' which aims to produce organisational changes, is similarly conducted from a position detached from the practice while researchers act within the given premises without high theoretical ambitions. 'Collaborative development work,' which aims to improve the practices of the research participants, takes the interests of the practitioners as its starting point while possibly ignoring theoretical goals. According to Eikeland and Nicolini, the rarest orientation to practice research is 'critical dialogue,' which aims to develop theory based on the practically acquired experience of the practice of practitioners. Such research articulates the practitioners' knowledge and produces theory that may become a resource for their action; the research collaboration provides the practitioners opportunities to imagine and pursue new possibilities of action (Engeström, 2001).

In the LPC research project, our research group aimed to construct new scientific knowledge based on an understanding of the partner companies' practices and to develop the companies' activity together with the practitioners. The starting point of the research collaboration was negotiation about the aims of the research and the research process to ensure that the knowledge produced would inform the practitioners' practice (Greenwood & Levin, 2007). Furthermore, in the encounters between practitioners and researchers we tried to create spaces for collective examination of the practitioners' practices and for knowledge co-construction. Sykes and Treleaven (2009) call this orientation 'second-person action research,' which can be validated by the community of practice involved in the research collaboration (Greenwood & Levin, 2007). After the research collaboration, the practitioners felt that the collaboration had help them to make sense of their activity and systematise their work practices.

The co-produced knowledge was articulated in different forms during the research collaboration and after it. We discussed the mirror data with the practitioners in workshops, described the research process and its outcomes in a com-

pany report and wrote a guidebook about the development of production concepts. Later we worked on a research article and I analysed the produced data again when writing this dissertation.

I propose that these attempts to articulate the knowledge produced together with the practitioners are examples of practice-based theorising. Such theories may be used by practitioners "for interrogating their own activity and exploring new ways of doing, saying, and being" and provide "an opportunity for practitioners to see beyond the current horizon of their own practice and expand the existing practice in new and groundbreaking directions" (Eikeland & Nicolini, 2011, p. 170). The basis for the theorising originated from our learning about the practitioners' work and from using concepts to analyse the practices together with the practitioners. Moreover, the conceptual models that we constructed during the research collaboration were evaluated and elaborated by the practitioners. Our experience confirms Islam's (2015) observation that practitioners are capable of conceptual and analytical work, provided they can take distance to their daily work for reflection. However, the orientation of our research practice shifted between critical dialogue, normal science and collaborative development work during the research collaboration (cf. Eikeland & Nicolini, 2011). At times, our research group viewed the research practice as tasks of data collection and the interventions as tools for carrying out the development of work practices.

While working on my thesis, I continued the development of scientific knowledge by analysing the data produced in the LPC project with concepts derived from the previous literature. Even though my research work was detached from field of practice that I study, the concerns of the practitioners were still present in my work. While I was aware of the criteria which the practitioners used for evaluating their own work, my analysis from an outsider position enabled me to illustrate the richness of their practice, which the practitioners did not always appreciate in their daily work. However, I doubt that my analysis in this thesis would support the development of practices in Fipak further than our research collaboration did. Despite my attempts to describe the working methods of data production and to provide systematic analyses of Fipak's pratices, I suspect that practitioners would find it difficult to apply the insights to their own situations without research collaboration. Therefore, I believe that bridges between organisation theories and their application to organisational practice may take place through research collaboration rather than through research outputs.

I suggest that the combination of ethnographic research methods with an action research approach may support practice-based theorising (Sykes & Treleaven, 2009). First, action research encourages researchers to negotiate the objectives and methods of the research throughout the research process to ensure that the practitioners are willing to commit to the suggested research approach (Neumann, 1997; Pålshaugen, 2002). Second, practitioners may participate in the ethnographic inquiry both as participants and researchers because it focuses on studying everyday organisational life (Ybema, Yanow, Wels, & Kamsteeg, 2009). Third, data produced with ethnographic methods may be brought into

the sphere of collective examination between researchers and practitioners; this mirror data provides a common object for reflective dialogues (Virkkunen & Newnham, 2013). Fourth, the research process is flexible in the sense that the methods and the conceptual resources may be accommodated to the needs of the practitioners. In the research collaboration with Fipak, we negotiated about the next phases of the process based on the initial findings. Furthermore, the analytical concepts used in the collective examination of the mirror data stemmed from the observation of the practitioners' practice and were only later elaborated theoretically.

Scholars of practice theory have referred to the methodology of developmental work research and Change Laboratory in cultural–historical activity theory as an example of intervention methodology (e.g. Gherardi, 2011). Even though our research approach drew also on this methodology, it departed from the Change Laboratory method in some respects. These include the emphasis on continuous negotiation, the selection of research participants, the role of the researcher and the structuredness of the intervention process.

Whereas action research stresses negotiation as an important part of the whole research process, in the Change Laboratory process this is expected to be accomplished during the first discussions between the organisation and the researcher (Virkkunen & Newnham, 2013). Ensuring that the participants of the research process represent the communities whose practice is the object of development is an important concern of action research approaches working with dialogues, which have created organisational structures, such as development organisations, for this task (Pålshaugen, 2002). In the Change Laboratory, this concern is addressed but the process does not include methods for dealing with the issue (Virkkunen & Newnham, 2013). Action research positions the researcher within the practice together with the practitioners to integrate their knowledge in a 'cogenerative learning' process (Greenwood & Levin, 2007). The Change Laboratory expects the researcher to remain an outsider who prepares and analysis the intervention process: The researcher can work as the organiser and orchestrator of the participants' learning process, thus not part of the process herself (Virkkunen & Newnham, 2013). The action research process often proceeds through cycles of planning, acting, observing and reflecting (Sykes & Treleaven, 2009) but the researcher can draw on many alternative methods to conduct the process. This may lead to using conventional methods without reflecting on their suitability for the setting under study (cf. Eikeland & Nicolini, 2011). Instead, the Change Laboratory proceeds with a prescribed structure that follows the expansive learning cycle and includes a set of methods for the different sessions of the process (Virkkunen & Newnham, 2013).

Both action research and the Change Laboratory methods have strengths and limitations. Many action research projects rely on the use of practitioners' knowledge with facilitation methods without providing avenues for rethinking the existing practice (cf. Eikeland & Nicolini, 2011). While the Change Laboratory method aims at transcending the current horizon of the practice, it relies heavily on the active involvement and expertise of the researchers, which can

impede the practitioners from taking initiative in the development of their practice (Blackler, 2009). I believe these traditions could benefit from "cross-fertilisation" in research processes like the one this dissertation deals with, which engaged researchers from both traditions.

8.4   Avenues for further research

Despite recent calls for more process studies of innovations (Crossan & Apaydin, 2010), practice-based accounts of the innovation process and its outcomes have been rare in the innovation literature. Even though previous studies have demonstrated the role of artefacts play in coordination practices (e.g. Deken & Lauche, 2014) or in network formation (Christiansen & Varnes, 2007), innovation management research lacks longitudinal studies that integrate the process and outcome perspectives (Crossan & Apaydin, 2010). I suggest that innovation research could benefit from the insights provided by science and technology studies on the intertwinement of technological, social and economic elements in the innovation process (see Nicolini, 2010 for an example). Furthermore, I encourage researchers to include existing or potential users of the innovation in their studies (e.g. Harty, 2010).

The study has suggested that insights from the innovation and operations management literatures maybe integrated by studying the relationships of product and production concepts over the course of the innovation process. This study is one of the first analyses of the interdependent evolution of product and production concepts (see also Jalonen et al., 2016). Due to the preliminary status of this work, the notions of product concept and production concept require further elaboration. Moreover, the investigation of their relationships would benefit from the development of methods for analysis that could account for their dynamic evolution. Previously, analyses of the change of production concepts have focused on stepwise development (Victor & Boynton, 1998) and used the elements of the activity system to discern changing relationships (e.g. Virkkunen, 2007). I believe the study of the interdependencies between the development of products and production would benefit from alternative theoretical constructs. Additionally, further research could explore experiments as a method for the integrated development of product and production concepts.

Practice-based studies of organising and the recent debates on sociomateriality in organisation and management studies have brought questions about the role of materiality into the foreground. However, materiality is often discussed in vague terms such as object or technology (Leonardi, 2012); I propose the concept of artefact provides a basic definition for studies on sociomateriality. The notion of artefact fuses the conceptual and material dimensions by implying that an artefact is always infused with meanings when it is part of a practice (Cole, 1996). Moreover, this allows the distinction between different kinds of artefacts by analysing their characteristics and use (Kallinikos, 2012). The present study has suggested boundary object as the basic artefact mediating collaborative work. However, alternative conceptualisations are also available. For ex-

ample, the notion of intermediary object has been employed in studies of product design (e.g. Vinck & Jeantet, 1995; Boujut & Blanco, 2003). Further studies are needed to explore how the notions of artefact developed in different streams of literature could be brought together to construct analytical tools that serve the analysis of various kinds of practices.

Furthermore, this study suggested that the relational approach to artefacts' participation in collaborative work enables the examination of transformation of the functions that artefacts perform in practices. The idea of the mediating functions of artefacts draws on the notion of mediation of cultural–historical activity theory and postphenomenology. However, other approaches to the mediation of practice exist as well (see Lanzara, 2009, 2010; Rückriem, 2009). The exploration of these approaches could contribute to the elaboration of the typology of mediating functions. Moreover, the clarification of the functions calls for empirical studies in different settings and the examination of recurring practices to allow the analysis of the transformation of the functions. Similarly, further empirical studies would also increase our understanding of the multifunctionality of boundary objects and other mediating artefacts.

The analysis of sociomateriality and the entanglement of conceptual, social and material elements of practices challenge conventional methods of social sciences. In recent years, the development of visual methods for the analysis of organisations has been on the agenda (e.g. Davidson, McLean, & Warren, 2012; Meyer, Höllerer, Jancsary, & van Leeuwen, 2013). In addition to questioning the primary importance of textual data, scholars of other social scientific disciplines have called into question the conventional understanding of data and appropriate methods. They argue for the need to reconsider what counts as data and what analysing means (Lather & St. Pierre, 2013; St. Pierre & Jackson, 2014). I believe that sociomaterial analyses of work would benefit from the development of new methods and sensitivities.

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Appendix 1: Coding examples of the mediating functions of boundary objects

Table 21. Frequency of mediating functions across the data on the product development process.

Mediating function	Event 1: Negotiation Kick-off meeting	Event 2: Product design Product designer	Event 3: Tool design Tool design meeting	Event 4: Tool manufacture Tool manufacture	Event 5: First trial runs				Event 6: Third trial runs				Event 7: Production runs	TOTALS
					Planning meeting	Trial runs	Report	Totals	Planning meeting	Trial runs	Evaluation meeting	Totals		
Problem solving	6	10	4	17	1	6	0	7	3	8	1	12	1	57
Evaluation	0	2	1	2	0	5	3	8	3	13	10	26	15	54
Explanation	0	0	16	27	2	0	0	2	0	1	0	1	0	46
Communication	2	4	11	2	8	2	0	10	1	0	3	4	0	33
Anticipation	8	4	1	7	2	1	0	3	0	0	6	6	0	29
Action	0	0	0	0	0	11	0	11	1	6	0	7	9	27
Documentation	2	1	1	0	2	6	3	11	3	3	0	6	5	26
Decision making	3	0	1	0	4	1	1	6	0	0	8	8	0	18
Delegation	0	0	0	0	0	1	0	1	0	7	0	7	5	13
Organisation	0	1	1	0	2	4	0	6	0	0	1	1	0	9
Standardisation	0	0	0	0	0	0	0	0	0	1	0	1	1	2
TOTALS:	21	22	36	55	21	37	7	58	11	39	29	67	36	314

Table 22. Mediating functions of boundary objects identified in the data of Event 5 (First trial runs).

Mediating function / Boundary object	Evaluation	Delegation	Documentation	Problem solving	Decision making	Explanation	Anticipation	Standardisation	Communication	Action	Organisation	TOTALS:
Automation (robot, magazines, grippers)	0	0	1	2	0	0	0	1	1	4	0	9
Creases	3	0	2	1	0	0	0	0	0	1	0	7
Documentation	0	0	3	0	0	0	0	0	0	0	1	4
Graphical design of the package	0	0	1	0	0	0	0	0	0	0	0	1
Injection moulding machine	4	1	2	2	1	0	0	0	0	6	4	20
Measurements	0	0	0	1	0	0	0	0	1	1	0	3
Mould	0	0	1	0	0	2	2	0	3	0	0	8
Mould (nameless)	0	0	0	0	0	0	2	0	1	0	0	3
Mould (Customer)	0	0	0	0	0	0	1	0	2	0	0	3
Mould (Food)	0	0	0	0	0	0	1	1	2	0	0	4
Mould (Module)	5	1	3	4	4	0	0	0	2	5	4	28
Front mould	1	0	1	0	0	0	0	0	0	0	0	2
Rear mould	0	0	0	0	0	0	2	0	2	0	0	4
Mould check list	0	0	1	0	0	1	0	0	0	0	0	2
Mould hoses	2	1	1	1	0	0	0	0	0	6	3	14
Package (Customer)	1	0	0	0	0	0	1	2	0	0	0	4
Package (Module)	4	0	3	2	0	0	0	0	2	2	0	13
Paperboard blank (Module)	3	0	5	2	0	0	0	0	1	3	0	14
Rim	2	0	1	2	1	0	0	1	0	2	0	9
Tempering device	1	0	1	0	0	0	1	0	3	1	0	7
Trial runs feedback form	0	0	1	0	0	0	0	0	0	0	0	1
Trial runs report	0	0	1	0	0	0	0	0	0	0	0	1
Trial runs order	0	0	1	0	0	0	0	0	3	0	0	4

Conventionally, product and process innovations are seen as independent outcomes of separate development processes. This dissertation challenges our understanding of innovation by demonstrating the interdependency between the development of products, production technology and production practices over the course of an innovation process. The study of the development of a hybrid package for food products highlights the participation of various artefacts – such as concepts, models and prototypes – in the development efforts together with people from companies, their customers, suppliers and university partners, whose engagements shape the innovation process and its outcomes. The role of artefacts in the process is studied by identifying the ways they mediate collaborative work. The dissertation suggests that the identification of product concepts and production concepts may help organisations in the management of the interconnected trajectories of products and production practices.

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