Biographies of an innovation: an ecological analysis of a strategic technology project in the auto-industry

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Declaration

In accordance with the University of Edinburgh regulations, I hereby declare that:

1. This thesis has been composed solely by myself;

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Abstract

The ‘localist turn’ in technology studies, exemplified by Actor-Network Theory (ANT) and Social Construction of Technology (SCOT), emphasises the agency of actors in innovation processes while, arguably, neglecting structural influences. They provide rather little guidance regarding methodological choices apart from encouraging rich description and offer only limited capacity to explain the dynamics of technological change. This thesis addresses the need to articulate a more nuanced and comprehensive understanding of the contextually-shaped, often highly contingent processes of technological innovation. For this purpose a single, in-depth longitudinal case study was conducted of the development, implementation and use of a strategic information system - a strategic network planning tool - in a German car company. It was analysed applying a biographical perspective which argues for extended analytical foci across multiple sites, moments and time frames in technology studies to account for the complexities and uncertainties inherent in technological change processes. A mixed repository of historical and ethnographic data has been collected, drawing on public and internal corporate documents as well as 44 interviews and extended periods of participant observation at multiple sites. The data was coded and analysed aided by simultaneously building an extensive data-rich timeline of the innovation journey. As a result, our empirically detailed focus on a twelve-year period is contextualised by a historical narrative considering corporate historical developments over three decades.

An ecology metaphor is articulated to appreciate multiple episodes and moments of innovation dispersed in space and time - a view neglected by common metaphors of systems and networks. The metaphor underpins a loose framework, tentatively entitled the Ecological Shaping of Technology, that draws on concepts from science and technology studies and cognate discussions in the sociology of professions to engage with the intricacies of space and scales of time in studying the ‘Biographies of Artefacts and Practices’ (Pollock and Williams, 2009; Hyysalo, 2010). The framework pursues a dynamic, longitudinal understanding of the evolution of a protracted technology development project which went through significant changes in conception and in the players involved and their configuration. This is conceptualised in terms of the development of a ‘kernel’ (Ribes & Polk, 2015) of resources and services managed by, and made available to, an alliance of players. While alliances can shift, the kernel persists

and evolves over time as players try to attract more resources by entering into negotiations in promising 'arenas of expectation' (Bakker et al., 2011) or navigating around those that are less amenable. Technology is portrayed as an element of a package of instrumentalities (de Solla Price, 1983) comprising theories, methods and instruments that are spread across a wider ecology of distributed boundary objects (Star & Griesemer, 1989). Technologies crystallise from efforts of adopting, testing and developing packages to solve specific problems (Fujimura, 1995). A specific technology is co-developed, according to the set of local constrains and specifications delineated by a kernel's alliance of ecologies. These are understood in terms of Abbott's (2005) conception of linked ecologies. The historically shaped and contingent ecological topography of an innovation project is highlighted as a major influence in the social shaping of technological artefacts.

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AIDS	Acquired Immune Deficiency Syndrome
ANT	Actor-Network Theory
BOM	Board of Management
BOM	Bill of Materials
CEO	Chief Executive Officer
EPOR	Empirical Programme of Relativism
FMER	Federal Ministry for Education and Research
GUI	Graphical User Interface
HIV	Human Immunodeficiency Virus
IT	Information Technology
LICOPRO	Lifecycle-oriented Production
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OR	Operations Research
NC	Numerical Control
MLP	Multi-Level Perspective
MACS	Multicenter AIDS Cohort Study
MNP	Major Network Project
MS	Microsoft
PMT	Production Management Team
SATFAB	Satellitenfabrik (engl. satellite factory)
SCOT	Social Construction of Technology
SIS	Strategic Information Systems
SME	Small and Medium-sized Enterprises
SSK	Sociology of Scientific Knowledge
SST	Social Shaping of Technology
VBA	Visual Basic for Applications
VINP	Very Important Network Project

1 Introduction

1.1 Motivation of this thesis

> "Give me a crate of beer and I will be writing up the history of [the artefact] for you in a weekend". (Chris, doctoral student, personal communication, 12 November 2011)

This was a comment by a former doctoral student located in the case study organisation who was the first to work on a technical prototype that, over a decade, evolved into the information-technological artefact that is the object of research of this thesis. His remark was made during a break in a focus group interview organised in a private space in a friendly atmosphere. It was a response to my attempt to explain the purpose of this research. His was a satirical comment to invoke a smile on the faces of bystanders. However it hinted at a lack of appreciation or at least understanding of the overall research undertaking. At that stage of research, when I was still struggling to clarify the goals of my research, something that was not resolved until very much later, I did not have the self-assurance needed to counter his wit. However, the comment remained with me ever since and became implicitly a benchmark for this research in terms of a contextualised instance of the infamous 'So what?' question every student has to respond to eventually.

Obviously, the informant was at some level right in his claim that it would be possible to condense the history of the artefact to a weekend writing exercise. However, we[1] dare to suggest, that the result would have been an anecdotal account from an actor-centred perspective emphasising detailed insights into technical descriptions. It might partly resemble an actor-network theoretical (ANT) narration that relies on the methodologically simple proposition of 'following the actor' in retrospectively explaining the story of a successful technology. An ANT approach does shed light on how a fabric of human and non-human actors is knitted to a strong network where effective individuals enrol powerful allies and become their spokespersons. Skilful translation of diverse strategies of multiple actors into homogeneous interests creates

[1] For narrative reasons this study will henceforth apply the plural pronoun "we" to reduce the distance between the author and our readers.

obligatory passage points strengthening the legitimacy of both the artefact as well as the spokesperson (Latour, 1987).

What could be learned from this hypothetical weekend-report? Without doubt, it would be an informative report with insights into how to negotiate with users, senior managers and suppliers. It would probably yield a firsthand account of Machiavellian engineers who made good decisions at the right time (Latour, 1988). However, what is it that would be missed out in this detailed report? To learn about potential limitations, we need to consider the perspective of our reporter. Although deeply involved in the development and initial diffusion of the artefact, the doctoral student described was a single individual who eventually dropped out from the technological project after his doctoral research was finished, barring him from learning about the details of further developments. Further, as an industrial engineer he was trained according to positivist paradigms of his field, where, for example, rhetorics of seemingly inevitable technological impacts are dominant. For the same reason it would probably lack the appreciation of a critical account that renders social, technical, economic and political aspects equally important to explain success as it is to explain failure. It could contain implicit narrative biases, where narratives had been reorganised and restructured so to remove noise and uncertainties that are common in everyday activities (Czarniawska, 2004a). Eventually, the superiority of the artefact's technical properties and their match with customer needs would emerge as the dominant success factors. Arguably, this is a speculative interpretation and extrapolation of the informant's comment. However, it elicits a widely spread perception of the role of technology in society which assumes a linear process in respect of the development and diffusion of technology.

This anecdote puts this doctoral study in perspective by reporting on an early experience in our data collection and relating this to an overall problem in understanding the nuances of technological change. It sets the scene for a description of the goal to research the role and influence of technology in society and, in turn, society's perception of these. In this introduction, after briefly explaining the research purpose, we outline the research questions that guide the narrative of this social study of a technological artefact. This chapter finishes with an overview of the structure of this thesis.

This thesis was motivated to question assumptions inherent in an actor-centric account and to explore the long and complex story of the development and implementation of the technological artefact. Our study examines the ramifications of the distributed ecology in which the artefact was embedded and by which it was shaped. The account of the previously mentioned doctoral student was an important starting point but it was by no means sufficient to understand why the development unfolded the way it did and why it came about in the first place. To understand these questions we set out to learn about recent corporate history and developments that predated the technological artefact and that played an important role as precursors to subsequent developments. A diverse set of data was collected drawing on ethnographic as well as historical methods to produce a comprehensive and extended understanding of an innovation project, the development and implementation of a strategic network planning tool within a German car company. Our detailed reconstruction of a twelve-year period elaborates how the composition of the project's organisational environment patterned the shaping of the artefact and how the emerging technological capabilities of the artefact in turn enabled the establishment of new relationships with other organisational units. Furthermore, the innovation project is contextualised by a historical narrative considering corporate historical developments over three decades.

Articulating the long and complex story of the technology systematically, however, was a demanding task that we achieved by applying the emerging methodological perspective of the 'Biography of Artefacts and Practices'. This was supplemented by our development of a tailored conceptual framework to take into account the extended historical approach. Both the perspective and the framework were the most significant elements shaping the framing of the research project. We will address both in more detail in the following section.

1.2 Research purpose and the crafting of research questions

The anecdote from the data collection incident intended to raise the issue of deterministic expectations about seemingly inherent technological properties. The limitations of the hypothetical report of our informant would neither be surprising nor uncommon. Contemporary technology studies both by academics as well as professionals are found limited in their capacity to credibly explain technological success in the long run (Pollock & Williams, 2009). Many studies, e.g. implementation or 'snapshot' studies, are confined to short time spans and single locations. Findings produced by those studies describe so-called effects and impacts of technologies, i.e.

simple-minded rhetorics of technological determinism, which do not account for and, thus, underestimate long-term consequences of technological developments on developers, users and other actors exposed to technological change. To uncover and to investigate shortcomings stemming from technologically deterministic thinking, numerous scholars from different disciplines including sociologists, philosophers, historians and economists undertook social studies of technological change in recent decades. These social inquiries into technology were greatly inspired by the social constructivist approach advanced by students of the Sociology of Scientific Knowledge (SSK). With a background in studying the social construction of knowledge claims made by scientists, scholars of SSK developed seminal perspectives including the 'Strong Programme'. This perspective outlines methodological tenets to guide social inquiries receptive, among others, to matters of symmetry and reflexivity in the explanation of success and failure (Bloor, 1976). Drawing on social constructivist theories, students of technology developed a range of studies and theories which amalgamated under the umbrella term of the 'Social Shaping of Technology' (MacKenzie & Wajcman, 1999). Characterised as a 'broad church' (Williams & Edge, 1996), the social shaping of technology tradition demarcates the historical origin of social inquiries into the technology/society relationship within the interdisciplinary field of Science and Technology Studies.

Three decades of research into the social shaping of technologies produced insights into the complexity of innovation processes within diverse organisational settings. A particular strand of research elaborated the notion of 'Social Learning' which emphasises the number of learning processes and intermediaries at play in the innovation process (Sørensen, 2002; Williams et al., 2005). Within this line of research, analysts of technology frequently criticised methodological and conceptual limitations of both professional and academic analyses of technological change dynamics (Pollock & Williams, 2009). To avoid such limitations, including an overly actor-centric perspective, this research adopted the emerging 'Biography of Artefact and Practices' perspective to look beyond solitary confinements of single-sited and short-termed analyses. The Biography of Artefact and Practices perspective addresses the limitation of conventional technology studies and proposes a longitudinal and strategic approach for the social study of technological change (Hyysalo, 2004; Pollock & Williams, 2009). Following the guidelines of a biographical perspective we framed our research project to take into account multiple locales and perspectives to give voice to not just the most immediate actors but also to other organisational players involved in the technological project. The case study began with an exploratory approach to learn about the scope and scale of the research problems in respect of the technological project under investigation. Rather than narrowing down on a set of predefined research questions from the outset, we maintained a flexible research agenda that was continuously shaped by early analysis of the data collected. The specific research questions foregrounded in this work evolved in the course of the study, and only took their current form as the analysis progressed (as we discuss below). Our revised research questions therefore are used as signposts to guide the reader through the research project (Creswell, 2009). Two major research questions have been articulated to translate our research interest in understanding the major dynamics driving the development of the technological artefact:

> RQ1. How does the development of a technological artefact in a private enterprise come about in the first place, and
>
> RQ2. how does a technological project sustain itself over time?

The first question addresses the corporate-historical influences that patterned the unique organisational and ecological backdrop which allowed the technological project to emerge. We wanted to understand not just how the technology was developed but also why it was there in the first place. The second question addresses the circumstance that the development proceeded over an extended period of time. It appeared rather unusual for a research department in a car company to sustain the development of a highly specialised technological artefact over more than a decade. Thus, we were interested in learning about what motivated individual actors and institutional players to keep dedicating time and resources to the project. The third research question addresses a research problem that emerged when we attempted to analyse data and to narrate preliminary results. The more we explored the complexity of the case study the more it became apparent that prevalent theories on technology failed to appreciate and to reflect on nuances in technological change dynamics. Embracing the complexity of the case study, the methodological struggle became the analytical centre stage of the research project. Thus, the research question that describes this emergent research problem is articulated as:

> RQ3. How to analyse and to report the long and complex story of a technological project considering historical and ecological influences?

This research question aims to make explicit the emergent nature of our major research interest which was to find an approach that takes into account the history, context and content of a technological project and the social shaping of the corresponding technological artefact. Since the Biography of Artefacts and Practices perspective is a recent conceptualisation that is scoped broadly by default, it does not offer a precise set of tools or guidelines of how to go about doing a biographical analysis of technology. For this reason, we developed a conceptual framework that helped us in analysing the history and the wider context of a technological project.

Innovation is a highly contextualised and contingent process dispersed over time and space. The third research questions addresses the need to articulate a more nuanced and comprehensive understanding of this complexity. We articulated an ecology metaphor to appreciate the multiple episodes and moments of an innovation project. It underpins our loose framework, tentatively entitled the Ecological Shaping of Technology, which draws on concepts from science and technology studies and cognate discussions in the sociology of professions to engage with the intricacies of space and scales of time. The framework pursues a dynamic, longitudinal understanding of technology development which can go through significant changes in conception and in the players involved and their configuration. In short, this thesis highlights that the historically shaped and contingent ecology of an innovation project is a major influence on the social shaping of technological artefacts.

In summary, the framing and scoping of our research project was contingent on the course of the data collection and analysis process. Our broadly scoped approach embraced the complexity of the case study and inspired the research design and research agenda of this thesis. The research questions were revised as the research journey unfolded. We articulated an ecology metaphor in support of the development of an ecological framework that conceptualises a nuanced understanding of matters of space and time in technological change dynamics. In so doing, we extended the biographical perspective to analyse innovation projects in large organisations. Combining the biographical approach with our ecological framework eventually enabled us tell the long and complex story of the development and implementation of a technological artefact. An overview of the empirical story is provided in the next section.

1.3 Outline of the innovation process

The subject of the biographical analysis was the development and implementation of an information system, the NetworkPlanner (see Figure 1 for an overview of the innovation process). The NetworkPlanner is a decision support system applied in practices of the strategic planning of production and logistics systems. It was developed by a team of industrial researchers in a German car company. The development did not follow a preconceived strategic plan but was a bottom-up initiative stimulated by historical and contextual circumstances. We examined corporate historical events in the 1980s and 1990s to understand the dynamics that patterned the organisational landscape and that enabled the emergence of the research infrastructure in which the technological artefact had been developed. In 2000, this research infrastructure started out as a handful of researchers tasked with the objective to engage with other research projects to support technology transfer processes. However, facing obstacles in the primary objective, the research team soon ventured into other research areas. Participation in publicly funded projects provided for new resources which allowed the research team to recruit doctoral students and to embark on the development of prototypical artefacts. As time moved on, the research infrastructure grew in size and numbers while the artefact gained in capabilities.

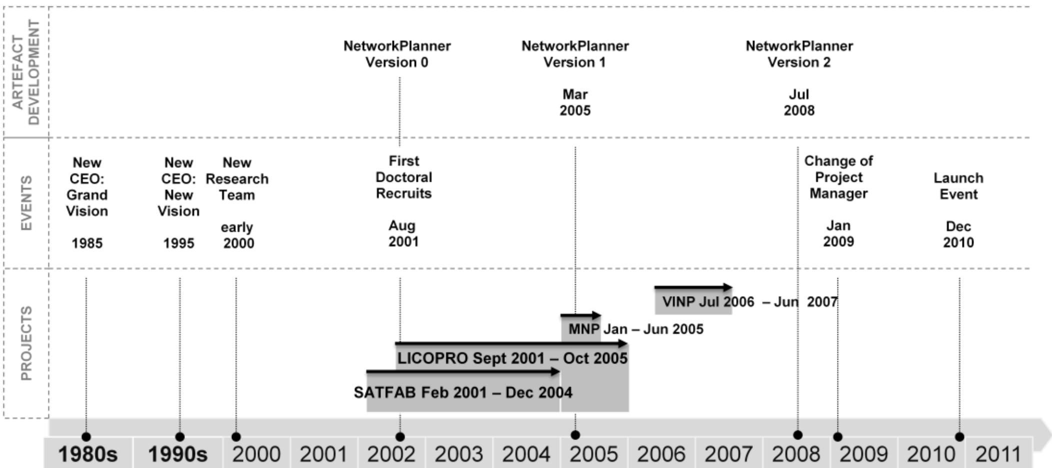

Figure 1 Overview of the development and implementation of the NetworkPlanner

Occasional engagements with internal departments provided for opportunities to learn about operational requirements and to test the prototype on real life business cases. The successful application of the artefact in a pilot project (Major Network Project, MNP) in 2005 was a major breakthrough. After successfully supporting another major project (Very Important Network Project, VINP), the NetworkPlanner was accepted as the standard planning tool in the respective business unit. To initiate the transfer of the artefact into operations, a redesign of the prototypical artefact was commissioned to an external software company in 2008. However, a few months into the development project, the undertaking ran into problems which were resolved by a change in the project management structure. Instead of closing the research project, it was ramped up to cope with unanticipated technological challenges. Eventually, the technological artefact was officially launched at the end of 2010 to mark the end of the research project and to transfer the NetworkPlanner into operations for good.

1.4 Structure of the thesis

This thesis is structured in nine chapters in total. This *first chapter* introduces the motivation, the purpose and the research questions of this study. It introduces the emergent approach in the design of the research study which will be detailed in the methodology chapter. The *second chapter* elaborates the literature that informed our understanding about the subject of this study and that traces the evolution of the understanding about the society/technology relationship. In the *third chapter* we explain the construction of a conceptual framework to address methodological and conceptual limitations identified in the preceding literature review. The methodology is described in the *fourth chapter*. Here we detail the methods we applied to go about doing this study and also account of external events that influenced the shaping of our research strategy. The *fifth chapter* is one of three chapters reporting on empirical details. In this chapter we begin with shedding light on the historical and contextual background of the case study to situate our ethnographic data within a larger picture. The *sixth chapter* and the *seventh chapter* report the detailed story of the multiple episodes of development and implementation of the strategic network planning tool under investigation. A discussion in the *eighth chapter* highlights the key issues of the empirical data and flags the interconnected dynamism of global and local processes in the technological project. The last and *ninth chapter* reflects on the overall research journey and relates our contributions to current debates in the academic field.

This chapter introduced the goals of this study and the roadmap to achieving those. In the next chapter, the literature review, we will establish the intellectual background of this study. It is a review of the evolution of the intellectual understanding about the mutual relationship of technology, innovation and society. Like a technology that is dependent to its social setting, the understanding of technology and innovation is situated within a dominant cultural and social setting. Since cultures and societies are subject of continuous change, our understanding of the technology/society relationship has changed in tandem. In a somewhat chronological manner, we will review how this understanding has changed over time. Eventually, this chronological review allows explaining how theorisations of technology placed emphasis on some issues and neglected others at the same time. Identifying and, more importantly, understanding the origins of limitations in literature enables us in turn to address these in the subsequent framework chapter.

2 Literature review: Evolving articulation of technological change

This thesis seeks to contribute to the theoretical articulation of technology dynamics in light of the development, implementation and use of technological artefacts. To do so, it is important to understand considerations of prior technological and social developments emerging primarily from the late 1970s. Initial theories on technology were developed to depart from modernist visions of technology which regarded technology as a reliable source of solutions to address social problems. New approaches in social studies of technology set out to explore the entanglement of social and technological factors in social shaping processes where various players sought to influence the course of action in order to advance their personal and institutional interests. From these social analyses it emerged that technology was not the discrete entity as portrayed, if at all, by mainstream social and economic theories but inextricably entrenched in historical and contextual factors of its immediate and wider social surrounding. This chapter will review these various conceptualisations of the technology/society relationship from different disciplines to build a theoretical and conceptual foundation for the construction of a loose framework that addresses the need to articulate more advanced and nuanced conceptions of technological change.

This chapter is separated into three sections. The first section traces the emergence of technology studies as a critique of the modernist view on technology as engineered solution for social problems, a view generally identified as technological determinism. Two major theories on technology, Social Construction of Technology and Actor-Network Theory, which both fall into the tradition of the Social Shaping of Technology, are examined in detail before the section will be concluded with a discussion about shortcomings of these early conceptions of technology. The second section contains a historical examination of innovation theories related to technology and thus inevitable will take us aback chronologically. Here, conceptualisations of the role and influence of technology in innovation processes both in broader society and in organisations will be discussed. The third section will focus on recent developments around the Social Learning perspective which builds on the tradition of the Social Shaping of Technology and which highlights long-term issues of implementation and use. The section, and thus the chapter, will be concluded with a discussion on methodological concerns that arise when designing research on technological artefacts.

2.1 Introduction: Critiques of technological determinism in technology studies

This section will begin with examining the notion of technological determinism, a reductionist view that presumes a rational technology/society relationship. It will be discussed how the field of technology studies and in particular the Social Shaping of Technology perspective emerged as a result of intellectual efforts to repel insufficient conceptualisations about technology and its relationship to society. Two frameworks, Social Construction of Technology and Actor-Network Theory, will be introduced before the section concludes with a review of the micro/macro debate.

2.1.1 Technological determinism and the "impact model"

Technological determinism is a reductionist theory of technology. It presumes that technological change follows an inherent logic and has a determinable effect on society (MacKenzie & Wajcman, 1999). In that view, technology is perceived as a "discrete entity" with identifiable properties that are unrelated to social contexts or the history of participating actors (Kling & Scacchi, 1984). Since it allows simplifying usually complex matters, technological determinism is popularly evoked by futurists and technologists to frame dominant visions and utopian thoughts where technologies have predictable impacts. Proponents of "technological utopianism" propagate that technology plays a primary role in social transformations (Kling, 1991, p. 354). For example, advances in computing allowed for the proponents of various "computerisation movements" to raise expectations that computers will have positive transformative effects in domains such as local authority, office work, education, and private households. Metaphors like "information society", "information age" and the general notion of "revolution" were utilised rhetorically to mobilise audiences and to fuel technologically deterministic ideologies (Kling & Iacono, 1988; Edwards, 1995). Similar potent claims were made in regards of computer-integrated manufacturing and computer-aided production management by technology vendors in the UK who oversold their offerings by promoting visions of novel information technologies having positive impacts on efficiency and productivity (Williams, 1995). Technologically deterministic statements are not limited to optimistic claims only but can also aim the other way. Marxist analyses (for example, Braverman, 1974) tended to describe novel production technologies as exogenous factors that transform social relations and skill requirements in workplaces at the expense of workers.

A technologically deterministic conceptualisation of technology by default invokes the "impact" model to explain changes apparently inflicted by the use of technology. Organisation and management researchers commonly apply variance approaches to examine differences among certain sets of variables in a given set of samples to identify the causes and effects of these impacts (Orlikowski & Scott, 2008). Adopting a discrete-entity view of technology conveniently allows looking for such variances in factors. Observed deviations were consequently classified and regarded as evidence for apparent impacts – or implications, effects or consequences for alternative terminology – of technology. However, since the discrete-entity model itself failed to grasp the complexity of technology, the "impact" model was an inappropriate concept to describe phenomena of complex technologies in organisations. Besides failing to reproduce "impacts" of one and the same technology in other social settings, also propagated as the diffusion and adoption of so-called "best practices" (Clark, 1995), the occurrence of unexpected impacts and effects were commonly reported.

The case of computerisation of the banking sector is an example of a larger ecology where belief in impacts and effects yielded other results than those expected (Edwards, 1995). The banking sector was the first major non-military sector in which computers were widely adopted. Although banks invested heavily to computerise their organisations and activities, the growth in productivity was low and many impacts were "neither foreseen nor desired by the designers" (Edwards, 1995, p. 278). An example of unexpected developments in a single organisation is Sætnan's (1991) in-depth case study of the development and implementation of an information system in a Norwegian hospital that drew inspirations from materials and production steering systems as applied in manufacturing industries. Instead of increasing efficiencies and optimising practices, as anticipated by the ministerial funding body, the technological artefact reinforced existing power relations:

> "[The system] thereby became a fast but strong-willed and contrary typewriter. Instead of becoming someone's ally in renegotiating routines, [the system] became a slave to the old routines and thus reinforced them" (Sætnan, 1991, p. 434)

Until recently, technology has received little attention in management and organisation studies. An analysis of 2027 articles published between 1997 and 2006 in four organisation and management studies-focused journals found that only 4.9% of all articles addressed issues of the role and influence of technology in organisations (Orlikowski & Scott, 2008). In other words, 95% of the articles did not consider the role and influence of technology in organisational life. Reasons for the widespread inattentiveness to technology were found to be diverse and ranged from lack of interest and the classification of technology as not significant to organisational life to methodological reduction due to the complexities of organisational life and technological systems. This generally resulted in an unsatisfactory state of conceptualisation on technology in management and organisation studies which fails to grasp the richness and intricacies of technology's role in organisational life. In these fields alone, and also in a more general sense, a better understanding of the technology/organisation relationship is needed to redress both technology determinism and the failure of social accounts to address materiality. Recent contributions in the field of organisation and management studies highlighted these methodological and conceptual shortcomings and started calling for greater attention to technology and for a more complex theorisation of the technology/organisation relationship (Orlikowski & Scott, 2008; D'Adderio, 2010).

2.1.1.1 Technology is not neutral

Naive and simplified interpretations of the role and influence of technology can risk partial or total failures of technological projects which result in the loss of investments, the loss of trust from and potential disenchantment of employees in a single organisation. From a societal point of view, however, the risk is to allow for dominant political powers to steer wider technological developments in their favour. Accepting a notion that technological development follows any inherent logic detached from social processes implies that technology is politically neutral. This view is strongly contested by some authors. Langdon Winner (1980, 1999) effectively argued that technology has capacity to carry political weight. His seminal analysis of the political dimension of technology in an article published in 1980 was reprinted and prominently positioned as the first article in MacKenzie and Wajcman's seminal 'Social Shaping of Technology' book (1999, first published in 1985). Examining the case of low-hanging bridges on Long Island in New York, Winner elaborates how urban planner and architect Robert Moses used his power to implant his social class bias and racial prejudice into the urban infrastructure from the 1920s to 1970s (Winner, 1980, p. 123-124)[2]:

> "According to evidence provided by Robert A. Caro in his biography of Moses, the reasons reflect Moses's social-class bias and racial prejudice. Automobile-owning whites of 'upper' and 'comfortable middle' classes, as he called them, would be free to use the parkways for recreation and commuting. Poor people and blacks, who normally used public transit, were kept off the roads because the twelve-foot tall buses could not get through the overpasses. One consequence was to limit access of racial minorities and low-income groups to Jones Beach, Moses's widely acclaimed public park. Moses made doubly sure of this result by vetoing a proposed extension of the Long Island Railroad to Jones Beach." (Winner, 1980, p. 123-124)

He outlines two senses in which technology can exert political qualities during the design stage and after their implementation, respectively. First, technology is designed and adopted to achieve a certain politically desired effect. The example of nuclear power plants illustrates how such technologies reinforce the necessity of maintaining an authoritative system with centralised control of power. Second, technology can be strongly compatible with specific social and political relationships. The example for this case is solar energy, which tends to be more compatible with democratic and egalitarian societies rather energy systems based on coal, oil or nuclear power. This is so because solar energy reinforces tendencies of technical and political decentralisation.[3]

The risk of seeing technology as politically neutral is that important political influences might be omitted from social inquiries. Technological determinist accounts try to render an image of technological change following an inherent logic or a particular trajectory. If this was true, technological change would be inevitable and thus outside of external

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[2] Winner's (1980) analysis is contested by relativists (Woolgar, 1991b) on the grounds that his interpretation of the political meaning of the bridges is one out of many possible interpretations. Although Winner (1993) agreed to the possibility of varying interpretations, he discarded Woolgar's (1991) critique by arguing for the hollowness of a relativist stance that stops short of taking into account wider societal concerns, for example, consequences of technological developments.

[3] A contemporary example for this thesis would be the UK energy system. Scotland, a part of the UK which seeks independence from central government, pursues a strong sustainable energy policy by committing to generate 100% of electricity demand from renewable sources by 2020 making this the most ambitious target in the European Union (Scottish Government, 2011). Meanwhile, the central government recently approved a deal to built a new nuclear power plant (Macalister, 2014).

political intervention. However, this view conceals the fact that behind every technology there is someone to gain from its development or adoption, either economically or politically. Technology vendors evoke images of technological trajectories in order to promote their products. Political parties emphasise benefits of technological infrastructures to reinforce existing and favourable power structures. Therefore, showing that technology has political capacity is a necessary step, firstly, to improve the understanding of the technology/society relationship and, secondly, to improve practices of technology policy making (Sørensen, 2002).

Failures of technology projects and disappointing outcomes of technological promises indicated the inappropriateness of technologically deterministic accounts. To understand reasons for the poor performance of technological endeavours, several academic disciplines engaged with exploring in more detail the role and influence of technology in society. It was the accumulating findings from these research traditions that innovative perspectives on technology were developed. The next section will introduce the research traditions which formed the basics of what became known as the social shaping of technology perspective which will be introduced thereafter.

2.1.2 Multiple research traditions criticise technological determinism

A stream of research activities in the 1970s and 1980s dedicated their efforts in studying the phenomenon of underperforming technology projects. It was the beginning of a new movement among scholars from various disciplines who started to challenge conventional perceptions of technology, labelled as technology determinism, prevailing at the time. These predominantly social studies of technology contributed to forming the groundwork for a research perspective that was interested in shedding lights on the complex relationship between technology and society. These studies gave rise to the perspective of social shaping of technology (SST). Before introducing the social shaping perspective, this section will examine the multiple research traditions that marked its intellectual origin. Williams and Edge (1996) identify four research traditions which originate largely in Britain: sociology of scientific knowledge, sociology of industrial organisations, studies of technology policy, and economics of technological change. To this we add the contributions of historians of technology, especially the works of Thomas P. Hughes, as a fifth stream. Each tradition was concerned with different aspects of the technology/society relationship and thus left individual imprints in SST-related theories. Next, each tradition will be discussed in turn.

The sociology of industrial organisation is distinguished by its focus on a particular social context, for example shop-floor workplaces, and its exposure and reaction to technical change. Socio-economic interests, social processes and goals of industrial organisations are examined to explain dynamics of transformations in relation to technology development and adoption (Williams & Edge, 1996). For example, Marxist studies in the tradition of the 'labour process theory' elaborated the influence of numerical control (NC) machine tools in shifting power balances in favour of management and at the expense of shop-floor workers (Braverman, 1974). However, subsequent studies of NC machine tools and its successor technology computer-numerical control (CNC) relativised such findings by stressing that under certain circumstances, like in smaller workshops, workers were able to gain back control despite embedded mechanisms that aimed to prevent this from happening (Noble, 1984).

Critical studies of technology policy is a branch in social science that is concerned with studying the relationship of technology and the state in respect of the latter's policy options to intervene in technological and thus economic development. Traditional technology policies implied linear innovation models which proved ineffective and failed in delivering promised economic and social benefits what eventually prompted technology policy studies (Russell & Williams, 2002b). For example, examining state interventions to reverse the industry's dependence on military technology after World War II was an area for technology policy studies (MacKenzie & Wajcman, 1999).

Economic theories differ vastly in the extent to which they acknowledge technology as a driver of economic growth. The majority of economic schools follow orthodox, neo-classical theories which pay little or no attention at all to technological factors. There, beliefs in the overarching regulatory power of price stability, instant availability of free information and market equilibria are dominating mainstream theories. In contrast, economists of technological change acknowledge the significance of technology in influencing economic performance of firms and economies. This group of researchers can be assigned largely to the field of innovation studies. Members in that field share neo-Schumpeterian beliefs that technological change is an inherent and endogenous quality of economies and follows an evolutionary model (Nelson & Winter, 1977, 1982).

Another distinct feature present among some members is that they take into account historical developments to explain long-term patterns (Clark et al., 1981).

Sociology of Scientific Knowledge (SSK) characterises a field that emerged from the philosophical endeavour to refute the belief in an apparent exceptionality of science (Yearley, 2005). Proponents of SSK adopt an impartial approach in studying scientific facts, beliefs or whatever was taken as knowledge. This particularly applies to beliefs that are regarded as true or false. SSK takes a relativist stance towards the truth value of knowledge claims by treating both as equally valid. What matters instead are the conditions under which such claims are produced in the first place. To ensure methodological rigour in the study of the so-called social construction of scientific knowledge, Bloor (1976) proposed the 'Strong Programme'. This approach stresses the four tenets of impartiality, symmetry, causality and reflexivity. A study that follows the Strong Programme aims in explaining truth and falsity according to social terms rather than referring to the natural world. For example, the take up of oncogene theory in cancer research is explained by referring to social interactions of researchers in diffusing the knowledge of the theory in scientific communities rather than referring to the superiority of theory over competing theories (Fujimura, 1995). Studies published under the tenet of the Strong Programme became an inspiration for studies of technology as it enabled students to bridge the dichotomy of the social and the technical (Edge, 1988). Soon after its adoption in social studies of science, researchers from SSK transferred the new analytical approach to the study of technology despite criticism from some colleagues that the social constructivist project remains unfinished in its originating field (Woolgar, 1991b). Other researchers joined in criticising the migration of concepts from SSK to technology, however, for reasons that science has fundamental differences to technology rendering analytical approaches less effective (Sørensen & Levold, 1992). Relativist-constructivism proved its value nonetheless as it bridged the dichotomy between the social and the technical. Previously, the technical aspect of a technology, i.e. the shaping process, was the matter of engineers who followed the blueprints of an apparent inner logic. Social scientists were concerned with the social, i.e. the study of the effects. SSK's analytical approach, however, allowed for an integrated approach which acknowledged the intimate relationship between technology and society: decisions made during the social construction process influenced the effects caused later (Edge, 1988). This turn to technology is predominately due to the approach titled the 'Social

Construction of Technology' (SCOT) which will be discussed further below (Pinch & Bijker, 1984).

Contributions from historians of technology have long documented in great detail the role of technology in influencing social change. Technology has long been used as a political tool to control others. For instance, in some places in England in the 12th century the use of handmills at home was forbidden in favour of centralised watermills which allowed nobles to collect additional taxes (Bloch, 1999). White's (1964) study of medieval technology elaborated how the heavy plough revolutionised agriculture and how the stirrup heralded feudalism in Medieval Europe. However, historians like White tended to represent technologically deterministic accounts of technology. In case of the stirrup, his causal claim that the stirrup introduced heavy armoured mounted knights and, thus, caused the emergence of feudalism was refuted by other historical studies. Both in Persia and China, where the stirrup was used before it reached Europe, the stirrup had no such 'effect' because these societies and their political systems where constituted differently compared to Europe (Dien, 1986). Historians may differ on the subject of theorising, and many abstain from it (Gaddis, 2002). Thomas P. Hughes and his historical studies of Thomas Edison's work (Hughes, 1987, 1999), however, contributed largely to theorising on the systems metaphor in the field of technology studies by introducing concepts of technological systems, system builders and the notion of the seamless web in general (Hughes, 1986). The idea of complex technological systems and the seamless web resonated well with ideas of social constructivists. This gave rise to a range of theories and concepts of which will be addressed in the next section.

2.1.3 Social Shaping of Technology

Prior to critical inquiries into the making of technology and its relationship with social contexts, rational explanations of technological change dominated which invoked a dichotomy of the technical and the social (Edge, 1988). The 'technical' was perceived as a subject matter of natural scientists and engineers. Their task was – here we draw on the vocabulary of Arthur (2009) without implying that he subscribes to a technologically deterministic view – to create technologies to harness natural phenomena for societal purposes. The 'social' matter was then left for social scientists to explain consequences and effects caused after technologies had been completed. Breaking down that technical/social dichotomy was the achievement of a stream of research that became known under the umbrella term of 'social shaping of technology' (SST) (Edge, 1988). SST is a generic approach to the study of technology with an anti-determinist and anti-linear agenda (Sørensen, 2002). A basic tenet of SST is that:

> "[...] there are 'choices' (though not necessarily conscious choices) inherent in both the design of individual artefacts and systems, and in the direction or trajectory of innovation programmes. If technology does not emerge from the unfolding of a predetermined logic or a single determinant, then innovation is a 'garden of forking paths'." (underlined in original, Williams & Edge, 1996, p. 857)

By emphasising the fact that choices are crucial in the design and development of technology, SST opened a debate over the negotiability and reversibility of technological choices (Williams & Edge, 1996). This debate is a departure from the idea that technology is a discrete "black box" independent from social contexts with contents which are predetermined by any exogenous force or logic. Instead, the creation of technological content is understood as being patterned by a range of organisational, political, economic and cultural factors. SST is thus concerned with demystifying the notion of a black box and locating its situation in social settings.

As has been demonstrated above, the origins of SST can be traced to various disciplines, thus it being a 'broad church' (Williams & Edge, 1996). Although each research tradition has contributed in some way to enrich the intellectual capacity of students of science and technology, some disciplines and even schools of thought within individual disciplines are found to be more vocally represented than others. Thus, this allowed for and led to misleading simplifications about what constitutes the social shaping of technology perspective. It was found that conceptualisations from sociology of scientific knowledge have "often been taken (unhelpfully, we would argue) to be synonymous with the SST approach" (Williams & Edge, 1996, p. 861). In particular, the Social Construction of Technology (SCOT) and Actor-Network Theory (ANT) are often spotlighted as the "primary conceptual tools within social shaping" (Howcroft et al., 2004, p. 330).

The 1980s have been an enlightening period of intellectual dynamism in technology studies. The debates kicked off during this time are of continued importance. First, they drove important conceptual developments in the field such as improvements to the effectiveness of technology policies (Sørensen & Williams, 2002). And second, they informed ongoing analytical issues in studying technology. The following sections below will address the latter issue and explore frameworks that developed analytical concepts to understand technological development.

2.1.3.1 Social Construction of Technology (SCOT)

The key intention behind the conceptualisation of the SCOT approach was to replicate the success of Bloor's (1976) 'Strong Programme' in studies of science and to apply it in technology studies. Studies in the tradition of the Strong Programme aim to explain the production and dissemination of knowledge claims through social terms rather than referring to any natural terms. The success of a technology is therefore to be explained solely within the domain of the Social World (Pinch & Bijker, 1984). To do so, SCOT draws on the relativist methodology as outlined by the 'Empirical Programme of Relativism' (EPOR). EPOR is a methodology in the studies of science to examine scientific controversies (Collins, 1981). It has two major stages. In the first stage, an analysis examines knowledge claims made by relevant scientists who represent different views and opinions on a controversial scientific subject. This stage intends to identify alternative interpretations of the same issue to establish that available scientific facts allow for 'interpretative flexibility'. In the second stage, the analyst examines how the 'interpretative flexibility' is limited and reduced in order to close the debate. The act of closure, hence, is based not on any technical superiority of one theory over another but rather on the successful persuasion, or silencing, of opponents. SCOT applies this methodology to explain how technology is being developed (Pinch & Bijker, 1984, Bijker et al.,1987).

The starting point in SCOT is 'relevant social groups'. This concept can include institutions and organisations as well as groups of individuals. Members of a relevant social group share similar beliefs and meanings over a technological artefact and its features. In their study of the evolution of the bicycle, Pinch and Bijker (1984) list different social groups including producers, young men, elderly men, women and tourist cyclists. Each social group had different views on the varying technical features of different models of bicycles at the time. For example, young and sportive men preferred the Penny-Farthing model, with its characteristic large wheel at the front and a small wheel at the back, for it allowed for high velocity. Due to its popularity at the time it gained the nickname 'Ordinary'. However, the Penny-Farthing posed a safety risk due to its height for elderly people and was regarded as inappropriate for women who used to wear long dresses at the time. The problematic issues surrounding the 'Ordinary' bicycle indicate that debates about a standardised design were not yet closed with the design of the Penny-Farthing model. Even the introduction of the air tyre, which was developed to improve comfort of riding and is standard nowadays, left space for interpretative flexibility as some engineers claimed that it made bicycles less safe.

Highlighting interpretative flexibility in the case of a technological artefact is the first stage in a constructivist analysis. The next stage is to analyse mechanisms how the interpretative flexibility is reduced and, thus, how the design of an artefact is stabilised. This can be achieved either by convincing an audience that the problem has been solved, this is where advertising can be helpful, or by redefining the problem so that the artefact provides increased benefit. As an example for the latter, the air tyre was eventually promoted primarily for its ability to increase velocity. In contrast to EPOR, SCOT goes further and proposes a third stage where the relationship of a stabilised technology to the wider social context is elaborated. For this purpose, the concept of a technological frame is introduced (Bijker, 1989). It broadly describes a set of concepts, techniques and practices that are shared by a community in its problem solving activities. A technological frame is related to a specific relevant social group and describes why multiple actors apply the same methods in defining and solving problems. Technological frames also guide interactions between actors with similar interests and shape their thinking and acting (Bijker, 2009). In case of the Ordinary bicycle, an example for a broad definition of a technological frame was the common social practice of young men to use the technology a "macho machine" for "racing, showing off, and impressing the ladies" (Bijker, 1989, p. 172). Similar to the concepts of 'paradigm' (Kuhn, 1996), 'technological paradigm' (Dosi, 1982) or 'technological regime' (Nelson & Winter, 1977, 1982), which all aim for engineering related social groups, the concept of technological frame aims to explain clustering of similar technologies and problem-solving strategies by also including nonengineers.

Since its introduction in the 1980s SCOT as a methodological approach went through different stages (Bijker, 2009). At its beginning the unit of analysis was an individual artefact, e.g. the bicycle. Thanks to influences from historian Thomas Hughes and his studies of larger technological infrastructures (1986, 1987, 1999), it was soon extended to technological systems to consider the intricate combinations of wider social, technical organisational, economic and political elements. The next extension was the consideration of technology as a 'sociotechnical ensemble'. This view is very similar to a technological system but allows gaining some distance from connotations of systems theoretical concerns. Hence, it is less restrictive and more inclusive in the sense of the 'seamless web' metaphor which acts as a reminder that non-technical elements play an important role in the development of technology. In its final and current stage, SCOT is applicable to regard and examine the relationship between technology and society as a 'technological culture'. Since societies are saturated with technologies, they reshape our social practices. Industrial automation and the use of robots have not only reshaped workplaces but also the very meaning of what 'work' means (Bijker, 2009).

SCOT has undoubtedly enriched the social shaping perspective by bridging the field of science studies and technology studies. Notions of 'interpretative flexibility' and 'technological frame' shed further light on the multiplicity of interpretations in linking technological capabilities to social benefits and, respectively, on how shared beliefs give preference to one technological option over another. However, these elements were also met with some opposition. Generally, criticism of SCOT addresses its problematic accounting of social structures (Klein & Kleineman, 2002). Since actor-network theory has faced similar criticism rooted in relativism and reductionism, a general discussion about problematic issues of social constructivist, or just constructivist as propagated by ANT proponents (Latour, 2005), approaches will be addressed further below after ANT's review in the following section.

2.1.3.2 Actor-Network Theory (ANT)

Actor-network theory also emerged in the early 1980s when the sociology of scientific knowledge gained traction in science studies. Like SSK, ANT is interested in understanding how knowledge is created and how it is disseminated. What distinguishes it from SSK is that ANT finishes what SSK has stopped short of, at least so their proponents claim. Bloor's (1976) Strong Programme appeals for symmetry when studying and assessing knowledge claims from competing scientists. The call for symmetry asks to treat claims for truth and falsity equally, i.e. each is to be assessed with the same criteria. For example, asymmetrical claims often emphasise technical superiority of successful cases while failure is explained in social terms, like resistance or incompetence of actors. Proponents of ANT go a step further and proclaim general symmetry between human and non-human actors (Callon, 1986). One can say, they propose an even 'Stronger Programme'. While SSK acknowledges scientists, organisations and social institutions as relevant actors, ANT grants non-humans and objects a similar status and the ability to voice their own interests. This radical move to allow for free associations – Latour (2005) describes ANT as 'sociology of association' – between humans, non-humans and objects is a deliberate strategy in order to break down boundaries of existing social structures. Proclaiming a new sociology, ANT departs from existing traditions in sociology where social scientists use predetermined analytical categories, such as groups, organisations or institutions, to make sense of reality and to create social orders (Callon & Law, 1982; Callon, 1986; Latour, 1987; Latour, 2005). Instead, existing social structures are rejected to make way for the view that actors create reality through recurring interactions. The notion of 'social' is reduced to associations, or chains of associations, between human and non-human actor, the latter also called actants. Whatever the 'social' is, it is to be found between two actors or actants (Latour, 1987; Latour, 2005). For actor-network theorists society is performative in the sense that social structures are the consequence of action. In contrast, conventional sociology implies an ostensive definition of society where social structures are predetermined and exist outside the performances of actors (Strum & Latour, 1999).

In ANT success is defined as the growth of a sustainable network. ANT's strength lies in the richness of vocabulary which was developed in order to examine and describe a growing network. In science studies the interests of actors play a principal role. An actor-network theoretical account is interested in examining "the manipulation and transformation of interests" (Callon & Law, 1982, p. 622). Thus, scientists, and other actors, engage in 'interest work' where they try to identify and manipulate interests of other actors and persuade them to join their activities. Successful attempts result in new members being 'enrolled' to social worlds as defined and controlled by the persuading actor. The identification, transformation and alignment of interests is the primary process, also called 'translation', which enables a network to grow (Callon & Law, 1982; Latour, 1987). The translation process proceeds along four stages, also described as the four 'moments of translation' (Callon, 1986). In the first stage, problematisation, the spokesperson of a network defines the problem and offers a rewarding perspective for the targeted actor to align her interests according to those of the network and to enrol. In this context, the concept of 'obligatory passage point' is introduced. The spokesperson manipulates, or transforms, the interests of the actor and suggests that her network is the best possible, maybe only, way to solve a problem. The network is thus rendered as the obligatory passage point that has to be passed in order to attain a goal or solution to a problem. The second stage is interessement and describes the moment of translation, when an actor considers the benefit of enroling to the network. During the process of problematisation, the spokesperson of the network had drafted an identity and location for the actor within the network. The actor has to decide if she wants to submit to the proposed identity and location. If the actor makes a positive decision, she successfully enrols to the network, marking the third moment of translation, i.e. enrolement. The last moment in the process is mobilisation. After enrolling to the network, the actor submits to the leadership of the spokesperson who from then on is entitled to speak in the name of the actor and all other members in the network. The actor also becomes 'mobile' in the sense that the spokesperson can utilise the actor or rather a representation of the actor for different purposes. For example, by representing the actor as a data set in a graph or report, the actor is utilised to further forward the common cause of the network. In Callon's (1986) study of fishermen and scallops, the population of scallops is represented quantitatively in tables and graphs. These sets of data are presented to others and used as 'immutable mobiles' (Latour, 1987, p. 227) to advance the cause of the network. By that, scallops that physically exist only in the sea are displaced to remote locations.

Since its beginning in the 1980s ANT has been developed further also due to the fierce criticism the approach met for its attempt to redefine sociology (e.g. Bloor, 1976). A notable contribution to reformulate the ANT project is Latour (2005). To move away from the apparent misinterpretation that ANT aims to establish "some absurd 'symmetry between humans and non-humans'" (Latour, 2005, p. 76), the approach is redefined to appear as a more general theory of action. To this effect, new concepts are introduced to avoid the plain human/non-human dichotomy. The notion of 'mediators' replaces actors as the source of action and the vehicle for meaning:

> Mediators transform, translate, distort, and modify the meaning or the elements they are supposed to carry (Latour, 2005, p. 39)

'Intermediaries', in contrast, are faithful in the sense that they do not alter the meaning they carry. As a consequence, action is no longer a result of causality but a translation of two mediators that engage with each other:

> “So, the word ‘translation’ now takes on a somewhat specialized meaning: a relation that does not transport causality but induces two mediators into coexisting” (Latour, 2005, p. 108)

As a theory ANT has moved from an approach describing translations of interests, i.e. manipulation and alignment of interests, to being presented as a social theory describing translations of associations where entities activate action through co-existence. Another consequence of this new theory of action is the heightened status of description as the outcome of scientific inquiry. According to Latour (2005) the new sociology seeks ‘thick descriptions’ (p. 136 in footnote) that do not leave wanting for any explanation, since explanations are residues of the old sociology. Because neither the observing social scientist nor the observed actors are able to respond to basic questions about the make-up of our social world, the social scientist just ought to provide a description of the observations made and to leave it to the reader to make an interpretation.

2.1.3.3 Micro/macro debate opens grounds for meso-level perspective

Both SCOT and ANT follow the tradition set out by sociologists of science and scientific knowledge. This tradition draws attention to micro-level dynamics in the production of knowledge and truth claims. Social constructivists contributed in repulsing rational and deterministic theories of technological change by emphasising that ‘effects’ of technology were traceable to choices made by actors rather than being inevitable qualities of technological properties (Williams & Russell, 1988). These studies produced detailed and insightful accounts which illuminate how complex networks of social interests influence technology development processes. In both theories, SCOT and ANT, actions of individuals are the focal points of analysis. Following their activities, so it is proposed, will reveal how society is constructed through recurring interactions rather than being defined by the existence of any social structures. It is such post-modernist, philosophical exercise that provided novel views on the technology/society relationship that prompted constructive criticism on conventional perspectives. However, while addressing previous limitations of conventional theories, actor-centric approaches also introduced their own methodological and conceptual drawbacks. Since every framework or theory intends to reduce the complexity of reality, reductionism is an expected consequence. In regards of social constructivist theorisation of technology, reductionism affects to large extent the conceptualisation of social structures.

A major issue with SCOT and ANT is the problematic accounting for social structures. It was found that actor-centric approaches tended to overstate the power and autonomy of local actors while neglecting social surroundings and infrastructures that shaped the context of actions (Williams & Russell, 1988; Sørensen & Levold, 1992; Klein & Kleinman, 2002). The lack of a strong representation of social structures limits the explanatory capacity of these approaches:

> "An acontextual account is underdetermined analytically. It leaves unexplained so many features: why the particular groups identified should be involved; their starting points; the different conditions affecting them; the ramifications of their actions, and so on" (Williams & Russell, 1988, p. 11)

Both theories shed light on the creation of knowledge and artefacts, i.e. the content of the black box of technology. However, the approach taken results in analysts climbing into the box and closing it behind them, as indicated by the title of the contribution by Williams and Russell (1988). Social structures outside the black box are neglected and overtly discarded as some irrelevant 'backcloth' of prior interest (Callon & Law, 1982). Instead, 'macro-structures' are explained, or rather described as Latour (1987) would phrase it, by extrapolating micro-level interactions between actors:

> "Society [...] is constructed from the bottom upwards; the 'macro' is in effect reduced to the 'micro'." (Williams & Russell, 1988, p. 1)

It has been shown that social constructivism propagates acontextual interpetations. To that we add the criticism that it further promotes ahistorical interpretations by refusing to account for the so-called 'backcloth' of prior interests. This is demonstrated best by returning to Winner's (1980) account of the low-hanging bridges in New York City. In his response to Woolgar (1991b), who challenged Winner's interpretations on grounds of interpretative flexibility, Winner (1993) accuses social constructivists of lack of ambition to examine deeper relationships between technology and interests of the actors involved. Following the urban architect Robert Moses in his efforts to socially construct urban infrastructures would reveal less of his deeply-rooted cultural and political interests than tracing his life work in a biographical account. Both accounts, a social constructivist and a biographical, would reveal valuable insights into the social shaping of an urban infrastructure and, respectively, the contribution of an individual in propagating and engraining particular cultural values in public life. It would be wrong to accuse proponents of SCOT and ANT of producing inaccurate descriptions of technological change. However, there is strong reason to doubt the explanatory capacity and reach of acontextual and ahistorical descriptions of micro-dynamics. SCOT and ANT do offer strong tools to examine 'what' and 'how' questions, but they are unilluminating in respect of 'why' questions.

To draw a conclusion from the limitations of social constructivist theories, critics of micro-sociology see an opportunity for middle ground by elaborating the space in between the micro/macro divide. A meso-level perspective emerges which is inspired by novel approaches of micro sociologists and informed by the existing stock of traditional macro-theories (Williams & Russell, 1988). This perspective sheds light on players which had previously been ignored:

> "[...] there are very important "intermediate" institutions and institutional arrangements (networks) involved in technological innovation, and they are neither fluid nor determined. Consider, for example, the role of banks, venture capitalists, colleges and universities, research institutes, and so on." (Sørensen & Levold, 1992, p. 14-15)

On one hand actor-centric theories highlight individual actions but neglect relations on organisational and institutional levels. For instance, organisation and business analysts would examine performances and strategising processes of individuals, employees and managers, of an individual company. On the other hand, macro theories would take a top-down approach with the national economy or the government as a starting point. They tend to focus on macro concepts such as economic growth, business cycles, policies and the diffusion of technology (Sørensen & Levold, 1992). The meso-level approach thus addresses a void in which a multitude of activities take place which micro and macro approaches under-theorise.

This section reviewed the origins of the field of technology studies. This field emerged in the 1970s and 1980s from various research traditions which criticised the widespread belief of technology determinism. This belief assumed that technology was a discrete entity separate from social settings and that technology contained inherent capabilities that allowed for deduction of any 'effects' and 'impacts' of technology. Multiple research traditions engaged with social studies of technology design/development and implementation to disprove technologically deterministic assumptions and to demonstrate the role of choices in shaping the contents of technologies. Two social constructivist theories were introduced and discussed to illustrate the contribution of a particular branch, sociology of scientific of knowledge, to drawing attention to micro-level dynamics of technology development and implementation. Although contributing largely to exposing technology determinism as a flawed concept, critics of the micro-sociologist approach highlighted deficits in the theorisation of social structures. This led into a micro/macro debate which crystallised into the call for stronger focus on the space between the two extremes. The meso-level perspective was identified as middle ground between the action and structure divide. To draw a conclusion, early theories on the social shaping of technology played an important role in repelling unsatisfactory and inadequate perceptions of the technology/society relationship. This project was fairly successful but the theorisation of technology remained controversial due to emerging incompatibilities between different schools of thought. Despite unresolved theoretical debates among students of technology (and science) the prevailing idea that technology is intrinsically entangled with its social environment carried on to spread to other disciplines in social science and beyond. The next section will review how technology studies enabled a new articulation of processes of innovation which previously held strong technological deterministic assumptions.

2.2 New articulation of technology and innovation processes in organisations

The distributed but vigorous efforts to repel technological determinism in society and academic communities fruitfully resulted in the emergence of the field of technology studies. New and radical methodologies encouraged social scientists to challenge existing imageries of the science, technology and society relationship and to reveal the social activities going on behind the close curtains of laboratories, R&D departments and policy-makers. Previously common depictions of a carefully engineered society where scientists and engineers project technological solutions into the world gave way to sober accounts of individuals, social groups and powerful elites imposing their agendas and interests onto the wider population. However, early theories on technology tended to overly emphasise sites of technology design. Historical studies of technology also had the benefit of hindsight. The successful critique of technological determinism risked introducing a new bias, i.e. social determinism, which gives too much weight to powerful actors. This is where studies of innovation offered valuable insights into a wider range of processes associated to technology development. Studies of innovation processes, i.e. processes of invention, development as well as diffusion of technology, widened the scope to other groups of players. In particular the focus on users in work organisations posed the challenge to scholars to consider that innovations often fail and that they have to be implemented and reinvented in use. This highlighted that technologies represent complex configurations of past technologies, techniques, tools and existing working practices. However, the understanding of innovation was strongly patterned by technologically deterministic views. As a result, innovation was largely misunderstood as a linear process where technology development progresses uniformly and relatively unproblematic through different stages. In their studies scholars of science, technology and innovation all faced similar challenges to tackle common misconceptions and inadequate conceptualisations.

As innovation is intrinsically linked with technology, the theorisation of technology inevitable affects theories on innovation. Therefore, in parallel with the critique of technological determinism that led to technology studies frameworks, there has been a discussion of innovation processes. Intellectual advances in technology debates have been mirrored in innovation debates and vice versa. This led partially to cross-fertilisation between scholars sharing grounds in both fields. In the first section of this chapter we have reviewed the evolution of technology studies as a field. This section aims to recount the evolution of innovation studies in respect of technology in general and in work organisations in particular. Unfortunately this requires a hop back in time to recall the origins of innovation theories and early conceptualisations of innovation models. Thus, apologies if some aspects of the discussion appear repetitious. The review will begin with an examination of the origins of the innovation model to understand how advances in innovation studies correlated with theorisations on technology.

2.2.1 Emergence and evolution of innovation models

A linear model of innovation aims to explain technological change by arranging social processes in a rational order which represents the flow of information and the increasing maturity of technological outputs. The discrete-entity model of technology witnessed its heydays from 1950s to 1970s when it served as the underlying concept for linear models of innovation. A linear model implies linearity in the social order of innovation activities where a technology is transformed and then passed on to the next stage in line. Thus, it is build around the assumption that technology is a separate entity that can easily move about in an orderly process through space and time. In its most basic form, the linear model postulates that:

> [...] innovation starts with basic research, then adds applied research and development, and ends with production and diffusion:
>
> Basic research → Applied research → Development → (Production and) Diffusion (Godin, 2006, p. 639)

The linear model started to emerge in literature in the 1940s. The conceptualisation of a model to depict the innovation process served initially, in turn and in different stages, as a rhetorical instrument for different scientific communities to pursue their own agenda (Godin, 2006). The first stage in the development of the linear model was initiated by natural scientists who put forward a conceptual distinction to demarcate the boundary between their honourable work on 'pure science' and the less prestigious activities of engineers and industrialists which the scientists belittled as 'applied science'. Second, in the attempt to make science better measureable and accountable, statisticians and researchers in the US National Science Foundation and in OECD expanded the yet rudimentary model of basic and applied sciences with the notion of 'development' to summarise activities of industrial management of research and the development of technologies. And third, economist utilised the model for their purposes by extending it with further innovation activities to integrate the process of bringing a commercial product to market.

The persistence of the linear model is linked to the need for science policymakers to justify growing public sector investments in research. Its dominance lasted up to the 1950s when practitioners and policy-makers became increasingly unsatisfied about technological progress which often resulted in failures. The mixed success of technological and scientific projects in the 1960s and 70s prompted studies of the innovation process in the hope to improve technological progress by enhancing project management capabilities. Studies of military technologies, e.g. Project HINDSIGHT in the US (Sherwin & Isenson, 1966), and commercial technologies, e.g. SAPPHO in the UK (Rothwell et al., 1974), were commissioned which generated new empirical insights into the innovation process. Besides reporting opportunities to improve existing management processes these studies highlighted that success was not entirely dependent on technological factors as depicted in the conventional technology-push model. These findings underlined that projects tended to be more successful the better they took into account user requirements. According to these findings, it was not exclusively the discovery of new scientific findings that sparked the development of new technologies. Instead, it was the coupling of user needs with technological capabilities that shaped successful technological projects. Consequently, a debate among economists arose promoting an alternative model which saw social forces, i.e. needs of a society and its individual members, being the imperative driving technological change.

The need-pull model (or demand-pull as it is also known) emphasised the prevalence of user and market needs over technological and scientific excellence. Rhetorics of the need-pull model centered around the notion that people have to be coupled with innovation activities including marketing and production (Godin & Lane, 2013). As a result, science and technology, previously holding the pole position in the linear model, were relegated further down the stream to give way for considerations of market needs. Although sparking new debates on innovation processes, the need-pull model was insufficient in eliciting a more complex theorisation of technology and its relationship with society. What changed in the 1960s, however, was that innovation became a central subject for an emerging field in economics that later turned to innovation studies. Beyond 1970s, innovation models became more elaborate and stressed the mutual dependence of both technological and social factors. Integrated models combining the strengths of both the technology push and need-pull models started to appear as more attention was paid to the intricate role of technology in organisational settings (Rothwell, 1992).

The field of technology studies emerged about the same time when innovation scholars developed models of the innovation process which were more sophisticated and sensitive towards complex relationships between the technical and the social. United in the undertaking to improve understanding of technological change, the two fields overlapped sufficiently to enable to some extent the exchange of concepts and ideas among academics from different disciplines in social science. Technology students familiar with micro-level, bottom-up approaches were able to participate in innovation debates. Likewise, innovation students, who are adept in studying macro-structural phenomena applying a top-down approach could draw on theories developed by social studies of technology. However, the exchange was limited and analysts of technology appeared to have benefited more from interactions than their colleagues from innovation studies (Martin, 2012). Nonetheless, fruitful interactions with other disciplines allowed technology studies to evolve into a multidisciplinary field. Reflecting its foundation in disciplinary diversity, theories and concepts generated by students of technology consequently transcended disciplinary boundaries. The next subsections will be reviewing how technology studies informed new forms of articulations of the technology/society relationship and the innovation process.

2.2.1.1 *Towards dynamic and interactive models of innovation*

Previously it was introduced how the combination of novel ideas from sociology of scientific knowledge with existing research traditions inspired a new generation of social studies of technology. Criticising technology determinism and the linear model of innovation, the social shaping of technology perspective emerged as an approach to understand technology as the outcome of numerous negotiations among a multitude of actors where choices are influenced by a range of social and technical factors (Williams & Edge, 1996; MacKenzie & Wajcman, 1999). The origins of the linear model of innovation date back to the first half of the 20th century when boundaries were drawn up between 'pure science' and 'applied science'. This separation and categorisation is difficult to hold nowadays with literature from innovation and technology studies providing much counter-evidence. Technology and science are no longer seen in a vertical and unidirectional relation to each other but understood as different cultures that are in a horizontal and interactive relationship (Edge, 1988). The linear model of innovation overlooks the interactive and cultural nature of the two domains and thus fails to grasp the diverse range of interactions and uncertainties that surround the evolution of technical artefacts and their role in influencing social outcomes (Williams et al., 2005). Innovation is a complex social activity with interactions changing depending on the maturity of the technology and the moment of the innovation process. Transformation is not limited to technology but is a quality that is mutually shared between a technical artefact and its social surroundings (Williams & Edge, 1996):

> "Technologies, once developed and implemented, not only react back upon their environments to generate new forms of technology, but also generate new environments" (Williams & Edge, 1996, p. 868)

Models of innovation and technological change therefore should reflect the dynamic and interactive journeys a technology takes in course of the innovation process.

Within technology and innovation studies we can identify two routes scholars have taken to articulate the dynamism and complexity observed in innovation activities. The approaches vary in the level of detail in attending to micro-level dynamics and in the degree of stability and continuity granted in theorising about technological change dynamics. One account seeks to explain broad patterns recognisable in the innovation process. It stresses the idea of continuity and is a top-down approach to explain systematically how meso-macro contexts interact with and influence turbulent and chaotic innovation processes. The other account attends to the fine structure of innovation processes shaped by particular contingencies emanating from complex configurations of multiple actors and contexts. It resembles a bottom-up account and stresses discontinuous elements in innovation processes. Both accounts attend to and provide explanations for technological dynamics. And thus they showcase a dilemma in that both account for dynamics in technological journeys albeit from different and yet irreconcilable perspectives. The remainder of this section will examine these two accounts in turn before the section thereafter introduces the perspective of social learning which attempts to find the middle ground between the two accounts.

2.2.2 Account of continuity: patterns in evolutionary technological change

Early studies of innovation were looking for consistent patterns and success factors in the production of ideas and in the application of problem-solving techniques. For example, analyses of patent data and clusters of inventions elaborated the idea of long waves such as Kondratiev's 50-year cycles to understand the relationship between innovation and economic development (Freeman et al., 1982). The effects of apparent social forces and trajectories of technological advancement have been subject of theorisation by multiple authors. Abernathy and Utterback (1975, 1977) introduced a dynamic model of innovation that outlined the lifecycle of an innovation as it moves through different stages of development and shifts from a focus on product innovation towards process innovation. It is thus an extension of the s-curve depicting the progress of learning about an innovation as proposed by Rogers' (2003) diffusion model. Other concepts included natural trajectories and technological regimes (Nelson & Winter, 1977), and technological paradigms and technological trajectories (Dosi, 1982). The latter two were a direct conversion of Kuhn’s (1996) concepts of paradigm and normal science into the innovation domain. A technological paradigm is defined as

> “"model" and a "pattern" of solution of *selected* technological problems. based on *selected* principles derived from natural sciences and on *selected* material technologies.” (italics in original, Dosi, 1982, p. 152)

Based on that, a technological trajectory is the progress directed by the parameters of a technological paradigm.

The notions of technological paradigms and trajectories imply a strong, prescriptive understanding of technological change and thus “are not entirely free from deterministic overtones” (van den Belt & Rip, 1989, p. 136). Indeed, analysts of dynamics in information technology implementations argued that after closer examination, it was difficult to uphold assumptions made by these concepts (Fleck et al., 1990). For example, to sustain any trajectory, a certain level of stability and harmony is required among the forces driving a trajectory. However, the authors of the study commented that:

> “[...] there are tensions within the sphere of implementation which served to frustrate the trajectory that was expected at the beginning of the life of the technology.” (Fleck et al., p. 637)

Thus, trajectories may be established in hindsight but it is problematic to identify them when a technological development is ongoing. The use of notions of trajectories therefore is the subject of rhetorics by promoters of technologies who draw up visions in the attempt to raise expectations. In contrast, the idea of technological regimes avoids to be entangled conceptually with any notions of inevitable technological change. A technological regime is a cognitive concept linked to a particular technology and related bodies of knowledge. It represents widely accepted beliefs of engineers and technicians “about what is feasible or at least worth attempting” (Nelson & Winter, 1977, p. 57). It varies only in nuances from Dosi’s (1982) ‘technological paradigm’ in that it is not as prescriptive in respect of technological progress. To illustrate the concept, Nelson and Winter (1977) draw on the development of the DC3 aircraft in the 1930s. Its design embodied the technological regime that aircrafts are best equipped with a metal skin, low wing and piston engines. Rather than trying to predict technological change, the technological regime concept foregrounds cognitive characteristics shared by a homogenous collective of engineers. It avoids making a normative assumption about behavioural patterns of firms and technological change but turns attention to the way how engineers are socialised to perform problem-solving activities in a manner fashionable in respective sectors. The concept of technological regimes originates from the application of an evolutionary theory in the economics domain which the next section will introduce.

2.2.2.1 Evolutionary theory of economic and technological change

The widely cited contributions by Nelson and Winter (1977, 1982) became a turning point for economists of innovation and technological change (Martin, 2012). Nelson and Winter (1982) elaborated a new model of economic and technological change to depart from neoclassical accounts. Two structural pillars of neoclassical and orthodox economic models are the assumptions that, first, firms adhered strictly to strategies of rational profit maximisation and that, second, the notion of equilibrium is a powerful and applicable concept (Nelson & Winter, 1982). The popularity of the concepts of maximisation and equilibrium by economists lies in the ability to build formal models embodying these assumptions. However, Nelson and Winter both rejected these models for their flawed representation of firm behaviours and their neglect to acknowledge technology. Instead, they elaborated an alternative theory of economic change that appreciated the role of technology.

Borrowing from the biological evolution metaphor, they developed the evolutionary theory of economic change (Nelson & Winter, 1982). An evolutionary theory assumes dynamics of change and reconfiguration. The biological evolutionary theory is concerned with the origin of existing and the emergence of new species. In economics, the evolutionary perspective is concerned with change dynamics in economic systems and the behaviours of players within the system, preferably firms. Similar to genes in biological organisms, firm behaviour is patterned by 'routines' which range from short-run operational characteristics to strategic and predictable behaviours. Routines represent the memory of an organisation. Successful problem-solving techniques are internalised through repetition. A routine can be seen to embody the truce of an intra-organisational conflict between members of an organisation who are required to collaborate beyond organisational and hierarchical structures.

The concept of 'selection environment' is pivotal in the evolutionary theory as it addresses the observation that firms' relative use of technologies changes over time – a phenomenon largely neglected by orthodox theories (Nelson & Winter, 1982). In a selection environment, a flow of innovations producing technological variations is taken for granted. Firms are constantly exposed to a variety of technological options from which they can choose in order to improve their routines. Search routines in firms evaluate options and select those that promise the most profit. In contrast to maximisation models, the selection strategy is based on "heuristics rather than on an algorithm calculating an optimum" (Nelson & Winter, 1977, p. 53). Variation in the range of options has two origins. Either a firm develops a technology or service all by itself and enables its diffusion through growth, or a firm draws inspiration from successful developments of others and, thus, facilitates the diffusion of a technology via imitation.

In sum, the evolutionary economics theory offers a conceptual framework to account for continuous technological change. It departs from orthodox economic models which assume a profit maximisation imperative and the notion of equilibrium seeking systems. Instead it highlights limitations in rational behaviours of firms by rendering the selection environment as an arena in which firms exercise search heuristics to sustain and to expand their economic activities. The theory is in line with observations of broader patterns and provides intellectual grounds for conditioned behaviours of other organisational players.

However, accounts of continuity are limited in explaining observations and dynamics on the micro-level. The selection dynamic is an example where a narrow interpretation according to the biological metaphor has limitations for it is not necessarily the 'fittest' technology that is successful. For instance, insignificant, historical 'chance' events can be decisive elements that predetermine the success of one technology over another (Arthur, 1989, 1999). An empirical example is the QWERTY scheme originating from typewriter key boards. Today's domination of the QWERTY scheme is a likely result of "historical accidents" where "the wrong system", in other words, not the best or most effective system, became a global standard (David, 1985, p. 335-6). An early lead over other schemes in 1880s resulted in a technological lock-in which became ever more costly to reverse.

This brief example is to remind of the dilemma that besides global events there are also local developments that can have significant influences on the innovation journey of a technology. The next section will explore contributions that underline the unpredictability of the innovation process from a discontinuous point of view.

2.2.3 Account of discontinuity: technology and innovation in organisations

Accounts of continuity are predominately concerned with a top-down approach that takes firms as the unit of analyses. In this discussion on the discontinuity perspective, the analytical flight attitude will be lowered to enquire about technology-related phenomena within firms and work organisations.

Innovation is a complex and discontinuous process which can, and often does, end in failure when the user/technology match does not fit. Technological success depends on aligning user needs and expectations with technical capabilities. Orthodox theories of innovation neglected the bargaining power of users in the innovation process. Instead, deterministic accounts of technology overemphasised supplier organisations and their efforts and struggles in diffusing technological innovations. In the diffusion model, technologies are perceived as discrete entities that can be moved to other locales with relative ease for straight out adoption. Therefore, attention is paid to factors impeding diffusion and adoption which is often grounded on uncertainties surrounding information available to potential users as, for example, in the case of farmers in the US resisting agricultural innovations (Rogers, 2003). Rogers (2003) takes as its starting point the creation of a productive innovation by the supply side and then charts the processes by which these are taken up. Emancipatory theories of technology contest the condoned dominance of the supply side and the basic assumptions underlying the diffusion model and, thus, call for a re-theorisation of the diffusion of innovation. Studies of innovation in industrial organisations provided grounds to examine the technology/organisation relationship in more detail (Fleck, 1988; Clark & Staunton, 1989; Clausen & Williams, 1997ab; Clark, 1997). These studies highlighted the contingency and discontinuity of social dynamics in episodes of implementation when users interacted with new technologies. A configurational perspective on technology was proposed to match the observation made. This technology in organisations debate will be reviewed in the following subsection.

2.2.3.1 Configurational technology and the user

In basic, the diffusion model assumed the implementation of finished technologies to be a more or less smooth ride interrupted only by problems in the flow of information to potential adopters (Rogers, 2003). Detailed analyses of technology implementations in industrial organisations revealed a more complex situation. Early studies on the management of innovation demonstrated that firms cope better with innovation if they had an organic organisational structure as opposed to a mechanistic one (Burns & Stalker, 1961). An organic management system is more flexible in dealing with uncertainties and changing conditions because of flat hierarchical structures and flexible problem-solving cultures. Interactions occur more naturally and are not impeded by organisational silos, where information tends to be hoarded and shielded from the outside, as is often the case with mechanistic systems. However, innovation is an interactive and dynamic process that depends on an uninterrupted flow of information between actors within the adopting firm but also between users and members of the technology-supplying firm.

A study of the implementation of industrial robots in manufacturing firms revealed how relevant bodies of knowledge emerged only after technologies have been put into practice in concrete locales (Fleck, 1988). Robots were initially promoted as universal machines capable of replacing human workers. The vision was stripped of any note on the social context. When implemented in manufacturing sites, however, robots had to be customised and adapted to very specific local requirements. The vision of a universal machine gave way of robots being configurational technologies. Instead of being simply diffused to new locales, robots had to go through additional development and innovation cycles at each implementation site. Extensive user participation was required to configure technologies and to make them work in the use context – if they were not abandoned altogether as happened often with advanced manufacturing technologies (Bessant, 1985). The configurations of robots and their components varied widely depending on the use case. New design configurations originated solely from problems encountered by users. Some user firms even began manufacturing robots themselves (Fleck, 1988). Fleck described this interactive and iterative process of configuration as 'learning by struggling' and coined the term 'innofusion' to emphasise the intricate conjunction between innovation and diffusion (Fleck, 1988, p 22):

> "Development is a thoroughgoing evolutionary process, in which environmental contingencies are explicitly built in at each stage of variation. Thus each instance of diffusion, each configuration, may well represent a unique variation, a new innovation in its own right. In short we have a process of innofusion" (Fleck, 1988, p. 22)

The recognition of technologies being configurational, rather than pieces of equipment, foregrounded the relevance of the user-producer relationship in innovation processes. This focus on users automatically puts the wider social structure of user organisations into perspective. The relationship of technology, organisations and the innovation process in organisation will be the subject in the following section.

2.2.3.2 Innovation in organisations

Users in industrial work environments are essential in adapting technologies and configuring them according to the technical and social requirements of the respective implementation site. Innofusion is not a unidirectional process limited to the configuration of the technology. In order to make a configurational technology work, the work environment is also exposed to changes. Therefore, development and the organisation of work have to be analysed as a unity, as cases in robotics, (computer) numerical-control technological and office automation have shown (Fleck et al., 1990). Further insights from studies of the development and implementation of computer-aided production management revealed how not only user-producer interactions at local implementation sites played a role but also how actors in professional associations, consultants and governmental initiatives contributed to the social shaping of industrial technologies (Williams, 1997a).

Mainstream theories of macro organisation behaviour were oriented towards efficiency as the underlying axiom of analytical frameworks. This was prevailing with approaches based on the notion of equilibrium and functionalist models of innovation (Clark & Staunton, 1989). The critique on the overemphasis of notions of efficiencies gained traction in light of Japanese firms, especially from the automobile industry, penetrating markets in North America and Europe. Efficiency as the dominating imperative in the board rooms of US car manufacturers was found to be a major cause for decreased capabilities to innovate – a phenomenon Abernathy (1978) termed the 'productivity dilemma' where the focus on increasing the efficiency of production outputs can be detrimental to innovation capabilities. Likewise, the emphasis on efficiency in studies of macro organisation behaviour resulted in the negligence of innovation. It was therefore necessary to spotlight the notion of innovation and to rearticulate its role in organisational processes and settings (Clark & Staunton, 1989).

The innovation process has been characterised as being infused with uncertainty and discontinuity. Close user-producer interactions are required to configure technologies to the social settings. However, it has not been addressed sufficiently yet that it is not only technologies that change in shape and appearance. Organisations themselves are susceptible to change and adaptations in order to deal with changing circumstances. Clark and Staunton (1989) argue that static and functionalist models of organisations contributed to distorting the technology/organisation relationship. To highlight the dynamism of organisations, they put forward the concept of 'structural repertoire' introduced by anthropologist Gearing (1958). The concept was developed to explain shifts in social structures of a society, a Cherokee village in this case, that occurred when external conditions changed. At each moment in time, a society takes a structural pose which is characterised by the number and quality of relationships among its members. The relationships defined the roles and status of individual members. For example, in peacetime when hunting and household matters dominated social activities young males tended to be deferential and noncoercive towards clan elders and other members of society. In times of war, however, cognitive and social structures shifted towards coercive and hierarchical relationships giving young males increased privileges. A structural repertoire is the sum of all structural poses a society can take. Similarly, firms and other kinds of organisations change their structural poses depending on internal and external conditions. An organisation will show significant differences in its behaviour in times of prosperity as compared to situations where it is at the brink of bankruptcy. Extending on the problematic issue of multi-state situations of organisations in relation to the innofusion of technology, the 'Decision Episode Framework' was developed (Clark, 1997). It focuses on strategic aspects of the coordination and steering work by users and technology producers when it comes to migration and configuration, or rejection, of technologies:

> "The framework is constructed in order to explain the role of the user in appropriating an innovation and is therefor devised to make the role of the supplier more transparent" (Clark, 1997, p. 38)

The framework renders the technology implementation and appropriation process as a series of episodes, i.e. sequences of change, rather than stages including agenda formation, selection, implementation and usage. In each episode users engage with supplier claims about their technologies and try to match them with their demands. At the same time, the ownership of the innofusion process in the user organisation is contested by multiple functional areas and professionals. The issue of ownership is also articulated in respect of the overall structural repertoire and the varying structural poses of the organisation prevailing in different episodes. To sum up, the decision episode framework is an attempt to describe the fuzziness of the innovation process in light of the contingent and contested social dynamics in the user organisation. It is a valid response to the diffusion model and other theories which miss to address organisational and institutional contingencies complicating the innofusion process.

In the case of urban planning, we learned how technology can be appropriated to reinforce political opinions (Winner, 1980). Thus, its configurability makes technology involuntarily an instrument for political manoeuvring. A study of the integration of health information systems in India revealed how the uneven distribution of political influence affected the strategising process of a small actor (Sahay et al., 2009). Lacking influential power the small actor was forced to seek alliances with bigger players in order to sustain the development of the information system. The emerging configuration of the artefact was thus patterned to large extent by engagements with temporary allies and their requirements. The notion of 'configurable politics' was proposed to acknowledge the possibility to advance a technological development by varying its technical configuration and linking it opportunistically to ongoing political debates (Sahay et al., 2009). A similar political influence on technology development and implementation was observed in a big bank. Implementing a multimedia technology, an internal team of researchers was required to regularly seek internal sponsors to support the ongoing implementation process (Gallacher, 2004). The case of a car company illustrates further instances of configurable politics in the innofusion of a supplier portal (Gerst, 2006). Disputes about organisational responsibilities and competences among different departments, collaborating competitors and external consultants rendered the complex arena in which local actors had to navigate and to align with to advance the development of the artefact. In all cases, the strategising process of actors involved was adapted according to contingent political situations stumbled across in course of the innofusion of the respective technology. However, stressing the configurability of technology for the sake of politics overemphasises design and downplays the user – a critique that applies to most early technology theories and that will be addressed in more detail in the sections on social learning below. Privileging sites of technology development renders unjustly the image of an engineered society where science and technology is solely at the service of powerful elites. Later accounts explore the opportunities for users and other more marginal players to influence innovation pathways (see also Clausen & Koch, 2002, and Koch, 1997, on company social constitutions).

In an early contribution by actor-network theorists, Callon and Law (1988) articulated the wider social context by describing the coexistence of two networks: first, a global actor network that supports a technological project by mobilising resources which create a limited negotiation space in which, second, a local actor network is granted relative autonomy to develop a technology. Any significant change in the global actor network was likely to be felt by the local network through a change in the availability of resources. Such resources are not limited to monetary funds but also could include political backing, for instance. The relationship between the global and the local networks was shaped by the technology in so far that technological properties enabled some options while constraining others. In the case of the British military aircraft TSR2 examined by Callon and Law (1988), the technical specification episode was dominated by the Royal Air Force which demanded for an aircraft whose specifics did not match the demands of the Royal Navy. Thus, the Royal Navy became an opponent of the project which consumed a considerable part of the national budget allotted to procuring new military equipment. Besides political challenges in the global network, the development also struggled with technical tensions in the local network and eventually was abandoned after public scrutiny increased and put additional negative pressure on the project.

The examples and concepts discussed above reassured the view that the outcome or success of a technology is not guaranteed but often strongly dependent on developments unrelated to the development of the artefact itself. Actors involved are required to manoeuvre along a complex network of users, supporters, sponsors and opponents:

> “developments proceed in a context of already strongly- articulated economic and social interests” (Williams & Russell, 1988, p. 10).

These interests also represent existing infrastructures and entrenched technologies in organisations which delimit the range of options available in the implementation of new technologies.

The critical perspective on the technology/organisation relationship shed light on the social dynamics of multiple actors and institutions, and emphasises the intricate relationship of technology and its social and organisational surrounding. It is in contrast to mainstream theories on innovation, e.g. the diffusion model, which assume that technology is an endogenous factor in relation to organisations. The detailed examination of technologies in organisational settings underlines that innofusion is an unpredictable process exposed to a range of uncertainties and contingencies inherent in social settings which at times is interrupted and discontinued for reasons beyond the reach of the actors immediately involved. Stressing the element of discontinuity in the innofusion process emphasises that technology is rather an indigenous phenomenon in any organisation. Technology is not separable from its social context. Equally, it is not simply added to or implemented in an existing social context. It is an integral element of a complex sociotechnical configuration. The next subsection will be addressing this issue of complexity in sociotechnical configurations from the view of existing infrastructures.

2.2.3.3 Information infrastructures in organisations

The understanding of technology being configurational emerged from studies of failures and struggles of suppliers to build universal industrial machinery for a range of purposes in diverse industrial organisations. Another starting point for a view on technology having configurational characteristics is the increasing accumulation of various interacting technologies in organisations. The role and influence of existing infrastructures on the shaping of new technologies is addressed with the concept of 'information infrastructures' (II). II as a notion is a re-conceptualisation of technology particularly in light of the increasing amalgamation of information technologies with communication technologies and other basic support systems (Hanseth & Monteiro, 1998). Instead of being concerned with individual artefacts or technological systems, the II concept attempts to take into account the involvement of a large body of technical and non-technical elements in organisational life. As a consequence, matters of standardisation and flexibility are the dominant concerns in the IIs perspective (Hanseth et al., 1996, Hanseth & Monteiro, 1998).

Management literature acknowledges the complexities surrounding IIs, corporate IIs in particular, but holds the view that it can be and should be centrally controlled (Ciborra

& Hanseth, 2000). This is challenged by some information systems researchers who find that infrastructures defy control. Rather,

> “infrastructures tend to ‘drift’, i.e. they deviate from their planned purpose for a variety of reasons often outside anyone’s influence.” (Ciborra & Hanseth, 2000, p. 4)

Therefore, II as a concept is shy of definition and has been characterised as “elusive” (Hanseth et al., 1996, p. 409) and “without absolute boundary” (Star & Ruhleder, 1996, p. 113). Scholars concerned with problematic issues of IIs are “jotting down a laundry list of characteristics” (Bowker et al., 2010) often with reference to Star and Ruhleder’s (1996) definition which offers a list of multiple dimensions. Bowker (1996), for example, draws on Star and Ruhleder’s (1996) dimensional characteristics and summarises them into five properties:

- embededness ("it is 'sunk' into other structures")
- transparency ("it does not have to be reinvented each time")
- reach or scope (it is not a "one-off event or one-site practice")
- being learned as part of membership (it is associated with a community of practice).
- being linked with conventions of practice (it "both shapes and is shaped by the conventions of a community of practice") (Bowker, 1996, p. 49)

Its broad definition allows the notion of II to be applied not only to modern information and communication technologies but also, for instance, to medical classification systems. Bowker’s (1996) historical study of the International Classification of Diseases emphasises how the infrastructural perspective foregrounds the contextual backdrop which, on one hand, plays an important role in shaping the classification system and which, on the other hand, is being itself shaped in course of the classification systems’ continuous development. Thus, as a “fundamentally relational concept” (Star & Ruhleder, 1996, p. 113), II underscores the dual relationship between surrounding elements and a technology. The notion of the ‘installed base’ stresses the significance of existing elements (Hanseth, 2000). It implies that a previous infrastructure is always in place and an infrastructure is never developed from scratch.

Similar to the social shaping perspective, the II concept guides analytical attention towards the wider context of a technology’s implementation site. Where the concepts differ is in the directions from where analysts are coming from. While the social shaping perspective is usually concerned with the innofusion of a single artefact or a family of artefacts, the II perspective starts with a consideration of an existing infrastructure as the enabler of organisational innovation. This difference is strongly visible in studies of strategic information systems (SIS). A SIS aims to provide an organisation with a competitive advantage that is grounded in the unique information infrastructure of said organisation so to avoid it being imitated easily by competitors (Ciborra, 1992). A common characteristic is that these systems often emerged unintentionally and due to tinkering and improvisation on the grassroots-level where the unique installed base consisting of technological and organisational capabilities are combined into an SIS (Ciborra, 1994, 1996). Thus, analyses of SIS rely stronger on enquiries into the role of existing information infrastructures than non-strategic information systems.

As a concept II is a valid complementary framework to technology-centred perspectives. It foregrounds the installed base of a given social settings and requires the analyst to explain processes of technological change taking into account historical and current developments within that context. From this point of view, the II perspective carries the potential to bridge the divide between continuous and discontinuous accounts of technology. However, II is arguably a complementary concept adding primarily to the description of sociotechnical surroundings and articulation of embededness of technologies in organisational contexts. It remains of limited use to explain why and how technological developments are initiated and sustained over a longer period of time. Another approach in conceptualisation is demanded to make use of historical contributions of the social shaping perspective and the improved understanding on the implementation and use of technologies in organisations. The next and final section in this chapter seeks to discuss recent contributions in the theorisation of technology and outlines limitations in methodological approaches which arise from these more nuanced articulations of technological change.

2.3 Conceptualising the new articulation of the technology/society relationship

So far it was discussed how the emerging fields of technology and innovation studies reshaped conceptions of the technology/society relationship through top-down as well as close-up examinations of innovation processes. Now we will return to theoretical debates about how to conceptualise and to bring together such different perspectives. Early theories of technology emphasised action and the role and influence of actors in the shaping of technology. Subsequent studies of technology and, in particular, the interaction of users and producers in their respective social environments shed light on how structural factors are important sources of contingencies in technology dynamics. Thus, these studies readjusted the focus on both action and structure which operate simultaneuously and are mutually dependent. Therefore, theoretical accounts have to address issues of action and structure equally and simultaneously. Building upon the debates in technology studies we are now in the position to address emergent theories that take into account both action and structure. This section develops our general epistemological framework and the foundation for the specific conceptual framework for this thesis. Next we will briefly return to the micro/macro debate to reflect on how the conceptualisation on technology has moved on since.

The major source for discontinuous dynamics has been identified as the contingency and uncertainty pertaining activities of individual and organisational actors. Especially the role of users is an essential and unpredictable element influencing the shaping, adaptation and adoption of technology. Behaviours and reactions of users are difficult to control. Even design-centred development methodologies, which aim to integrate the user perspective early on in the development of a technology, are of limited use, at times misleading, because these methodologies still separate the development site from the use site. Such heroic perceptions of the design stage have therefore justly been dubbed to be a 'design fallacy' (Stewart & Williams, 2005).

The discussion of the continuous account of technological change indicated that according to this view individual technologies are not the concern because a constant stream of innovation and technologies is taken for granted. As a consequence, individual accounts of technologies and actors easily go missing in this stream. In contrast, the discontinuous account recognises the significance in the contingent fates of individual technologies and actors. Eventually, it is the successful accommodation of technical capabilities within idiosyncratic social settings that allow a technology to advance on its innovation journey. In the beginning of this chapter, theories on technology have been introduced which emerged predominately in the 1980s. Social Construction of Technology (SCOT) and Actor-Network Theory (ANT) have been presented as widely known theories in the broad church of the Social Shaping of Technology perspective (MacKenzie & Wajcman, 1999; Williams & Edge, 1996). However, these early approaches have been developed under specific circumstances. SCOT and ANT in particular where inspired by intellectual movements in studies of science and scientific knowledge. Limitations of transferring ideas from those approaches into the domain of technology studies have been exemplified in the micro/macro debate.

The micro/macro debate circulated around the problem of justifying an appropriate entry point for the analysis of technological change. While social constructivist approaches demanded for a micro-level-only analysis, others argued for a stronger appreciation of the meso and the macro-level. It seems that the micro/macro debate has not been resolved as much as participants in the debate have simply moved on. For example, the use of vocabulary shifted partly from the ambiguous use of micro/macro to local/non-local terminology (MacKenzie, 1988).

Early concepts in the emerging field of technology studies were concerned with making explicit the numerous choices and decisions made in regards of the design of technological properties. The debate between sociologists of the micro and sociologists of the macro was initially a methodological one: what level of detail should an analysis take into account; what is the appropriate unit of analysis, and so on. In that respect, micro-sociologist taught macro-sociologists a lesson in that they showed that actions and intentions of individual actors at the local were essential in shaping phenomena in the non-local, e.g. in other laboratories (Latour, 1987). Locality as a spatial differentiation has been adopted as a unit of analysis but the conceptualisation of the non-local remained contested. In actor-network theory, accepting the conceptualisation of the non-local requires submission to a new idea of sociology – a move which arguably depends more on ideology than rationality.

The preferred locales examined in early social shaping studies were sites of development and implementation activities. For example, in their historical study of the bicycle, Pinch and Bijker (1984) analysed how the bicycle design was socially constructed through the resolution of controversies around technical variations and their problematic adoption by different user groups. However, it remained undertheorised how these controversies emerged and how analysts learned about the nature of these controversies. Thus, the issues of testing and experiencing by users which stimulate the emergence of problems and controversies in the first place were neglected. Indeed, actor-network theory's proposal of a new sociology generally disposes of the conventional understanding of time and space in favour of an all-encompassing notion of actor network. Generally speaking, initiatives to advance the intellectual project of articulating new conceptualisations of the technology/society relationship with special attention to issues of time and space remained sporadic. A movement that appears promising but is gaining momentum only slowly is the attempt to propose a new articulation under the umbrella of 'social learning'. This will be discussed in the following subsection.

2.3.1 Social learning

The social learning perspective emerged from the intention to find a broader definition to socio-technical change as compared to narrow definitions found underlining technology policies in OECD countries. The narrow focus of such policies on economic growth and competitiveness of national or regional industries resulted in over-promoting new technology development. Issues of deployment and implementation, i.e. the concerns of users, were secondary. As a result of this negligence, the innovation process was less efficient and produced technologies that users struggled with (Sørensen, 1996). The research perspective of Social Shaping of Technology (SST) brought to attention that technologies are the produce of choices made throughout the innovation process. Social learning posed to address some weaknesses of SST. It advances the social shaping perspective by examining in more detail and with a more nuanced understanding who it is that makes these choices, when and under what circumstances (Williams et al., 2005).

A weakness of SST has been identified by researchers of cultural studies. While emphasising the shaping dynamics during stages of design, SST studies gave little attention to efforts of marketing technologies and products to end users. Besides a few exceptions, e.g. Noble's studies of the industrial-military complex and ideologies of scientists and engineers (Noble, 1984) and feminist studies of patriarchal ideology, Mackay and Gillespie (1992) argue that attention to issues of ideology has been largely neglected in SST. Thus they call for integrating notions of culture and appropriation of and by users. This is where social learning draws inspiration and tries promoting a dialogue with relevant research strands including works from a cultural studies perspective and from studies of 'organisational learning' (Williams et al., 2005).

It is not a psychological route of cognitive learning that social learning analysts are promoting (Sørensen, 1996; Williams et al., 2005). Rather, the focus is set on social processes around developing understanding and meaning-making by actors in relation to technology. The number of opportunities for interactions between actors and technology is infinite. The notion of space as a result of social processes is proposed as a helpful method to order and to make sense of interactions (Clausen & Koch, 2002). Space in the sense of social interactions is not a continual phenomenon, however. Besides space, social processes occur during occasions, i.e. episodes of negotiations and interactions. Therefore, the activities and modes of social learning in innovation processes vary depending on space and occasion. Different locations hold different opportunities for learning at different times as the following examples exemplify.

Production functions of economists missed to explain sufficiently how workers' acquisition of knowledge about machinery, materials and work process increased productivity. Arrow (1962) highlighted that although the accumulation of experience did not go unnoticed among economists, the observation was not adequately taken into account by neo-classical economic models. He introduced the notion of learning-by-doing to highlight learning as an important concept and to explain the observed changes over time. This concept acknowledges workshops and work processes as the spaces and occasions for learning. While Arrow (1962) explored learning in production, Rosenberg (1982) extended the scope and reflected on learning that occurred subsequently when a product was used. His learning-by-using concept exemplifies that the characteristics of a technology or product have to be revealed after a prolonged period of use. Another learning process was elaborated by Andersen and Lundvall (1988) who examined the space between producers and users. Their learning-by-interaction concept points out how producers and users enhance their capabilities by institutionalising linkages to enable the exchange of information and experience. Learning is not restricted to producers or users. Regulatory bodies also have power to intervene in the innovation process through the introduction of regulations. Learning-by-regulating is a form of learning that aims for long-term developments by encouraging those qualities of technological development that are deemed beneficial for society and restricting others (Sørensen, 1996).

Learning implies not only the acquisition of knowledge but also the transformation of existing knowledge. Social learning is also a response to criticism of the diffusion model which regards knowledge, and also technology, as a static entity that can be relatively easily transferred from one locale to another. On this note, social learning stresses that innovation is an inherently creative process which unfolds as knowledge and technology are created and reflected upon through multiple occasions of learning at different space (Sørensen, 1996).

2.3.1.1 Making sense of technology: appropriation and domestication

Expanding on the studies of science and technology, studies of media and communications explored the consumption of technologies in the domestic sphere and highlighted that technologies had a material as well as symbolic meaning (Silverstone & Hirsch, 1992; Silverstone, 2006). It did not only matter that a technology was acquired but details of its exact location within the household and its use and meaning remained subject of negotiation among family members, a domain that remains largely governed by gender stereotypes (Silverstone et al., 1992).

In design-centred approaches users were ascribed a passive role. By designing the functionalities of a computer and thus limiting the actions of users, the technology and its designers attempted to 'configure' the user (Woolgar, 1991a). As even historical studies of technology have shown, users tend to reject their ascribed roles and are long accepted as important contributors to both the invention and innovation process (von Hippel, 1976; Noble, 1984; Fleck, 1988). To leverage the occasion of use of technology conceptually, an appropriation perspective is proposed. The appropriation of technology is an active process where technology is being integrated or embedded into a local culture (Silverstone & Hirsch, 1992). Appropriation is an important process to make a technology work. However, appropriation has been a widely adopted term which gained varying meanings. Therefore, the model of domestication has been pointed out for it is a more narrowly and well-defined approach applicable for the study of technology (Williams et al., 2005).

Traditionally, domestication refers to the taming of a wild animal. Similarly, a technology can be domesticated, like a pet, to become part of a family (Berker et al., 2006). The domestication results in turning a wild technology into a useful, reliable and trustworthy tool like the telephone, radio and TV. However, the process is not a onesided but a dual process where the user and her social practices also are appropriated. Taking into account the complex and interactive relation between users and technology, the domestication model provides for a better account of explaining so-called 'impacts' of technology, an endeavour that conventional technology assessment attempted but failed for the lack of a nuanced view of technology as the following:

> "Domestication research suggests that only when the novelty of new technologies has worn off; when they are taken for granted by users in their everyday-life context that the real potential for change is visible" (Berker et al., 2006, p. 15)

To summarise, the social learning perspective holds three promises (Sørensen, 1996). First, emphasising the role of use and consumption of technology, it draws attention to the need to expand analytical tools to understand better how technology becomes integrated and part of our culture and everyday lives. Meaning of technological artefacts emerges through negotiations between actors who engage in different learning processes. It is only in use and in the process of embedment in a specific social setting that an object is given an identity and meaning as has been remarked in cultural studies of commoditisation of things as well as human beings – the latter better known under the term slavery (Kopytoff, 1986). As negotiations between actors progress, the meaning of a technology can change over time. In other words, technologies have biographies that span more than just the development and implementation. Second, by drawing attention to different episodes in the biography of technology, social learning sensitises us that temporality is an important aspect. Relationships between technology and various actors unfold over time. Consequences emerge only after a period of use and experience gathering. This process can neither be predicted nor sped up. Third, the enhanced understanding of nuances in technology development and use allows for policy-makers to devise better strategies for regulations.

2.3.2 Mapping dynamics in the social learning framework

Above we have discussed that the design-centric analytical focus of earlier theories on technology were found to neglect cultural aspects in the innofusion process. Increased attention on matters of use and consumption of technology subsequently elicited a heightened sensitivity towards dynamics driving the innovation process. From the social learning perspective it emerges that three facets in the theorisation of technology require more sophisticated articulation of analytical concepts.

First, actors have predominantly been conceptualised as polarised and homogeneous groups. Especially users and corresponding episodes of use and consumption have been identified as under-conceptualised. Previous conceptions of users as static and passive elements are more and more giving way to the appreciation of users as active participants in the mapping of the innovation journeys of technologies. Second, the turn of attention to more differentiating notions of users also implied an increase in attention to the specifics of locales. Users usually do not share the same physical space as those designing technologies. Also, users of the same technology can be located in diverse locales. Characteristics of localities account strongly for differences in use and consumption and, thus, require more detailed inquiry. Third, change over time has been flagged as another under-conceptualised issue. The meaning of a technology is dependent to specifics of a particular time and space. As time moves on, social interactions and relationships between actors change and so does the meaning of the technology. The issue of time therefore has to be reconceptualised to acknowledge flexibility in the meaning and identity of technologies. In other words, the notion of biography of technology needs further exploration.

Issues of use, space and time are by far not novel in technology studies. However, the social learning perspective demands to analyse these facets in unity. Changes in use and consumption occur over time as experience is gained and the meaning of a technology unfolds. A technology also witnesses shifts in space as it moves to other users and locales as its transformation continuous. Thus, the social learning framework is relevant for analysts of technology for it is concerned with how and why different actors engage in collaborative activities and how these engagements play out over time and space (Williams et al., 2005). The next sections will explore social learning concepts that have been elaborated in scope of studying technological dynamics and which address the three relatively under-theorised facets addressed above.

2.3.2.1 Intermediaries and socio-technical constellations

Adopting the social learning perspective reveals that a simple dichotomy of producers and user does not explain the variety of actors involved in technological change processes. In between producers and users there is a large space occupied by other kinds of actors. Intermediate actors, who have been missed out in the bulk of previous research studies and who have gained due attention only in recent years, have emerged as important players in the innovation process (Howells, 2006). An intermediate actor can be a single individual, a group, an organisational department or an institution. Intermediaries identify, filter and provide relevant knowledge. They fulfil a gap-filling and bridge-building function between producers and users by developing networks and facilitating contacts (Howells, 2006). Besides identifying and providing existing knowledge and artefacts, intermediaries have also a transformative capability. They configure and transform existing relationships and visions of technology (Howells, 2006; Stewart & Hyysalo, 2008). For instance, intermediaries play an important role in conducting social experiments such as pilot studies or commercial trials (Jaeger et al,. 2000; Williams et al., 2005). Located in-between producers and users intermediaries are dependent on functioning relationships between the two. In this position they are concerned to frequently evaluate their situation and to creatively adapt their strategies to the changing circumstances of their operational domain. For this quality they are particularly characterised as 'reflexive actors' to acknowledge their special interests and role in the innovation process (Williams et al., 2005).

In the past the ecology of intermediaries has been growing and it has become more complex (Howell, 2006). The increasing participation and significance of a multitude of players in maintaining the innovation process challenges the applicability and validity of prevailing theories of technology. Social learning is a necessary recalibration of analytical sensitivities in the social shaping perspective to acknowledge stronger uneven trajectories and a relative degree of unplannability of technological developments (Williams et al., 2005). The element of discontinuity and uncertainty in the planning process is also due to the range of interests represented by various intermediaries. Not every actor and intermediary has interest in the success of a project. As exemplified in the development of the British military aircraft TSR2, the Royal Navy was opposed to the project promoted by the Royal Air Force and therefore tried to intervene (Law & Callon, 1988). Thus, the notion of socio-technical constellations is put forward to convey the idea that there also are gulfs between actors and intermediaries who remain "rather peripheral, distant and loosely connected" (Williams et al., 2005, p. 81). The idea of socio-technical constellations is closely related to matters of space and thus leads us to that second facet in the next subsection.

2.3.2.2 *Space and the topography of social learning*

Space in its physical meaning is a geographical location or area that exists naturally. In contrast, social space has been defined as cognitive concept which comes into being through occasions of social interactions (Clausen & Koch, 2002). According to this definition there is no such thing as empty social space. However, actors have interests, visions and expectations. They are constantly on the lookout for opportunities to make profits, as rational economic theory wants us to believe on one hand. The social learning perspective, on the other hand, acknowledges the social surroundings of actors which largely predetermines their capabilities as well as limitations. The notion of 'translation terrain' develops this idea of social space further and conceptualises a space that describes existing linkages between actors and potentials linkages to proximate actors (Williams et al., 2005, p. 84):

> "Social learning is shaped by its local context. Learning processes and outcomes differed between players according to their particular situation. In analysing the different patterns that emerged, our studies highlighted the importance of the specific 'translation terrain' – the immediate array of players with their historical and contingent concerns and capabilities, each trying to map out their strategy in interaction with other players and in the light of their broader social, economic and cultural setting." (Williams et al., 2005, p. 84)

A translation terrain is the spatial illustration of a specific socio-technical constellation. It depicts the immediate array of users interacting, either collaboratively or competitively, in scope of a particular technological development. However, it also includes actors interested in but peripheral to the development at hand. Actor-network theory, for example, describes a successful technological project as the construction of a strong global network of actors sharing the same interests. Local opportunities or conflicts are paid attention to only when the stability of the network is under threat. In contrast, the translation terrain emphasises that players are constantly exposed to actions by proximate players and thereof resulting changes to social settings. Participants in a technological development and players in general regularly map their translation terrain and strategise accordingly. Changes in the socio-technical constellation of the translation terrain enable opportunities or threats to arise which affect the decision-making process and thus influence the shaping of a technology.

A related concept that complements the spatial articulation of technological change is that of the 'development arena' (Jørgensen & Sørensen, 1999). It is defined as:

> "A cognitive space that holds together the settings and relations that comprise the context for product or process development" (Jørgensen & Sørensen, 1999, p. 410)

This definition is fairly broad as it aims to include a number of actors, locales and processes involved in product development. For the purpose of this discussion, we are narrowing down the definition to elaborate the notion of 'arena'. It stems from Arabic and marks sand grounds which are constantly in motion and thus never settled. In political science the term arena depicts "spaces and locations where negotiations, conflicts and ideas are exchanged and developed" (Jørgensen & Sørensen, 1999, p. 412). Arenas are the grounds where players meet for collaborations and for contestations. Events and activities that happen inside arenas have consequences outside. The development of a technological product thus entails multiple occasions in which players enter arenas to engage with other players collaboratively and competitively.

The concepts of translation terrain and associated arenas, both established and latent ones, contribute to what can be classified as the topography of social learning processes. The translation terrain maps the topography of a technological development and serves as a tool for players to strategise which arenas to seek and which to avoid if possible in order to advance their cause. A topographical view of social learning processes is intimately associated with issues of time as will be explored in the following subsection.

2.3.2.3 Time and its representation

Change is a transition from one state to another within a set period. However,

> "history is not just an event in the past but is alive in the present and may shape the future" (Pettigrew, 1990, p. 270).

Time is the frame of reference that defines what change we take note of and how we explain the change observed (Pettigrew, 1990). The properties of the frame of reference therefore are in a direct relation to the explanatory capacity of a study. Common studies of technologies, including snapshot and implementation studies, are unreflective about their inherent analytical timeframes. As a result, they often are retrospective, benefitting from hindsight, biased from a managerial view and of short duration and therefore ignorant of the extended lifespan of a technological artefact (Pollock & Williams, 2009, p.

85). Even after implementation, users have yet to learn about and explore the properties and consequences of a technology and the new practices it enables which unfold only over extended periods of time (Silverstone & Hirsch, 1992). As it unfolds, a technology is exposed to changes in itself and in its social setting which both transform its meaning and identity. These transformations give rise to "the unfolding of multiple histories" and "the different historical timeframes around which an object, event or activity may need to be analysed" (Pollock & Williams, 2009, p. 106). Social learning's call for a nuanced view leads us to a differentiation of multiple timescales and multiple levels of generality that come with them. We will briefly discuss two representations of time: a hierarchical and a multi-dimensional view.

The first representation of time is inherent in the multi-level perspective (MLP). This perspective examines how a number of players interact over an extended period of time and a wider scope of space (Geels, 2002, Ravena et al., 2012). Three hierarchical levels with varying timescales are distinguished: technological niches, sociotechnical regimes and landscape developments (Geels, 2002). Individual technologies emerge frequently and explicitly in 'technological niches' over short periods of time. These have an influence on and are being influenced by 'sociotechnical regimes' of wider social structures and institutions where change dynamics advance only slowly but are relatively traceable. Developments in the 'landscape' are characterised by inertia and barely accountable to single events as these developments are accumulations of events occurring over multiple years and decades, for example, "oil prices, economic growth, wars, emigration, broad political coalitions, cultural and normative values, environmental problems" (Geels, 2002, p. 1260).

The ground for such multi-layered and hierarchical analysis of time has been prepared by subscribers to the Annales School. In particular, French historian Fernand Braudel strongly influenced the Annales School's agenda with his examination of the structure of the 'longue durée' and the three-tiered conception of historical time (Hunt, 1986):

> *structure* (the long-term) at the base, then *conjoncture* (medium-length units of ten, twenty, or even fifty years), and finally, *événement* (the event or short-term) (italics in original, Hunt, 1986, p. 211).

A major weakness and reason for the decline of the Annales paradigm was its methodological lack of focus, in particular on that of agency of individuals, among the vast explanations of ecological, biological, structural, political and economic developments. MLP resembles the Annales School methodologically but is smaller in scale and targeted to study technological change. Nevertheless, proponents of MLP have been prompted to address similar criticism for its strong emphasis of structure over agency (Geels, 2011).

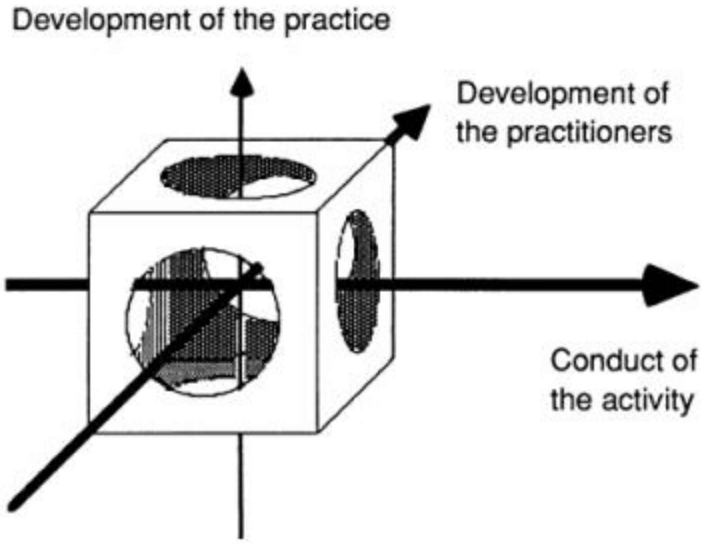

Figure 2 "Hutchins cube", a representation of how multiple developments and speeds of change (the arrows) are present within a "moment of human practice" (the cube) (Hutchins, 1995, p. 372, as cited by Hyysalo, 2010, p. 51)

A second and different conceptualisation of time is highlighted by studies adopting the social learning perspective. Hyysalo (2004, 2010) elaborated a more complex understanding of temporal issues by drawing on Hutchins' (1995) study of distributed actions and cognitive learning during the navigation of a military vessel (Hyysalo, 2004, p. 12):

> "any moment in human conduct is simultaneously a part of the unfolding of a task, the development of the individual doing it, the development of the work community, and the development of the professional practice." (Hyysalo, 2004, p. 12)

In his illustration of a culturally constituted activity Hutchins (1995, see Figure 2) demonstrates how three timescales, each represented by its own dimensions, are at play in any moment in human practice where different things "are all happening at the same time in the same activity" (Hutchins, 1995, p. 372). This is in stark contrast to MLP and the Annales School, where time (and space) is split into different layers and different contexts.

It is not intended to highlight one representation as more applicable than the other. Rather, these representations were introduced to serve as a reminder that time is relative also in regards of the social analysis of a technological development. Choices of how time is represented thus have a strong influence on the analytical approach of a study. Exploring different representations of time and interrelated methodological implications, Czarniawska (2004b) distinguishes chronological and kairotic time which are based on Greek mythology and language, respectively:

> "Whereas Chronos measures time in mechanical intervals, Kairos jumps and slows down, omits long periods and dwells on others." (Czarniawska, 2004b, p. 775)

A hierarchical and multi-layered representation of time, in the tradition of the Annales School, follows chronological sequences where cause and effect appear to be comprehensible and traceable. Thus, it is common among historical and structural studies that take long-term perspectives which benefit from hindsight. Another feature of chronological analyses is that space is broadly taken into account as developments unfolded at different locales in different orders (sometimes simultaneously). A kairotic representation of time is a common characteristic of studies of recent or ongoing developments where events and agencies are yet unfolding and where the significance of individual episodes is yet unclear. Since such studies often are short-term oriented, the representation of space is limited to one or a few locales where actions are currently taking place. In short, time and space are intrinsically entangled. Choice about one dimension inevitably affects choices about the other. Historians are most familiar with how choices about the representation of time influence the interpretation of past events and, thus, the outcome of an historical analysis (Gaddis, 2002, p. 22):

> "Historians have the capacity for selectivity, simultaneity and shifting of scale: they can select from the cacophony of events what they think is really important; they can be in several times and places at once; and they can zoom in and out between macroscopic and microscopic levels of analysis" (Gaddis, 2002, p. 22)

This review of matters of time revealed that the temporal dimension is a crucial factor, especially in the development and implementation of technology which can span multiple locales and long periods of time. Time is a sensitive analytical subject and its (often implicit) representation determines the explanatory and analytical capacity of a research study. Following the call for a more nuanced understanding of technological change, it is necessary to take into account more complex conceptualisations of time, history and time scales. To conclude, the strategy of designing a research study and its representation of temporal as well as spatial dimensions predetermines to large extent the potentiality to generalise from the findings of that study. A discussion on analysing technological change and the lifecycle of individual artefacts inevitably leads to an examination of matters of time, space and research methodologies in general. For this reason, the next section will address methodological concerns and introduce the biography of artefact approach.

2.3.3 Designing research to reflect complexity of technological dynamics

Above it has been discussed how technological dynamics can be analysed from a social learning perspective. However, deploying such nuanced concepts and theories also requires an appropriate organisation of a research undertaking. The design of a research study predetermines the range of possible outcomes. Since existent research approaches yielded unsatisfactory analytical results, the design of a research study also becomes a concern for the analyst of technology.

Historians have contributed vastly to both empirical and theoretical developments in technology studies. Especially Hughes' (1993, 1987) historical studies on the evolution of electrical power systems advanced the understanding about large technological systems and provided fruitful grounds on which further theories of technology were developed, e.g. the social construction of technology (Bijker et al., 1987). However, since Hughes conducted his studies about a century after the deployment of the first commercial power distribution plant, it is obvious that many findings benefitted from hindsight. To confirm the 'success' of that technology, for example, it does not need any archival work.

While historians typically are concerned with events and people that are long past, other scholars are more interested in recent history and ongoing developments. Sociologists are concerned with events whose witnesses are yet accessible to give accounts of their individual experiences. Among the best ways to study recent history is, arguably, that of historical sociology. In his study of the guidance systems of nuclear ballistic missiles MacKenzie (1990) explains how an ethnographic approach, drawing on interviews and observations, allowed him to learn about the social shaping of these systems. An archival-only approach as applied by historians would not have yielded such deep insights into the intricacies and controversies surrounding the social shaping of guidance systems. Of course, relying on statements of individuals runs the risk to learn about facts that are questionable in nature, be it due to deliberately or unintentionally false statements. However, methods of triangulation against other interviews and documentary materials allow mitigating such risks to large extent (MacKenzie, 1990).

A historical, ethnographic approach addresses important epistemological concerns of how to learn about the social shaping of a technological development. Another issue is of ontological nature and poses questions like what aspects of a technological development are to be analysed. There are different ways to frame a research design. Typical research designs, such as snapshot and implementation studies, define the scope and scale of an analysis and thus predetermine the range and quality of possible findings to be made and conclusions to be drawn (Pollock & Williams, 2009). The following subsection will examine such methodological pitfalls before introducing the biography of artefact perspective which tries to avoid those shortcomings.

2.3.3.1 Limitations of episodic studies of technology

Technologies can take years before any major benefits or consequences materialise. By default, snapshot studies, which focus on few particular moments in time such as before and after the implementation in the organisational setting, ignore the longevity of technological dynamics. Similarly, studies of the introduction of new technologies in organisational settings, labelled implementation studies, are restricted in scope and focus on single sites and limited episodes of the lifecycle of a technology (Pollock & Williams, 2009). Such studies frequently produce, often managerial-biased, accounts referring to ‘success factors’, ‘impacts’ or ‘best practices’ (Botta-Genoulaz et al., 2005). Although users and other actors are acknowledged as important ‘human factors’ these engineering-focussed studies fail to elaborate on them.

This spread of snapshot and implementation studies compared to longitudinal studies stems largely from biases inherent in research designs and restrictions to accessibility. Besides being typically retrospective and unreflective of contextual social struggles, disciplinary traditions frame limitations in terms of methodological and analytical qualities (Pollock & Williams, 2010). Different academic disciplines and schools within those even tend to give preferences to some mode of research over others which are

> "constrained within particular loci, timeframes, disciplinary perspectives and concerns" (Pollock & Williams, 2009, p. 81)

Especially in regards of design-oriented studies, this has been flagged as a 'narrative bias' which are inclined to produce particular kinds of stories about technology (Stewart & Williams, 2005). The other reason for narrowly defined technological studies is the fact that the opportunities for researchers to access sites of development and implementation are limited. This is evident in the case of enterprise resource planning systems. The lifecycles of such systems span much longer timeframes than are reasonable, for example, for implementation studies that cover a few months or up to a year or two (Pollock & Williams, 2009). Maintaining access over longer periods of time depends on factors beyond the control of researchers and requires political currency which researchers often lack. Studies with opportunities of extensive exposure to organisational environments depend on coincidence and the goodwill of managers involved. Therefore, many studies with in-depth or comprehensive insights into some or all episodes of the design, development and implementation of a technology often are produced by researchers who previously have been associated with the organistion. For example, Suchman (1987) and Gerst (2006) as well as this study are made possible only because the researchers have been employees of the organisations concerned and, thus, were able to draw on privileged access not available to other researchers.

2.3.3.2 Biography of Artefacts and Practices

The 'Biography of Artefacts and Practices' approach attempts to combine methods of historical sociology with characteristics of longitudinal studies, i.e. studies of the same objects over a longer period of time. To large extent parts of the perspective emerged from a consistent research interest into studies of organisational technologies which have been conducted scattered over several decades (Brady et al., 1992; Clausen & Williams, 1997ab, Pollock et al., 2003; Pollock & Williams, 2009). Another branch of the biographical perspective was developed in course of a systematic research programme dedicated to examining the technological evolution of a particular set of health technologies (Hyysalo, 2004; Hyysalo, 2010). The perspective's development is partly motivated by frustrations caused by theoretical and methodological limitations such as those discussed above and which were observed among a number of studies of related subjects on information and communication technologies including enterprise resource planning systems and its predecessors.

Proponents of the biographical approach aim to learn from these methodological shortcomings and propose a perspective that accounts for the intricacies of technological change in respect of time and space. It is a research perspective that follows technologies

> "as they evolve and mature, progress along their lifecycle, and move across sectoral and organisational boundaries" (Pollock & Williams, 2009, p. 80)

With that focus it is an intellectual companion of the social shaping and social learning tradition. While these approaches cover theoretical and epistemological grounds, Biography of Artefact and Practices acknowledges methodological concerns that have been raised by these theories. It addresses the problematic issues flagged up in the previous section on mapping the nuances of technological dynamics and attending more critical to matters of actors, space and time (see section 2.3.2.). In short, the biography of artefact calls for research designs that take into account:

- Multiple timescales,
- multiple sites,
- multiple methods, and
- multiple practices (Hyysalo, 2004, 2010; Williams & Pollock, 2009; 2010)

The roles of different timescales and spaces have been elaborated in detail by the discussions on social shaping of technology and the social learning perspective. Innovation is a discontinuous process patterned by uncertainties, scattered over spatio-temporal dimensions and contingent to influences from related developments. To grasp the innovation process of a single technology, a study has to examine events and developments driven by multiple actors at various sites and at different timescales.

Besides calling for more nuanced conceptions of space and time, the biographical approach highlights that important choices are to be made in terms of methods and concepts applied and the relationship of the case studied with existing knowledge (Pollock & Williams, 2009). The deployment of multiple methods is proposed to do justice to the demanding requirements of a comprehensive study of the biography of a technology. Appropriate methods include

> "historical studies, ethnographic research, qualitative studies of local and broader development and the use of larger-scale research instruments and quantitative data" (Pollock & Williams, 2009, p. 110)

Drawing on a diverse range of methods enables to capture data of different scales and granularity to enrich the understanding of the many practices involved in any technological development, deployment and use (Hyysalo, 2010). A single study can hardly grasp the complexity of a technology project for a number of reasons. This thesis, for example, only barely scratches the surface of some aspects of the biography of the technology concerned due to limitations of time and resources. For this reason, along the notion of 'multi-sited ethnography' (Marcus, 1995), the idea of a 'strategic ethnography' has been sketched to indicate that a biography itself is a long-term project that ideally be attended to by a team of researchers instead of single individuals (Pollock & Williams, 2010).

This chapter has outlined the path we have taken to develop our line of thought. We discussed the origins of technological studies and traced the theoretical development of relevant theories on innovation and technological change to the articulation of more nuanced conceptualisations of theories of technology. Thorough theorisation of the latter issue has been a recent undertaking and, thus, leaves room for more detailed discussions. Therefore, we cut the general literature short to continue with a more targeted engagement with literature in the next chapter. The next chapter also introduces and explains the rationale for the conceptual framework that we have developed to contribute to more nuanced articulation of theories and concepts of technology.

3 Conceptual framework of the Ecological Shaping of Technology

The previous chapter ended with the concern that existing theories of technological change lack methodological and epistemological capacity to adequately take into account issues of time and space. This chapter continues seamlessly with the discussion of theories of technology but will focus in more detail on the concerns raised. To do so, we will continue with a more targeted review of literature which leads to the discussion of a conceptual framework that we developed to address identified theoretical limitations.

The foundation of theories of technological change, actor-network theory and social construction of technology in particular, are based on the assumption that attribution of any special status of historical occurrences is to be avoided. Proponents of the actor-network theory (ANT) framework especially suggest focussing exclusively on the manipulations and transformations of interests of individuals (Callon & Law, 1982). Their preferred subjects of inquiry are powerful and privileged individuals, i.e. scientists and engineers, whose presence in the spotlight of social inquiry is taken for granted. The social inquiry focuses on the activities of these actors who engage in translation and alliance building processes constructing intrinsic networks comprising human and non-human actors. In this perspective, context and social structures do not exist as entities outside the network but are represented by allies tightly interwoven in the actor-network (Latour, 1987; Callon & Law, 1982). What about history, one is prompted to ask. Callon and Law (1982) address that question and express their view that tracing social structures, context and history is not of special relevance anyway:

> "Though it may be that for any particular study this process can only be traced so far before a 'backcloth' of prior interests has to be taken for granted, our aim would be to avoid attributing any special status to that backcloth". (Callon & Law, 1982, p. 622)

In short, the intellectual origin of early ANT downplays a broader historical analysis. Despite attempts to reformulate early conceptualisations by various authors (e.g. Latour, 2005) this legacy remains strong at the core of the approach and is, therefore, subject for criticism. ANT proponents continue to advance the imperative to 'follow the actor' to trace relevant contextual information in the form of associations to other actors in proximity. But which actor do you follow, is the next question. Because ANT emerged from laboratory studies, the scientist is regarded as a key figure in actor-network theoretical accounts of technological development (Latour, 1987). Actor-network theoretical accounts of engineering-related projects put their emphasis on engineers, who take the role of the heroic actor building networks of heterogeneous elements (Law, 1987). Other authors criticise the framework for its atomistic and actor-centric focus which overstates the potentials of individual actors (Sørensen & Levold, 1992) and its inevitably militaristic tone (Fujimura, 1995). Sørensen and Levold (1992) also raise the insufficiently addressed issue of context and history and note that:

> "The problem is that the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions" (p.32)

Merely observing engineers or scientists will not provide the insights necessary to understand historical processes as they occur beyond the reach of what can be observed locally and temporarily. Instead, they call for a biographical approach by arguing that a "heterogeneous mix of historical, ethnographic, economic, and sociological competence seems required" (Sørensen & Levold, 1992, p.32). Obviously, some theories of technology are methodologically restricted to take into account details of history and context, either by design as in the case of Actor-Network Theory, or by decision as in the case of Social Construction of Technology (SCOT) where the theorists lean on foundational ideas of ANT (see Pinch & Bijker, 1986). Therefore, these methods are of limited capacity in addressing certain social inquiries. They are valuable tools for the inquiry about issues of how technological development occurs and proceeds. But issues of context and history, or more generally time and space, which are crucial aspects to address "why" questions, are inappropriately and unsatisfactorily accounted for.

These fundamental assumptions on the role of history and context marked an essential building block for numerous studies and a vast literature that produced a language and methodology to study the making of scientific facts and technological artefacts. However, as argued in this study, the methodological pitfalls that ensue upon adopting such actor-centric perspectives are severe. They, arguably, particularly misrepresent long-term dynamics. Previously it was argued that broader history and context were sacrificed to proclaim a new sociology which breaks down the human/nonhuman divide. Further, the "warlike" (Star, 1991, p. 82) and militaristic (Fujimura, 1995) character of the Latour-Callon-Law metaphor of network building, as illustrated in Latour's (1988) modern re-interpretation of Machiavelli's 'The Prince', introduced substantial methodological bias overstating the potential of individual actors (Sørensen & Levold, 1999). Feminist and other writers criticise ANT for being a managerial theory that systematically downplays voices from the margins of stabilised networks (Star, 1991; Gad & Jensen, 2010). A possible way to ameliorate these problematic issues with ANT is to downgrade its self-proclaimed new sociological order and to see it rather in the manner of a "postplural attitude" or "nonhumanist disposition", which admits that "it just might be a mistake to follow the actor in some cases" (Gad & Jensen, 2010, p. 73-74). However, in light of our case study, historical events played an important role in patterning conditions of the social shaping of technology. Hence, the methodological biases of actor-centric theories constitute a profound limitation to respond to fundamental questions about origination processes of technological artefacts. These processes, however, are a primary concern in this work. On a one-dimensional axis that measures historical and contextual sensitivity, actor-centric theories would be found on one end. The intention of this thesis is to explore frameworks and theories that could be found on the other end of the axis where context and history are granted substantial explanatory relevance. This exploration begins with a discussion of different metaphors and their applicability for our endeavour. The discussion will critically examine the metaphors of networks and the closely related systems metaphor and suggest that the ecology metaphor is more applicable to appreciate the multiplicity and diversity of actors, locales and timescales in the development and diffusion of the artefact.

3.1 An ecological perspective

The following discussion aims to sensitise the reader to the differences between different metaphors that may be applicable for the study of technological change. The metaphors of network and system are most common and contributed significantly to the development of theories in science and technology studies but at the cost of limiting social inquiries in terms of time and space. To avoid the methodological downsides of network and system metaphors, this study applies an ecological metaphor as a guiding perspective to appreciate flexibility and shifts in relationships between different actors involved at different times in the case studied. The discussion below will introduce the ecology metaphor and highlight its potential contribution to the biographical study of technological change.

The ecological perspective has its roots in studies of natural ecosystems. It gained momentum in the 1960s and early 1970s and marked a departure from systems thinking which characterised ecosystems with features identified in closely coupled biological systems in terms of being closed, regulated and stable (Scoones, 1999; Folke, 2006). Systems-thinking was inherited from physics which lent much of its methods to the analysis of theoretical and empirical ecology. Traditional analyses in the systems thinking tradition focussed on the measurement of quantitative features, for example, differences in quantitative characteristics of ecosystems and the exact details of these differences (Holling, 1973). The emergence of the ecological perspective is rooted in the criticism that systems-thinking, an analytical approach that worked well in one area, was only of limited use in another area such as the study of natural ecosystems (Holling, 1973).

A similar critique has been raised for the transfer of concepts from studies of scientists at work in laboratories, from where actor-network theory emerged, or generally from sociology of science to technology studies:

> "I shall argue that to transfer the concepts of a sociology of science to technology is to ignore basic differences between the two, as activities and as products." (Russell, 1986, p. 331)

Critics argue that the work of scientists is aimed at the production and distribution of scientific knowledge whereas engineers are concerned with the development and implementation of technological artefacts and systems. For instance, a major difference between the two areas is that their primary products - respectively knowledge and artefacts - vary in mobility and universality of their character. While scientific knowledge is arguably universal in its application and easily distributed to other places, for example as published texts in journal articles, technological artefacts can be rather cumbersome logistically and pedantic in terms of local requirements at each implementation site (Sørensen & Levold, 1999).

Returning to the ecological metaphor, problematic issues about the systems approach were identified regarding the introduction of notions of a single equilibrium state and global stability (Holling, 1973; Scoones, 1999; Folke, 2006). Failings in accounting adequately for issues of external change dynamics, temporal and spatial heterogeneity and elements of surprise gave rise to the ecological perspective. The ecological perspective developed from concepts that acknowledged aspects of ecosystems which went unnoticed in the systems perspective. For example, the latter perspective did not appreciate the ability of ecosystems to persist despite severe fluctuations of external influences by changing to different states of stability. The notion of 'resilience' was introduced as alternative to the notion of 'stability' as a property to explain behaviour of ecological systems (Holling, 1973; Folke, 2006). The two properties are distinguished as follows:

> "Resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist. [...] Stability, on the other hand, is the ability of a system to return to an equilibrium state after a temporary disturbance." (Holling, 1973, p. 17)

The notion of resilience puts spatial and temporal considerations into perspective by highlighting that the evolutionary history of an ecological system has important explanatory power to explain complex dynamics and interrelations. In this view, stability, or a state of near equilibrium, in an ecosystem is understood only as a temporary achievement in a specific locale. Unexpected changes in external conditions, for example a climatic change, can throw the ecosystem off balance. From a systems perspective, a shift in the balance of an ecosystem would be classified in terms of instability in the system. The resilience perspective, however, allows for a more nuanced interpretation for it is more appreciative of dynamics of temporally and spatially wider scales. It does not recognise any global stability from which the ecosystem can diverge. Rather, a shift in external conditions would be regarded as a shift in qualities of relationships which ultimately result in a move to a different state. In this instance, it would take into account how species in neighbouring locales less affected by the climatic change would react to changes in its surroundings as time moved on. One reaction observed in biological ecosystems was that climatic changes in one locale triggered immigration of other species from neighbouring locales (Holling, 1973). An ecosystem that is quickly affected by change would be characterised as instable but resilient if it persisted albeit in a different state of equilibrium regarding its constituting elements. Flexibility to change to another state of stability becomes a valid analytical property in the ecological perspective. Unexpected events and dynamics, as they naturally occur in reality, are constituent elements of the concept. Actor-centric theories like ANT or SCOT, on the other hand, are based on narratives of global stability where a network or system rests in a single state of equilibrium. Success and failure are delimited by the ability of individual actors to accumulate allies and resources to gain power in order to maintain a state of equilibrium. Instabilities in these social constructions, important and anticipated dynamics in an ecological view, are regarded as cases of failure attributed to the central actors. Such simplified and deterministic explanations are favoured in domains where performances of projects are measured and individuals held accountable for outcomes. This perhaps helps explain why actor-centric theories have a tendency to reinforce a managerial view on technological change (Star, 1991).

The ecological perspective is not new to the social sciences. Scholars in various disciplines have taken initiative to depart from traditional approaches (Scoones, 1999) including Science and Technology Studies (Star & Griesemer, 1989; Akera, 2007). However, social sciences remain strongly influenced by theories and methods which invoke limitations of network and system metaphors:

> "In the past, social science debates have often taken a static, equilibrial view of ecological systems, premised on assumptions about a balance of nature. This has led to a framing of issues that has tended to ignore questions of dynamics and variability across time and space, often excluding from the analysis the key themes of uncertainty, dynamics, and history. Such a selective view of ecological issues necessarily results in a partial and limited social analysis". (Scoones, 1999, p. 480)

The general critique that prompted the emergence of the ecological view in ecosystem studies applies equally to theories on innovation and technological change. Scoones' quote above accurately delineates fundamental flaws in atomistic and actor-centric theories such as ANT and SCOT. For this reason, the ecological perspective is adopted as a guiding principle to interpret social dynamics and interrelations as part of a larger, interconnected ecology. However, any metaphor that is transferred from one domain to another bears the risk of introducing unanticipated conceptual or methodological problems due to the differences between the two domains. To minimise such risks, this study adopts the ecological perspective without applying mechanistically concepts that were developed in ecosystem studies, for example, the concept of resilience or 'domain of attraction' (Holling, 1973). Instead, this study will embrace the basic principles of the ecological metaphor as discussed above and, furthermore, it will draw on existing theories and concepts in social sciences that offer valuable concepts in line with the metaphor.

Like the empirical case studied in this thesis the process of 'innofusion', (i.e. the iterative combined learning cycle of innovation and diffusion [Fleck, 1988]), of any technology is complex in terms of its temporal and spatial qualities. The beginning of a technological project starts long before any technical artefact is put together. Historical and socio-political dynamics pattern the starting conditions for any set of actors by enabling and delimiting a range of actions within a certain environment. Even when technology projects are under way, they are not exempt from both exogenous and endogenous changes to the fabrics of their supporting infrastructures. Although strategising and planning are important activities in the innofusion process, it is the innovator's capacity for dealing with an evolving and unpredictable landscape that shapes the technology along the way as the development unfolds. Thus, to gain a better understanding of how a technology emerges, the ecological metaphor elaborated above is proposed as the underlying foundation. To facilitate such an ecologically-aware social inquiry, a loose framework has been developed. For this purpose, four concepts have been selected that are in support of the ecological metaphor (see Table 2 on page 98 for an overview). In general, the framework attempts to particularise the unique spatial and temporal specifics of a technological project. The next section will highlight the spatial dimension and introduce the first two concepts to map the 'ecological terrain' of a technological project.

3.2 Mapping the ecological terrain

The first two concepts, linked ecologies and arenas of expectations, will propose an interpretative scheme to view actors as members of interlinked ecologies. These concepts help mapping an ecological topography, a 'translation terrain' of immediate actors with contingent histories and diverse agendas (Williams et al., 2005), that engage in promissory activities in arenas of expectations to compete with other alliances of ecologies over funding and other forms of attention. Drawing on the notion of a 'translation terrain', an 'ecological terrain' outlines the immediate array of contiguous ecologies that share commonalities in their agendas and thus engage collaboratively with each other. Therefore, the first step in examining the ecologically-aware social shaping of technology, or in other words, the ecological shaping of technology, entails the mapping of the 'ecological terrain'.

3.2.1 Linked ecologies

In the beginning of this chapter it has been elaborated that for the study of technological change a perspective is recommended that acknowledges variability of spatial and temporal dimensions. An ecological perspective is put forward for its inherent appreciation of the evolutionary history of an organisational and institutional topography in which any technological project is embedded. A project's topography, i.e. the historically shaped organisational structure that delimits an actor's range of activities while at the same time providing resources and authority for actions in the first place, predetermines opportunities and qualities of relationships to other ecological entities. On one hand, the research project studied is surrounded by multiple other research projects or, more generally, groups of actors engaging with specified problem areas. On the other hand, the research project itself is an ecological entity in the surrounds of another project. Insufficiently accounting for this latter characteristic is what Abbott (2005) has identified a common limitation of ecological accounts in social sciences including his own previous work on the sociology of professions (Abbott, 1988). Typical accounts attribute parts of the social world ecological qualities but regard the rest, which is often outside of the analyst's immediate attention, as fixed. To address this critique and to theorise the idea of social ecologies he proposed the concept of 'linked ecologies' (Abbott, 2005, p. 246):

> "Instead of envisioning a particular ecology as having a set of fixed surrounds, I reconceptualize the social world in terms of linked ecologies, each of which acts as a (flexible) surround for others. [...] The argument does not presuppose any ecology as ''central'' but rather makes a general claim about the structure of the social process." (Abbott, 2005, p.246)

His general claim about the flexible structure of the social world is a key principle in the linked ecologies concept. No ecology can be regarded central for it is only one out of many. Any centrality is therefore an ex post attribution by the analysing student who attempts to reduce the complexity of his observations.

Abbott's change of mind about the limitation in his earlier work on sociology of professions is based on the insight that success of an ecology is dependent on its interaction with other ecologies which themselves are neither simple nor unified entities.

Reflecting for example on the role of the state, often described in terms of a passive audience, he explains that the state "is itself an ecology, a complex interactional structure filled with competing subgroups and dominated by ecological forces quite similar to those driving the system of professions" (Abbott, 2005, p. 247). Constant fluctuations among multiple linked ecologies cause transformations in the topography of a larger ecology. This opens potentialities for new interactions but also forecloses opportunities for existing cooperation. Success, therefore, is to a large extent an external criterion that depends on contingent events and dynamics in contiguous ecologies. For a technological project to be successful, it has to bring together a combination of actors across multiple ecologies. Where a network-metaphor stresses the growth and strength of this combination, the ecological perspective highlights the changing texture of these relations. Alliances are not made because some spokesperson successfully translates the interests of others; alliances are made because partnering actors see a potential reward in their own struggle to compete against other alliances of actors. The historiography, in other words a biography, of a technological artefact thus requires paying attention to the history of alliances and linked ecologies.

The analytical unit of an ecology is generally defined by three components: "actors, locations, and a relation associating the one with the other" (Abbott, 2005, p. 248). A location is a cognitive space constructed by social interactions. It is the result of actors constructing a relation to it - a process Abbott (2005) termed 'ligation' in order to distinguish it from the conceptually different meaning of the term 'linkage'. In the linked ecology framework, therefore, location is a relational term as it refers to at least one group of actors attempting to gain control, i.e. jurisdiction, over an object of interest. The outcome of a ligation process can vary in degree depending on the success of actors of an ecology to convince the actors of another ecology holding authority over the location. In the best case, an ecology is granted exclusive jurisdiction over a location. In other cases it comes to a settlement where the location has to be shared with actors from other ecologies. For example, professions in the medical domain fight over locations, e.g. particular diseases such as alcoholism or the 'Alzheimer disease', to be granted exclusive jurisdiction for its treatment by state authorities (Abbott, 1988, 2005).

In order to understand how professions and professional jurisdictions change over time, an explanation is required for how social entities, such as a profession, come into existence in the first place. One way to make sense about this would be to assume that a social entity exists first and, consequently, delineates a boundary to its outside world. Another approach would be to examine how a boundary precedes the existence of a social entity. Abbott (1995) gives preference to the latter approach because he sees the former view of social reality to presume a rigid assumption about fixed entities. As a consequence, he argues, it struggles to explain change in those entities. Instead, Abbott (1995) draws attention to what he calls 'sites of difference'. A difference can be any quality according to which things can be distinguished from each other. A site of difference is the social space in which a difference matters or is acted upon. If multiple sites of difference can be lined up in some systematic order, in a sense that it can be described as a dimension of difference due to recurring appearances, they become 'proto-boundaries'. Proto-boundaries indicate possible breaking points. A new social entity comes into existence as sites of difference are linked up with each other and, subsequently, detached from their currently hosting social entity. The case of social work shall provide an example to illustrate this process. The profession of social work emerged over a period of fifty years starting around 1870 (Abbott, 1995). Prior to that there were only 'friendly visits' of wealthy people to the poor, and activities of charities, welfare institutions, churches and other institutions providing social services. These activities demarcated sites of difference which slowly became proto-boundaries as similarities among these practices were noticed and articulated. Linking up these proto-boundaries, a process Abbott (1995) describes as 'yoking', resulted in the creation of social work as a professional field. Yoking together proto-boundaries is noted as one way to create a new entity. New entities or change in existing constellations of entities can also be initiated by removing differences.

To advance the terminology of how ecologies link up with each other, Abbott (2005) developed the concepts of hinge and avatar. A relationship between two linked ecologies develops when each ecology can benefit from the interaction with the other in some way. This condition of mutuality is termed a 'hinge'. Hinges create opportunities for actors within ecologies to connect with other actors and locations across ecological boundaries. Although hinges represent dual rewards, a hinge can take different shapes depending on the ecology examined. While one ecology may be dependent on the services of another, the other ecology might be interested in the alliance only to use the former ecology as political currency. The other concept of avatars addresses situations where a formal linkage is either no option or an option not sought after but where an ecology still wants to engage with another ecology. An avatar represents an image of a dispatching ecology within another receiving ecology. An example that Abbott (2005) provides to illustrate the use of avatars is the establishment and shaping of undergraduate degrees by professional bodies. In order to cater for a specialised and practical education of students in favour of a particular profession or identity, undergraduate degrees are created jointly between academic and professional bodies. Computer science is an example of an discipline that was created to meet for increasing demands from professionals. Undergraduate degrees, the avatars of professional bodies within the academic ecology in this case, were strongly shaped by the needs of professional organisations, the dispatching ecology. As time passes, however, shaping dynamics can erode the boundaries between an avatar and the ecology in which it is embedded. For instance, today computer science has been largely adopted by the academic ecology. It is no longer an undergraduate-only discipline but offers various postgraduate degrees and even PhD programmes.

The linked ecologies concept offers a promising conceptual foundation for an ecological perspective on the social study of technology. It provides a specialised conceptualisation for interpreting processes in a social and interconnected world. However, it is necessary to emphasise the particular origin of this concept in light to the purpose of this study. Abbott (1998, 2005) conceptualised the notion of linked ecologies seeking to understand how professions develop and evolve. He takes an institutional perspective to analyse social interactions on a broader scale. This study, in contrast, seeks to theorise meso-level dynamics by examining local actions and behaviours on the micro-level. Thus, there is a latent discrepancy in terms of generalisation regarding the original conceptualisation of the concept and its application in scope of this study. While Abbott advances an institutional understanding of linked ecologies, where interactions between ecologies are grounded on hundreds and thousands of interactions by numerous actors over long periods of time, our purpose is to explore a functionalist interpretation by applying it to a single case study with lower numbers of interactions over limited periods of time. Thus, the application of this concept is promising in light of the dynamics witnessed in the case study, but the issues of different levels of generalisation are to be taken into account when drawing on this concept for analytical purposes.

So far the elaboration of the framework addressed basic epistemological and ontological concerns. A general discussion of metaphors emphasised the insufficient acknowledgement of temporal and spatial considerations in common metaphors such as network and system. The ecology metaphor was introduced as an alternative perspective, and as the preference for this study, for its stronger account of historical dynamics, the multitude of locales and contingent processes involved in technological change. Further, the concept of linked ecologies was introduced to provide a conceptual foundation that is in line with an ecological perspective. It outlines an ontology of ecologies and describes why and how different ecologies interact with each other. The following section will introduce the notion of 'arena of expectations' to reinforce the notion of linked ecology by helping to understand in more detail how relationships between different ecologies are established and maintained.

3.2.2 Arenas of expectations

'Arenas of expectations' is a concept that emerged from the growing field of sociology of expectations which recognises expectations as an essential driver of technological change (van Lente, 1993; van Lente & Rip, 1998a). Expectations have the capacity to "guide activities, provide structure and legitimacy, attract interest and foster investment" (Borup et al., 2006, p. 285-286), particularly in the early stage of development when levels of uncertainty are high and promises, which are positive expectations, are used to mobilise actors and resources (van Lente & Bakker, 2010). A way to represent the mobilisation of actors is to understand the process as a promise-requirement cycle (van Lente, 1993). The cycle begins with an actor (enactor) making a promise to another actor (selector) who sees the potential to gain a reward which can be funding, attention or other forms of credit. As soon as the selector accepts the promise, a mandate is given to the enactor whose selected promise turns into a requirement (van Lente, 1993; Bakker et al., 2011).

A promise-requirement cycle is not an isolated process but is nested in a particular social context. They start out in niches where they are protected from competitive real life conditions. For example, the fuel cell is a yet emerging technology which would not survive was it not for the protection of its niche by combined funding from public and private sources (van Lente & Bakker, 2010). The shape and contents of promise-requirement cycles can vary depending on the expectations they carry. Three levels of expectations can be distinguished: specific, functional and generic (van Lente & Bakker, 2010). Each level of expectation addresses different sets of qualitative features (see Table 1).

Table 1 Levels of expectations (van Lente & Bakker, 2010)

	Specific	Functional	Generic
Builds on and adds to	local agenda (of a firm or research laboratory)	agenda of a technical-scientific field	societal agenda
Leading to	technical requirement	functional requirement	protected space (niche)
Character	articulates a specific technical possibility; quantitative; 'material X will meet criterion Y in two years'	highlights a range of functions; qualitative; 'materials like X will have good electric properties'	sketch of encompassing future; general; 'new materials like X will change the economy'
Fallibility	high	medium	Low

The space or the "battlegrounds" where promissory interactions take place is termed an arena of expectations (Bakker et al., 2011, p. 159, see Figure 3):

> "These arenas can be defined as the loci where expectations are voiced by the enactors and tested by the selectors, where they are confronted with experience, knowledge, and interests." (Bakker et al., 2011, p. 159)

The concept of arenas of expectations is helpful in understanding where and how promise-requirement cycles operate. Arenas are located between enactors and selectors. Enactors feed and maintain expectations in an arena in the hope of being granted a mandate to continue their undertaking.

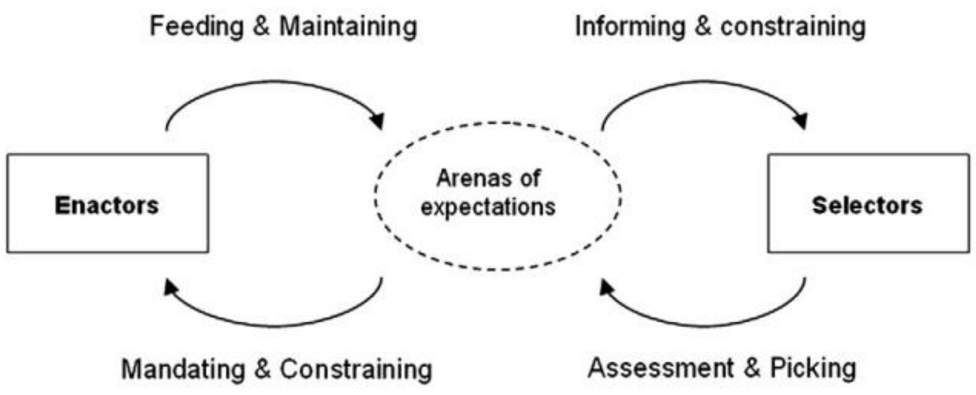

Figure 3 Arenas of expectations (the figure is taken from Bakker et al., 2011)

A mandate turns promises into requirements and thus constrains the enactor not to deviate from their promises. Selectors inform (and constrain) themselves based on promises available within the arena. After assessing expectations, a mandate is given by picking the winners of the evaluation. This cyclical process shapes an arena and general expectations inherent in that arena as the knowledge about successful assessment criteria makes enactors adapt their strategies accordingly to increases their chances in future mandate struggles. Drawing on Kuhn's (1996) idea of a disciplinary matrix, which was adopted to broaden the interpretation of the term 'theory', Van den Belt and Rip (1989) elaborate the notion of a 'cultural matrix of expectations' to explain this phenomenon of mutual positioning of actors that are not directly linked to each other. A cultural matrix depicts a deeply rooted set of beliefs and expectations shared among multiple actors that success can be achieved if a specific strategy is pursued. An outcome of mutual positioning is the, often implicit, articulation of an agenda shared by multiple actors (van Lente & Rip, 1998b).

An important distinction of promissory activities within an arena of expectations from ANT's equivalent of the translation process, a process in which other actors' interests are aligned according to the interests of the spokesperson and in which the enrolled actors become muted (Callon, 1986), is that expectation theory allows keeping sight of any power imbalances between the two actors. While ANT's spokesperson flattens the world and inserts selectors into a single large network with scallops, baboons, electrodes and humans closely tied to each other, selectors in the promise-requirement cycle retain their ontological form and location in the selection environment. As a consequence, or rather non-consequence for no ontological transformation is happening, the selector retains its voice and independence in deciding about renewing or withdrawing the mandate from the enactor as the engagement unfolds. An aspect that Bakker et al. (2011) do not highlight, however, is that the classifications of enactor and selector are not clear cut. Actors can have more complex and reciprocally constituted interrelations. A selector can become an enactor itself due to the adoption of a technology as our case study will discuss show. Generally, the nature and quality of a relationship between an enactor and a selector, who holds financial or political powers, is significantly different than a relationship with peers or non-human components. Changes in this relationship are also differently interpreted. In ANT, the retreat of an actor is assessed as a treacherous act signifying potential instability in the network. In an ecological perspective, the retreat of a selector would simply be a change in the ecological topography. Furthermore, it is a chance event for contiguous ecologies to act upon a potentially new opportunity to link up.

The idea of contiguous ecologies also aligns with the co-existence of multiple arenas (Bakker et al., 2011). Actors and expectations can interact beyond the confines of individual arenas at various levels of aggregation. For example, the testing of highly detailed and specific expectations can take place in arenas different to the arena where generic expectations are voiced and maintained. An issue of spatiality is inherent in the analysis of interaction across multiple arenas. However, although the spatial metaphor of an arena is adopted, matters of spatiality are not further elaborated by the authors of the arena of expectations concept (Bakker, et al.,2011). This remains a conceptual shortcoming from the analytical point of view taken in this thesis and will be taken into account in the later discussion.

3.2.3 Combining the concepts to guide the mapping exercise

The concept of arenas of expectations has been introduced to serve, similar to linked ecologies, as an analytical instrument that informs social inquiries in line with the ecological perspective. Both linked ecologies and arenas of expectations help in mapping the ecological terrain, the set of immediate actors engaging with each other within a concrete landscape of linked and contiguous ecologies, and the strategies and agendas pursued by players involved. The two concepts address similar dynamics but from different angles and by drawing on different terminology. Indeed, Abbott (2005) defines the space of 'arenas' as general zones of experience where no ecology has yet gained a clear authority over the location concerned. Herein lies the potential benefit where the two concepts can add to each other when being applied in combination.

Linked ecologies can be understood as the more abstract theorisation of social processes which enables the generalisation to a larger picture. Meanwhile, the concept of arenas of expectations provides strong analytical capabilities to examine the concrete process of formation of a linkage between two ecologies. In other words, the arena of expectations offers a more detailed theorisation of the ligation process. Basically, the ligation process comprises of an ecology claiming and competing with other ecologies for the jurisdiction over a location and another ecology granting the jurisdiction over it. The arena of expectation expands on these dynamics by distinguishing enactors from selectors. Ligation becomes a cyclic process in which expectations are raised, evaluated and selected. The varying aggregations of expectations also provide opportunities to differentiate a social inquiry. In short, the arena of expectation idea adds more depth and contrast to the analysis of how ecologies link up with each other and why they possibly break up again.

The combined application of these concepts promises to help in keeping track of how the topography of an ecological terrain changes. This enables to map interactions between players and to analyse social learning processes taking place between them. Transformations and reconfigurations of linkages between ecologies go along with change of practices within these linked ecologies. They allow for new opportunities of social learning as actors find new ways to interact with and to interpret meaning of a technology in new contexts. Mapping the ecological terrain in a longitudinal approach is therefore an important prerequisite for a biographical analysis of a technology.

The next section will explore a set of concepts that conceptualise the processes that eventually lead to the social shaping of a technology and to social learning process in which the meaning of an artefact is elaborated. These concepts are necessary to form a consistent but yet loose framework for investigating technological change from an ecological point of view.

3.3 Mapping the technological development

Seminal social studies of technology (MacKenzie & Wajcman, 1999; Bijkers et al., 1987) and subsequent studies of the use and consumption of technology (e.g. Sørensen &

Williams, 2002; Williams et al., 2005) have prominently investigated the mutual relationship between technology and society. The social shaping perspective has emerged as a 'broad church' (Williams & Edge, 1996) which unites a range of scholars from various disciplines who are looking into opening the black box of technology to learn and to make visible what is happening inside and how it is put together. Thanks to the social shaping perspective, we know that the processes of development, implementation and use of technology do not follow any inherent logic but are driven by countless choices: small and big, deliberate and unconscious, evident and hidden, etc.. Thus, technology results as a consequence of numerous choices made by actors involved in the shaping process (Williams & Edge, 1996).

But where does technology emerge from? Some theories in the social shaping domain deflect this question by arguing for its irrelevance in bringing to light any explanatory insights about the technology itself and its creation process. We have learned from actor-centric theories that it is the immediate and contemporary networks and systems that shape technological artefacts. But where do these networks and systems emerge from? Atomistic theories, that follow activities of individuals, struggle with providing an explanation for existing structures and thus imply:

> "some sort of *tabula rasa* as the beginning moment of research, to be gradually filled in as we encounter the "real" world" (italics in original, Clarke & Star, 2008, p. 116)

However, many contributors to Science and Technology Studies who where unsatisfied with this response have filled this void with alternative ideas. There exist now many concepts that theorise about the spaces in which actors exist, how these spaces come into existence and how these spaces interact with each other. For instance, Clarke and Star (2008) outline the social worlds framework, an inherently ecological framework that seeks:

> "[...] to understand the nature of relations and action across the arrays of people and things in the arena, representations (narrative, visual, historical, rhetorical), processes of work (including cooperation without consensus, career paths, and routines/anomalies), and many sorts of interwoven discourses." (Clarke & Star, 2008, p. 113)

The social worlds framework overlaps with the framework developed in this thesis, as it shares fundamental assumptions, and concepts, about how social worlds exist in parallel and how they interact with each other. Where the frameworks diverge is in the attention paid to the artefacts that emerge through social interactions between social worlds, or linked ecologies. Our framework focuses on the development and implementation of artefacts and stresses temporal and spatial dimensions in the shaping process.

Although the matter of technology is of primary concern, it is not the central unit of analysis as it is in other frameworks like, for example, Molina's (1995) sociotechnical constituencies. Instead, technology is regarded as a (re)configuration of (existing) technologies (Arthur, 2009) that is being designed and embedded within a linked ecology. Technology, thus, is inherently configurational in the sense that technology is developed and configured iteratively according to the requirements of its users, a process we have already been introduced to as 'innofusion':

> "Development is a thoroughgoing evolutionary process, in which environmental contingencies are explicitly built in at each stage of variation. Thus each instance of diffusion, each configuration, may well represent a unique variation, a new innovation in its own right." (Fleck, 1988, p. 22)

Shaping and configuration processes do not take place in empty space, for there is no such thing as empty social space. Foregrounding the locality of social shaping processes and relationships to other spaces is thus the motivation to develop a distinct framework. Although the question 'What is technology?' poses an interesting empirical and philosophical challenge, it is not necessarily a crucial exercise for conceptualising the relationship between technology and society. A more revealing and conceptually relevant question is "How is technology made?" (Bijker, 2009). However, as has been addressed above, this question stops short of investigating origins of technological change. Thus, this study aims not only to explore how technology is made but also where it emerges from.

Considering the ecological perspective elaborated above, the conceptual concern addressed below is how to reconcile the development of linked ecologies with the notion of configurational technology. The way how and why ecologies are momentarily linked, i.e. the ecological landscape at a moment in time, defines the dominating technical requirements and specifics according to which technology is shaped. It is the temporary texture of an ecological landscape that patterns the content and shape of an artefact. It is thus why we explicitly speak of the ecological shaping of technology in contrast to the more general notion of 'social shaping of technology' (see MacKenzie & Wajcman, 1985; Williams & Edge, 1995).

The previously introduced concepts of linked ecologies and arena of expectations proposed an approach to map social dynamics across an ever-changing terrain of linked ecologies. A further set of concepts will be introduced and discussed that help in understanding how technology results from interactions within contingent and historically shaped linked ecologies. In other words, these concepts intend to help mapping the process of technological development and the crystallisation of a technological artefact within a dynamic environment. The first concept of the kernel of a research infrastructure explains how a technological project maintains stability while allowing for flexibility to incorporate change over a longer period of time. The other concept is the instrumentality package which aims to link the reciprocal evolution of scientific knowledge and technological artefacts. In the next section the concept of the kernel of a research infrastructure will be introduced first.

3.3.1 Kernel of a research infrastructure

The previous concepts have focussed on outlining a loose conceptual framework to reduce the complexity of social reality and to facilitate an ecological analysis of the case studied. These concepts describe what ecologies are, how they come about and why they hold together. This is somewhat a complete but yet static representation of an ecology. What is missing is a consideration of time that accounts for occasions and episodes of emergence, stability and continuity as well as for change, surprise, disruption, and discontinuity, since ecologies and relationships between ecologies shift and transforms over time. To emphasise change in ecologies, the concept of a 'kernel' (Ribes & Polk, 2015) is regarded a valuable addition to the framework. However, before introducing the concept, a detour will be taken to highlight why a more nuanced and temporal view on the issue of change and flexibility, defined in terms of capacity to respond to unanticipated change, is necessary to push the ecological agenda further.

3.3.1.1 An ecological approach to change

What is change and "What is an infrastructure flexible relative to?" ask Ribes and Polk (2014). Although these questions, primarily the first one, appear as trivial philosophical exercises these are easily overlooked questions that are worth being addressed to supplement a discussion on technological change. Flexibility and change are highly ambiguous terms and can have distinctive meanings depending on the context and perspective. For example, in manufacturing the term 'flexibility' yields different descriptions depending on what aspect of the complex manufacturing process is considered (Slack, 1987). In an industrial context, flexibility is only one of a number of similar terms such as reconfigurability, agility and changeability which all have somewhat different meanings (Zaeh et al., 2005). Appreciating nuances in the interpretation of the term change thus promises to improve the understanding of what there is that can change.

Examining the meaning of change in regards of information infrastructures, three facets of change can be distinguished: technoscientific, sociotechnical and institutional (Ribes & Polk, 2014).[4] Starting with the sociotechnical facet, it is described as follows:

> "The sociotechnical facet is the intersection of social organization, coordination, and collaboration technologies, users, and information systems." (Ribes & Finholt, 2009, p. 288)

It is argued that the sociotechnical is the most studied and theorised facet in the field of information infrastructures (Ribes & Finholt, 2009). Reasons for the dominance of the sociotechnical view can be found in the bias of disciplinary and methodological traditions and the resulting limited scope of research foci (Pollock & Williams, 2010). A further reason why many studies emphasises the sociotechnical is inherent in Abbott's (2005) critique that implicit assumptions about the static nature of entities at the periphery of scientific enquiries are limiting analytical reach. Because common approaches focus on the actions of central players and neglect events peripheral to the immediate locale, relevant change dynamics escape an analyst's attention. To overcome

[4] The ambiguous use of terminology requires a note of clarification. Ribes and Finholt (2009) draw on Latour's (1987) term "technoscience" to describe as technoscientific those objects that attract the interest of scientists. However, Latour's interpretation of technoscience goes far beyond Ribes' and Finholt's narrow definition. The very existence of the concept of 'technoscience' intends to do away with the categorisation of anything that is social, technical or institutional (Latour, 1987, p. 174 , emphasis in original): "I will use the word **technoscience** from now on, to describe all the elements tied to the scientific contents no matter how dirty, unexpected or foreign they seem". Grouping observations in categories such as technoscientific, sociotechnical or institutional runs the risk of violating the basic principle of the term 'technoscience'. In their narrow definition Ribes and Finholt omit this original and radical meaning of the term. Thus, to avoid confusion when making sense of the three facets, it is recommended to refer to 'technoscience' as namesake only and to ignore its intellectual origin.

this bias, an "ecological approach to change" is called for (Ribes and Finholt, 2009, p. 289). Consequently, the technoscientific and institutional facets are elaborated to facilitate a more nuanced and ecological understanding of change:

> "Accounting for the flexibility of research infrastructure in the face of change demands an inspection of features beyond the design of information infrastructure, systems, and practices. We find that change may be rooted in transformations to the practice and objects of science (technoscientific), and in funding and regulatory regimes (institutional). A robust and adaptable sociotechnical architecture is necessary but not sufficient to explain successful adaptations to change in each facet." (Ribes & Finholt, 2009, p. 288)

Since the kernel concept originates from the empirical study of a research-based organisation, a research infrastructure, its authors draw on vocabulary from the field of science. However the definition of the technoscientific facet can be unproblematically expanded to consider not only practices and objects of science but also that of technology. From this follows that technoscientific changes address changes in the package of scientific knowledge and technical artefacts utilised in an ecology.

Besides the empirically common focus on sociotechnical aspects, issues of technoscientific and institutional change are inevitably foregrounded when a more nuanced, ecological perspective on change is taken. For example, instrumentalities, i.e. technological and scientific objects, are found to be connected to collective practices across multiple locales (de Solla Price, 1983). Events in a remote location can influence a local technoscientific configuration and vice versa. Political dynamics in remote institutions can have drastic effects on a local organisation of work and vice versa. Distinguishing changes according to the three facets, therefore, has the sensitising effect of stimulating an ecological perspective and drawing attention to events and dynamics beyond a single site when investigating the development of a research infrastructure (Ribes & Finholt, 2009) or an information infrastructure in general. The next section will built on these three facets and elaborate how practices are embedded in and interconnected across different time-scales and locales.

3.3.1.2 *Different time-scales in ecologies of actions connected through structure*

The kernel concept originates from studies that examined the subject of time in the field of 'cyberinfrastructures' (Ribes & Finholt, 2009).[5] The term cyberinfrastructure circumscribes ambitious science projects with long-term-oriented institutional configurations. The challenge to plan such long-term developments, for example a clock that is built to last ten thousand years, requires dealing with issues that span over different time-scales from immediate technical problems to long-term institutional concerns. Thus, efforts to think today about future requirements of infrastructures prompted the conceptualisation of time as the 'long now' (Ribes & Finholt, 2009). In general, the long-term perspective is an inherent concern of a biographical view on the innofusion of a technological artefact (Pollock & Williams, 2009; Hyysalo, 2004, 2010). The 'long now' is a reminder that related practices can operate on different scales. There are different examples available which conceptualise how practices on different scales are interconnected, for instance, enacting technology, organising work and institutionalisation in building information infrastructures (Ribes & Finholt, 2009); problem-solving, career-building and line-of-research-building in scientific work (Fujimura, 1988); or, more generally, conduct of an activity, development of the practitioners and development of the practice in the case of navigation of a battleship (Hutchins, 1995). What all these representations have in common is that a local activity, e.g. building a technological component, analysing a probe of cancerous cells or navigating a ship, is simultaneously embedded in and connected to a broader set of practices divided across multiple sites and occurring at different speeds.

This interconnectedness of practices and distributed quality of collective work is what has been characterised as 'ecologies of actions' (Fujimura, 1995). In these complex interrelations ecologies of actions are subject to constant changes on technoscientific, sociotechnical and institutional dimensions. When investigating a particular development within these ecologies, for example the development and implementation of a new technology, a perspective has to be taken that allows tracing how a particular

[5] The term cyberinfrastructure is common in the United States and known as 'e-infrastructure' in Europe (Ribes & Finholt, 2009). For generalisation purposes, the term information infrastructure will be preferred. For now, Star and Ruhleder's (1996) basic principles of an infrastructure are considered to define information infrastructures broadly as a technological development that is embedded in organised practices.

set of ecologies organises and maintains its distributed activities. Hence, to learn how technology is shaped in a dynamic environment, a conceptualisation is sought that appreciates moments of both change and stability. Furthermore, such a conceptualisation should account for change and stability in a sense of the 'long now' where micro-level dynamism is part of a long-term, largely stable pattern. To recognise this 'long now' relationship the concept should reconcile the short-term perspective of change dynamics and the long-term perspective of stability. The next section will introduce the concept of the kernel which promises to build a bridge between short-term changes and long-term stability.

3.3.1.3 Kernel of a research infrastructure

The kernel concept draws inspiration from computing (Ribes & Polk, 2015). A kernel is the main component of an operating system that facilitates the interaction between the user and the hardware by managing the access to services and resources of the computer. The kernel of a research infrastructure serves a similar purpose in a social context:

> "The kernel of a research infrastructure is made up of the resources and services that members work to keep available in preparing, managing, and responding to changing research objects, all the while continuing to support ongoing investigations" (Ribes & Polk, 2015, p. 3)

While the concept of a package of scientific and technical objects, as discussed shortly in section 3.3.2, spans over a wide range of ecologies, the kernel is narrower in scope as it targets a specific infrastructure. However, it is broader in scope in the sense that it is not limited to a single package or approach as it encompasses all resources and services available to an infrastructure.

Tracing how an infrastructure sustains access to and availability of resources and services to associated ecologies despite ontological changes is how the kernel concept consolidates the notions of flexibility and stability. While flexibility is an important concern, "persistence is the kernel's most important quality" (Ribes & Polk, 2015, p. 3). To maintain this balance, the kernel focuses on ontological changes to the objects of investigations of an infrastructure:

> "[...] ontology refers specifically to the objects of investigation, and change to how they emerge, fade, or recur as objects of investigation. The kernel is the constellation of concepts we employ to explain

> technoscientific flexibility: the capacity of research infrastructure to support investigations of partially or wholly unexpected objects." (Ribes & Polk, 2015, p. 3)

What the object of investigation is depends in turn on the infrastructure under investigation. The kernel was developed based on the study of the 'long-now' of the Multicenter AIDS Cohort Study (MACS) that was founded in 1983 and which is still in existence today (Ribes & Polk, 2015). When it was established, the object of investigation for MACS was the, at the time, poorly understood causes and patterns of transmission of the AIDS disease. As time moved on, the knowledge about the disease improved and the object of investigation changed. The discovery of HIV as the root cause and the development of a treatment that turned AIDS from a fatal to a chronic illness, required MACS to adapt its focus and the resources and services available to it to investigate the shifting objects of its research in order to sustain its activities. In other words, MACS's kernel transformed in parallel to its research objects as time moved on. Examining ontological changes of the research objects enabled in return understanding of how MACS adapted to remain "the same study" over time, a quality the authors referred to as technoscientific flexibility (Ribes & Polk, 2015, p. 2). Three major change processes were identified according to which the kernel changed. Besides the initial process of building a kernel, the processes of 'repurposing', 'elaborating' and 'extending' shape the form and contents of a kernel and its inherent resources and services. 'Repurposing' describes the addition of new objects of investigations without any corresponding changes to the kernel. 'Elaborating' is the introduction of new instruments or analytical categories that bring additional depth to the investigation of objects. Finally, the process 'extending' brings in new resources and services that enable the investigation of new objects. Another distinct dynamic is characterised as 'forking'. This occurs when the kernel is split up or imitated to address research objects that require more autonomy. For example, to study how AIDS affected women (MACS focused on men), the kernel was forked to establish the Women's Interagency HIV Study, a "sister site" which shared some space, instrumentalities and even organisational members with MACS (Ribes & Polk, 2015, p. 23).

Previously we have noted that transferring a concept from one domain to another bears the risk to ignore conceptual incompatibilities. However, to avoid the complex process of developing a matching concept from scratch, we temporarily borrow this concept from the science studies domain to draw attention to important elements highlighted by the kernel concept. Similar to linked ecologies, we proceed carefully in our application of the kernel metaphor and its extended conceptualisation when conducting our analysis. To extend the concept beyond the science domain and to apply it in the study of technology, technological artefacts such as the system studied in this thesis are to be considered as a resource and a service that are available for actors in an infrastructure. As a resource it is subject to configurational activities that change its shape and functionality. At the same time it is a service that is offered to others as a promising resource to solve problems. While a science-oriented organisation engages in generating knowledge about a research object, a technology-oriented organisation engages in problem-solving activities. In the latter context, a technological artefact becomes a resource available in the kernel to address the objects the infrastructure is concerned with. The notion of an object of investigation, which is the subject of technoscientific change, does not transfer well to technological artefacts. A generic term such as object of intent or, generally, objective would do more justice to non-scientific investigations. For instance, the objective of a technology development-oriented kernel could be the solution of a particular technical or business-related problem.

The main contribution of the concept of the kernel to the ecological perspective is to provide a conceptualisation of how resources and services are prepared, managed and made available to others in an infrastructure and how they change over time. Previously introduced concepts of linked ecologies and arenas of expectations addressed issues of sociotechnical and institutional change as ecologies interact and create alliances through the construction of social relations and collective practices. These concepts emphasise changes in the fabric of an alliance of ecologies, i.e. ontological changes to the objectives pursued in these ecologies. The kernel, however, addresses how these changes relate to the configuration of resources and services of an infrastructure within the ecology. While changes in social relations between ecologies can have immediate effects, for example, when conflicts interrupt or discontinue interactions between ecologies, effects on an infrastructure's resources and services trickle-down slowly. A technological artefact does not disappear as does social space when interactions cease. Similarly, a newly linked up ecology can immediately draw on an existing kernel that has been developed through interactions with other ecologies. A kernel's ability to account for persistence across time and space is what motivates tracking the accumulation and transformation of resources and capabilities in analysing the development and implementation of a technological artefact. Therefore, the kernel conceptualises a persistent structure that is stable enough to mediate between practices on different time-scales and in different locales, and flexible enough to allow for change over time. This feature is particularly helpful in relation to promise-requirement cycles.

In the empirical case studied, the technological artefact accumulates functionality through numerous promise-requirement cycles with various actors involved. While the actors on both sides of the promise-requirement cycle, i.e. the enactors and the selectors, change over time, the kernel remains 'the same' as do the technological artefact and the services made available by the kernel. This focus on something that remains 'the same' delimits a particular viewpoint that is constructed by the set of actors involved (Pollock & Williams, 2009). The concept of agora, which is the Greek term for "market" or "marketplace", has been introduced to conceptualise broadly the social space where all producers and consumers of technology interact (Kaniadakis, 2006). A market player can be a producer and consumer at the same time: its role is determined by its interaction with other players. A viewpoint makes a slice of the agora and highlights a certain set of relationships between players. We remind that our research delineates a particular viewpoint on a particular set of actors involved in the development and implementation of a technology. The kernel concept is instrumental in our attempt to follow not just the actors but also technological components, resources and services that are accumulated and transformed over time. It anchors the analytical focus to a particular locale within a broad ecology and wider infrastructure where change occurs. Thus, the kernel is a fundamental element in defining what is constituted by the notion of the 'local'.

3.3.2 Instrumentality Package

The kernel concept introduced a shift in focus on material and technical qualities which emerge as social interactions unfold over time. A growing stock of resources facilitates the accumulation of expertise and technical capabilities. Expertise allows members of a research infrastructure to make use of technical capabilities as a means to accomplish its objectives. Subsequently, competence over a problem area enables a research infrastructure to develop its own technological artefacts to enhance its services. This process can stretch over time and space. Although the kernel concept allows keeping track of these changes, it does not conceptualise how and why these resources change.

Therefore, a set of three concepts are combined to address the evolution of knowledge into technological artefacts within a distributed ecology of innovation. The three concepts are boundary objects, a theory/method/technique package and instrumentality. The conceptual combination of these concepts is termed an ‘instrumentality package’; an local representation of the package in a kernel is termed ‘instrument’. The key feature of an instrumentality package, however, is that it is not limited to a single kernel but extends to developments in remote locales not directly related to the kernel concerned. It highlights the common lineage of related technologies which are connected by the fact that the same theoretical assumptions underline their developments. Understanding the emergence of a technological artefact requires an understanding of the origin of the theoretical assumptions embedded in the artefact. Next, the three concepts will be introduced in turn beginning with the concept of boundary objects.

3.3.2.1 Boundary objects

Accounts of the development and use of technology frequently focus on actors and their interactions. These concepts may also often interpret interactions as attempts to translate and thus manipulate interests of others (as in the case of actor-network theory), or as attempts to settle disputes about technical details (as in the case of social construction of technology). An alternative approach takes a similar route as actor-network theory but without attributing extraordinary capabilities to single individuals to create exclusive bottle-necks. The concept of ‘boundary objects’ (Star & Griesemer, 1989) proposes an interpretation that allows for multiple viewpoints and agendas and thus provides an alternative to ANT’s narrowly-defined and managerial view:

> “Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They are weakly structured in common use, and become strongly structured in individual-site use. These objects may be abstract or concrete. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation. The creation and management of boundary objects is a key process in developing and maintaining coherence across intersecting social worlds.” (Star & Griesemer, 1989, p. 393)

Analysing the historical dynamics in the development of a museum and its ecological surroundings, the authors elaborated the idea of multiple obligatory passage points as bridges between different actors and their social worlds. In contrast to ANT’s single obligatory passage point, which is controlled by a single or a limited set of dominant actors, the compelling idea of boundary objects is that it distributes the centre of authority across a wider range of actors. Instead of framing a narrative around a dominant perspective, subordinating all other interests according to the dominant interest of the central spokesperson, multiple viewpoints are acknowledged to highlight other narratives where other, often marginalised (Star, 1991), agendas are prevailing.

To sum up and to indicate how boundary objects are interpreted in light of this study, boundary objects are interfaces that allow for collaborative interactions between ecologies. Boundary objects can have different meanings depending on the viewpoint of the respective ecology but they offer enough similarities to encourage continuous interactions. This definition strongly resembles what Abbott (2005) termed a 'hinge' in his analysis. In Abbott's view a hinge is a dual reward that stimulates two ecologies to work together. The duality refers to the fact that the reward can look different for each ecology. Both, a hinge and a boundary object share the common trait to connect two distinct social worlds or ecologies, respectively, for collaborative purposes. This study will give preference to the use of Star and Griesemer's (1989) boundary objects concept for its comprehensive definition and its relation to the packages concept that will be addressed in the following section.

Earlier in this chapter it was criticised that concepts from the domain of science had been uncritically transferred to the domain of technology. Boundary object was conceptualised researching the evolution of a museum. Although many objects addressed in Star and Griesemer's (1989) study were of physical nature, the generation and distribution of knowledge about methods and facts remained a major focus of their study. The next concept addresses this problem to some extent by distinguishing boundary objects according to levels of abstractions and their spatial affiliation. This distinction addresses and appreciates the differences in characteristics between the domains of science and technology.

3.3.2.2 Theory, methods and technique package

The previous concept of boundary objects theorised in more details about the linkage between two ecologies. Ecologies share a boundary object where each side of the boundary object has a specific meaning that distinguishes each ecology but still has enough similarities to bond a relationship. Yet, a limitation of the boundary object is that its conceptualisation does not look far beyond the two ecologies it is connecting. It has only a weak relation to other boundary objects. This is where Fujimura's (1988, 1992) package concept extends the boundary objects idea. Studying the emergence and diffusion of the oncogene theory in cancer research, she proposed the concept of a package of theory, methods and techniques that is 'co-developed' by diverse groups of actors of different disciplines as a theory is being adopted, tested and developed in multiple laboratories (Fujimura, 1995).

In her earlier work Fujimura generally referred to 'standardized packages' (Fujimura, 1988, 1992). She appears to retract from this generalised definition in her later work (Fujimura, 1995) where she attributed the 'standardised' attribute to technologies and techniques only, not to theory. This differentiation makes some justice to a differentiation between science and technology but is not sufficiently distinctive yet for this study. Fujimura's focus is the diffusion of knowledge about facts and techniques to make use of this knowledge in different laboratories to innovatively address a multitude of existent problems previously addressed with traditional sets of knowledge. Because of the complexity of her empirical study she can only brush the surface of the kinds of issue that are at the heart of this study, which is the development and implementation of a localised instance of a technique, a technology, that was concretised from an abstract and general theory. What Fujimura refers to with 'standardisation' is the increasing mobilisation of more actors in the development and provision of technologies and resources such as probes of cancer-causing molecular cells called 'proto-oncogenes'. These actors are attracted by the expectation to gain economic advantages through economies of scale as the methodology is taken up by more and more laboratories. A major distinction between science and technology is that knowledge and technological artefacts have different mobilities (Sørensen & Levold, 1999). While scientists in public laboratories are incentivised to share their findings, privately-funded scientists and industrial researchers are more reluctant and restricted to do so. Private organisations tend to avoid disclosure of scientific findings that ensure a competitive and profitable advantage. Rather, knowledge is absorbed by private organisations and only selectively shared with others. In short, standardisation of techniques and technologies occurs differently outside the scientific community.

This brief detour on standardisation is to remind that the emergence of any 'standardised technology' and technology in general is by far more complex than Fujimura could have addressed in her study on distributed knowledge and practices in cancer research. Indeed, the reasons for the lack of attention to artefactual qualities of the package can be attributed to Fujimura's empirical focus on the co-development and diffusion of the oncogene theory. The social shaping of artefacts that resulted from the analysis of oncogene theory is considered but not addressed in detail. This study will extend Fujimura's approach by emphasising the social shaping of technological artefacts.

The significant conceptual contribution of Fujimura (1995) is that she links different, distributed boundary objects to each other through a lineage of abstractions in different practices. The way how different social worlds, or ecologies, are interlinked through multiple boundary objects shapes the local practices in these alliances of ecologies. Together, these practices form a distributed network of collective work. Although the actual content of the work in each ecology looks different, all practices are connected by an instrumentality package containing related theoretical conceptualisations and technologies. A novel general theory can provide a new perspective on problems that were previously overlooked, ignored or unsolvable. It does not need to go as far as heralding a paradigm shift (Kuhn, 1996). But it must be significant enough to create a 'bandwagon' to mobilise more actors (Fujimura, 1988; Fujimura, 1992). This is achieved through the redefinition of research objects into doable problems by combining new theory with new methods and techniques:

> "This combination of the abstract/ general proto-oncogene theory and the specific, standard technologies was used to generate novel doable problems. By locally concretizing the abstraction in different practices, researchers with ongoing enterprises (re)constructed the new idea and the new methods in new sites, thus further extending the network." (Fujimura, 1995, p. 333)

Similarly, the process of concretisation and localisation of a technological development has been addressed as a process of crystallisation where an artefact emerges as the relationships of its surrounds solidify (de Solla Price, 1983; Fleck, 1988). Because the articulated package concept privileges knowledge-related aspects, it will be amended to distinguish it from Fujimura's original conception. To do so, the package concept will be extended by the notion of 'instrumentality' (de Solla Price, 1983).

3.3.2.3 Instrumentality

Understanding the relationship between science and technology has been a core concern of the entire science and technology studies discipline. One approach in analysing this relationship centred on the development and transformation of the means available to scientists and technologists. De Solla Price (1983) examined the science/technology relationship by exploring historically how the use of theories, methods and technologies influenced the work of practitioners of science and technology. His empirical findings advance the perspective that progress in science and technology is a reciprocal development. For science to progress, it requires new or refined technologies to enable better observations of nature and more sophisticated sense-making practices. For technology to advance, it requires for a better understanding and mastering of nature or, as Arthur (2009) put it, for improved capabilities to harness natural phenomena. Such reciprocal progress relies on the co-development of what de Solla Price (1983) termed 'instrumentality' and which he defined as

> "to carry the general connotation of a laboratory method for doing something to nature or to the data in hand" (de Solla Price, 1983, p. 13)

For example, Galileo Galilei's astronomic observations were an important step in heralding the Copernican Revolution. But this was made possible only because he could make use of the telescope which was "a new technology arising from the ancient craft of making eye-glasses" (de Solla Price, 1983, p. 8). Instrumentality does not refer to the invention or improvement of a technological artefact only but also to the competence in using it. Emphasising de Solla Price's example of Rosalind Franklin, who contributed with her extraordinary expertise on x-ray crystallography to the development of the 'double helix model' of DNA, Faulkner (1994) points out that knowledge and skills in handling techniques and artefacts are equally important characteristics of instrumentality. The notion of instrumentality, therefore, implies the reciprocal advancement of both technological artefacts and scientific knowledge as well as skills and practices to utilise the two.

Fujimura's (1995) concept of a theory, methods and technique package articulates the establishment and ramification of an ecology of related practices in science and technology. The instrumentality concept is added to the framework to emphasise the close relationship between science and technology, and to reinforce technological artefacts in the array of theory, methods and techniques. Indeed, in our framework, the notion of technological artefact replaces that of technique. To follow up on this route it could be reasonable to articulate a distinction between method, technique and technological artefact. However, for the purpose of this study and for the sake of simplification, we drop the notion of technique. The array of instruments is not to be understood as a one-way roadmap of technological development where a technology yields from the concretisation of theory. Since science and technology are reciprocal developments, the array also operates the other way round where a technological artefact can be the starting point for the discovery of new scientific facts as in the case of Galileo Galilei.

To sum up, science and technology interact through the development, (re-)configuration and skilful use of instrumentalities (de Solla Price, 1983; Fleck, 1988; Arthur, 2009). Fujimura's (1995) package concept, which stops short of appreciating the influence and role of technological artefacts in the interactive science/technology relationship, is extended by the notion of instrumentality to offer a conceptual tool to map the reciprocal evolution of technological artefacts as well as scientific facts. We term the extension an 'instrumentality package' to distinguish it from Fujimura's original concept. An instrumentality package is broadly defined as a distribution of practices that draw on theories, methods and technological artefacts which are associated to each other. The main feature of an instrumentality package is characterised by the common lineage of its constituents. The package transforms over time as its constituent instrumentalities are worked on and distributed to other locales where new problems and requirements shape the characteristics the package.

3.3.2.4 Mapping the evolution of technical qualities

A valuable property of the package concept is its implicit appreciation of multisitedness. An instrumentality package connects a scientist in a public laboratory, who articulates a general and abstract theory, with an engineer in a company, who designs a concrete and specific instrument or technology based on the principles of that general theory and under consideration of the specifics and requirements of the locale where the product will be implemented at. The concretisation of an abstract theory in a specific locale is simultaneously the testing of it under new local conditions. Outcomes of a crystallisation process in one locale, in turn, inform the generic development of abstract theory. The package concept thus confirms its validity as an extension of boundary objects in that it

> "serve[s] as a dynamic interface between multiple social worlds and concurrently represents the contingent articulations of [the same practice] at different sites" (Fujimura, 1995, p. 335).

An instrumentality package underlines the role of expectations as each ecology has different requirements and reasons to ally with other actors in the package-ecology. Each actor is driven by a mix of incentives which, depending on their context, range from egoistic, opportunistic to idealistic commitments rather than being simply 'translated' to do so by a central figure (Fujimura, 1988). These incentives feed and are fed by dynamics of expectations which are influenced by what is happening in the wider ecology.

To conclude and to emphasise the contribution of the instrumentality package concept to this framework, it extends the boundary object (Star & Griesemer, 1989) and theory, method and technique package (Fujimura, 1995) concepts and specifies further how multiple ecologies are either linked up or associated to each other through links between related instruments being utilised in these ecologies. The distinction of abstract theories and concrete instances of methods and technologies underlines the collective and collaborative work across multiple, heterogeneous sites. It delineates a process of local concretisation or instantiation of general abstractions that leads away from reductionist cause-and-effect interpretations towards an ecological, process-oriented understanding of technological change (Akera, 2007). The package concept reinforces the understanding that scientific and technological change is not the product of an isolated actor-network but part of a larger whole intertwined in an ecology of 'metonymic relationships' (Akera, 2007).

3.4 Summary

This chapter has introduced a number of concepts that outline a loose framework that was termed 'ecological shaping of technology'. In contrast to the generic meaning of 'social shaping of technology', a view that technology and society are closely intertwined and shape each other (MacKenzie & Wajcman, 1985; Williams & Edge, 1995), the ecological shaping of technology stresses concretely that each technology carries the imprint of the particular historically and socio-politically shaped constellation of an alliance of ecologies, with a unique set of resources and practices at its disposal, in which the technology emerges. Acknowledging that technology is socially shaped is not enough to explain why a technology was developed and adopted. A detailed and historically-rooted examination is necessary to learn about the particularities of an interlinked ecology of various locales and arenas where the shifting agendas of individuals, organisations and institutions define the objectives for collective work, and eventually, the patterns of technological artefacts. Four concepts where selected to guide a social inquiry into the ecological shaping of the development and implementation of a technological artefact (see Table 2 for an overview).

Table 2 Overview of the concepts to guide a social inquiry into the ecological shaping of technology

Concept	Description
Linked ecologies (Abbott, 2005)	An ecology is a set of actors that attempt to gain control over a location. Ecologies form alliances to compete with other alliances.
Arena of expectations (Bakker et al., 2011)	The social space for promise-requirement cycles where expectations are voiced and evaluated.
Kernel (Ribes & Polk, 2015)	A kernel manages and makes available resources and services for the investigation of research objects. It accounts for technoscientific flexibility and stability simultaneously.
Instrumentality package	An instrumentality package comprises of related theories, methods, techniques and technologies that form a network of distributed boundary objects.

The 'ecological shaping of technology' framework was developed to inform a biographical perspective on technology. The biography of artefact perspective emerged from the critique on methodologically and analytically restricted studies of technologies which suffered from disciplinary bias and narrowly framed research foci (Pollock & Williams, 2009; Hyysalo, 2010). The framework developed here embraces the conceptual principles proclaimed by the biographical approach which include the broadening of research foci to expanded time-scales and spatial distribution of collective practices. Thus, the biographical approach is a close ally of the ecological metaphor as it was outlined in the beginning of the chapter.

What is regarded as the core advantage of the ecological shaping of technology framework is its analytical scalability in terms of time and space. Its detachment from individual actors and focus on ecologies enables the analysis to trace developments across time and space. Interactions are not centred on the alignment of dominant individual or group interests but driven by the mutual negotiation of expectations over joint benefits. Furthermore, success and failure are no longer attributable to individuals, previously hailed as heroic scientists and engineers, but the contingent achievement or performance of a distributed ecology. To wrap up, the ecological approach is a corrective to common theoretical frameworks of technology which are too reliant on restrictive metaphors.

4 Methodology

This methodology chapter outlines the rationale for choosing a research strategy and appropriate research methods that helped producing evidence to investigate research problems and to answer research questions. It aims to provide a reader with enough information to evaluate the validity and the methodological adequacy of this study (Seale, 2004). This chapter documents the approach we have taken in collecting and interpreting the data necessary to address our research purpose. It begins with a discussion of the emergent character of the research design which was greatly influenced at the outset of the research by various external events. After elaborating how these events shaped the research focus, the research strategy will be discussed which also includes a reflection of our role as researcher and an overview of the case study organisation and the technology under investigation. Since we pursued a 'biographical' approach to study a technology, the strategy is a combination of three approaches: case study, participant observation and the historical method. Based on these strategies we derived the data collection procedures which will be introduced before we turn attention to the data analysis process. The chapter concludes with a discussion of the validity and credibility of this study and the consideration of ethical issues.

4.1 Emergent research design

Research design prescriptions stress the importance of a proactive approach which begins with a thorough planning process to produce a research design (Blaikie, 2009; Creswell, 2009). Generally, the research design outlines a set of guidelines that comply with specific theoretical assumptions about the representation of reality. It connects these with strategies of inquiry and methods for collecting empirical data to support arguments with evidence (Denzin & Lincoln, 1998). This research project is characterised as a qualitative study because we are committed to an interpretive approach in which we aim to scrutinise and criticise politics and methods of positivism (Denzin & Lincoln, 1998). Positivist-oriented studies involve the use of research instruments based on an a priori conception of the issues under examination. In contrast, nonpositivist, e.g. constructivist, studies are characterised by discovery (Denzin & Lincoln, 1998). In an ideal situation, as many decisions as possible will be made before the research project is carried out. In practice, however, it is impossible to finalise a design that will be ready to respond to any unforeseen circumstance. Especially studies that engage with exploratory and developmental work, as this one does, are difficult to plan because later stages depend on the outcomes and experience made during earlier stages of a research project (Blaikie, 2009). Furthermore, unexpected events are likely to appear and thus can require improvisation and further adjustments which in the long run alter the research design. This study has experienced several critical events that affected the research design significantly. Therefore, to understand how the research design of this project came about, it is necessary to draw attention to significant factors that arose particularly in the early stages of the research project before proceeding to a detailed discussion on our methodological approach.

4.1.1 Complications and discontinuities in the early stages of the research journey

This research journey began in October 2009 located both in a different university and discipline than it has ended. Starting in a school of computing the initial research proposal envisaged exploring the take up of social media technologies in private organisations. However, the anticipated supervisory configuration to support this research interest did not come about due to institutional circumstances. Consequently, an alternative supervisory team was put in place. An unexpected consequence of this change was that the new supervisory team asked for a change in the direction the research was taking. This change was pursued to avoid an early topical bias and to be more general about researching a wider technological field. As it turned out later, this foresightful decision helped mitigate a practical problem that emerged during an exploratory data collection pilot.

A first pilot study was conducted in a familiar organisation to probe the data collection strategy. This pilot raised critical issues about accessibility to relevant participants in the target organisation. An option would have been to look for another case study. However, this option was discarded for the reason that the pilot study organisation indicated the possibility to sponsor the study if it was adapted according to its requirements. Since funding for this study was not fully secured at that time, we decided to take advantage of the opportunity. As a result, the initially proposed research focus was adapted to accommodate the new research object. What started as improvised workaround, turned into a strong empirical case study in terms of accessibility and depth of data. The supervisory advice to change the direction of the doctoral research and to take a more general stance on the study of technology resonated well with the early experience in the field. Instead of researching the narrow subject of social media, the focus turned towards the general development and implementation of information technologies.

A further disturbance affected this research project when one of the PhD supervisors took up a position in another university in September 2010. Since this supervisor was the driving force for changing the initial research focus, his departure left a gap in the intellectual guidance for this study despite the effort to keep the supervisory configuration going for occasional meetings were still manageable. As a result of the change in direction, the weakened supervisory support and complications in the early stages of the research journey, doubts about the match of the research topic with the institutional setting cropped up. Eventually, a radical decision was made to transfer to the current university and research institution that was found to be more suitable to and experienced in doing research on the new research focus. The transfer was undertaken in August 2011 – by which time the majority of data had been collected.

4.1.2 Implications on the articulation of research questions

A problem emerging from these complications was inconsistency in the research design. Uncertainties and unexpected shifts in the supervisory team, the institutional context and the case study organisation took their toll and complicated the establishment of a clear line of sight on the research purpose. What began as a curiosity about the emerging trend of social media, micro-blogging in particular, turned into a general examination of the role and influence of technology in professional organisations and eventually to a detailed investigation of the innovation process of a particular technological artefact. These extrinsically-motivated shifts in research interests complicated the process of translating the research problems under investigation into clear research questions. Although precise research questions are perceived as one of the most important elements of a research project it is acknowledged that they can be emergent in their composition (Blaikie, 2009; Creswell, 2009). Indeed, the use or non-use of research questions can be dependent on both the purpose of the study and personal preference (Punch, 2000). An alternative to narrowing down the research focus could be to uphold a broader focus in order to examine the 'problem behind the research', particularly in cases of unfolding studies (Punch, 2000, p. 16).

This thesis represents a somewhat idiosyncratic case of an 'unfolding' study, where important circumstances were unstable in the first years. Consequently, this research remained broadly focused on the case study at hand. Postponing the narrowing down on specific research questions, the data collection stage maintained a broad perspective as we collected a wide range of information about actors and dynamics involved in the technological project concerned. Although some research questions were formulated for occasional oral presentations to academic audiences, they were not the driving influence until late in the research project, by which time they had been radically reformulated. Thus, the revised research questions in this thesis are those articulated in the course of this study, and are used as signposts to guide the analyst and the reader through our research journey to analyse findings from a largely completed empirical study to reach our final conclusions (Creswell, 2009). We argue that had this research project encountered fewer difficulties, it probably would have been easier to identify specific research questions earlier and, thus, this study could have unfolded differently. However, we were required to adapt to these circumstances. Our research focus was rather broad and not closely specified and progressed in a somewhat pragmatic manner. This led us to adopt a distinct investigatory strategy. Indeed, the methodological emphasis of this study was greatly influenced by the availability of a broad and rich set of data.

4.1.3 Research problems and corresponding research questions

As explained in the previous section, the eventual research questions were articulated very late in the research project and, thus, are articulated predominantly as signposts for the reader. After overcoming practical obstacles and settling in a new institutional environment, the major driving force of this study was the intention to disentangle the many intertwined stories that had been discovered in multiple locales during the data collection. We developed an interest in understanding how and why these spatially and temporally dispersed stories and practices concurred with each other in the social shaping process of the technology concerned. Translating this initial research interest into research questions, two major research questions can be phrased as follows:

> RQ1. How does the development of a technological artefact in a private enterprise come about in the first place, and
> RQ2. how does a technological project sustain itself over time?

The first question addresses the corporate-historical influences that patterned the unique organisational and ecological backdrop which allowed the technological project to emerge. We wanted to understand not just how the technology was developed but also why it was there in the first place. The second question addresses the circumstance that the development proceeded over an extended period of time. It appeared rather unusual for a research department in a car company to sustain the development of a highly specialised technological artefact over more than a decade. Thus, we were interested in learning about what motivated individual actors and institutional players to keep dedicating time and resources to the project.

Another research problem began to appear in terms of analysing the empirical data and narrating the results. The more this complexity was explored the more it became apparent that prevalent theories on technology failed to appreciate and to reflect the nuanced interdependence of multiple innovation processes in technological change dynamics. Instead of narrowing down the focus, and thus reducing the complexity of the case at hand, we decided to embrace and to make sense of this complexity. Consequently, the methodological struggle became the analytical centre stage of this research project. The research question that would describe this emergent research problem can be articulated as:

> RQ3 How to analyse and to report the long and complex story of a technological project considering historical and ecological influences?

This research problem emerged when the methodological limitations of prevalent theories and frameworks were identified in the process of making sense of and explicating the data analysed. By phrasing this research question we aim to make explicit the emergent nature of our major research interest which is to find an approach that coherently takes into account the history, context and content of a technological project and the social shaping of the corresponding technological artefact. In the following section we will elaborate how we proceeded to address the identified research problems. It documents how we set out to answer these research questions.

4.2 Research strategy

The research strategy describes in general terms how the researcher goes about conducting the study. It details on the set of skills, assumptions and practices that are being applied to put the research design into practice (Denzin & Lincoln, 1998). Our research strategy has been shaped in line with our research interests. Although the research interests changed in course of the study, especially in the early years, the major focus remained on technological dynamics within a specific case study organisation. The research strategy was developed according to the intention to explore the role and influence of technology in that organisation. After the transfer of this doctoral research project to a different academic institution, parts of the strategy had to be interpreted anew and in the light of a new perspective.

4.2.1 A biographical approach to research design

The 'Biography of Artefact and Practices' perspective is an emerging approach to define a methodological guideline for the social study of technology (see section 2.3.3.2). The biographical perspective calls for a longitudinal and strategic approach to study technological processes which reach across multiple locales and unfold in different speeds. Technology analysts are encouraged to design a research project to take into account these spatial and temporal nuances of technological change. First and foremost, a biographical account requires a diverse set of data. To collect this data, we drew on methods from multiple research strategies including case study research, participant observation and the historical method.

Rather than applying each strategy independently from each other, these strategies supplemented each other throughout the data collection process. Such a combinatorial application of different methods was necessary due to the emerging understanding of the case under investigation. The ethnographic investigation yielded detailed information about events and activities involving the technological project and its immediate vicinity. These insights about individual actors and practices were then put into perspective by a broader examination of historical contexts which on the other hand produced new leads for the ethnographic investigation of different locales or moments in the innovation process. Hence, the data collection was a reciprocal process in which the utilisation of one method informed and called for the utilisation of the other method.

Utilisation of multiple methods is a common approach in science and technology studies where longitudinal analyses take into account historical contexts of current or recent developments. Describing this systematically is the concern of the biography perspective. Applying a mix of ethnographic and historical approaches in scope of a biographical study of a technology and in scope of a doctoral study has been pioneered in the examination of a health care technology (Hyysalo, 2004). Strategic ethnographies combine decades of social analyses of manufacturing-related technologies that draw on historically grown sets of interrelated studies. These studies shed light on historical developments in the broader technological field as well as on the locales of individual firms and actors (Pollock & Williams, 2009). Recent contributions reaffirm that the empirical intertwinement of historical and ethnographic perspectives in the studies of technologies and practices has been widely adopted and that it is gaining more traction. The biographical approach has been advanced by studies of various technologies and practices including the investigation of virtual worlds (Johnson, 2010), dynamics of dispersed peer-innovation (Hyysalo & Usenyuk, 2015), novel conceptualisations of the innovativeness of technical artefacts (Höyssä & Hyysalo, 2009) and of users of technology (Pollock & Hyysalo, 2014), and the evaluation of new concepts in the interaction of users and developers (Hyysalo & Hakkarainen, 2014). Hence, this study continues this line of research and contributes to the biographical approach by examining dynamics of a technology project within a large corporation. The following sections will introduce and discuss the different strategies in more detail to highlight the strength of partially overlapping methods applied to this study.

4.2.2 Case study

Historically, the case study approach has suffered from discussions that confused it with techniques of data collection and analysis. But it re-emerged in the 1980s when it was found to be a flexible approach adaptable to the purpose of a study, be it as a research strategy or a method to select sources of data (Blaikie, 2009). Case studies are applicable in both qualitative and quantitative studies. The approach also suits different research purposes including studies that seek to explore, describe or explain social phenomena (Yin, 1994). The case study strategy is recommended when investigating a contemporary phenomenon that is intricately connected with its social context (Yin, 1994). It is this feature that makes the case study particularly suitable for the purpose of examining a technological artefact.

Although the technology flags our main entity of interest, its genesis is intricately connected to its historically shaped surrounding. Thus, attention is dedicated to the unity of both technological and social change which is embodied by the notion of the technological project. This understanding of a technological project differs from how a project is commonly defined in an industrial context. While the latter type of project usually has clearly defined boundaries, in terms of budget and duration, the interpretation of a technological project that we adopt for the purpose of this study is much broader in the sense that it transcends time and space. The constituents of the technological project change as time moves on. The artefact changes in shape, individuals involved come and go, new sponsors are enrolled while others cease their allocation of resources to the project etc. Thus, the unit of analysis of this case study is the technological project as it shapes and is being shaped by its socio-political surrounding. In contrast to a holistic case study, which focuses on global features of a case organisation, this is an embedded case study that examines in detail how events unfold across sub-units of one and the same organisation (Yin, 1994). The embedded case study allows studying technological and organisational change in tandem as processes span various levels and locales simultaneously (Blaikie, 2009).

A narrow case study can yield detailed insights, but it also marks a weak spot as there is a risk that the larger social setting may drop out of the frame (Yin, 1994). Such methodological limitations in conventional studies of technology have been frequently criticised and are the reason for the development of the biography perspective (Pollock & Williams, 2009). To avoid this shortcoming and to keep sight of the greater picture, we followed the new perspective's principles and applied a mix of research strategies. Especially the historical method shed light on the corporate history and helped relating micro-level findings to broader events which unfolded across multiple locales and at different timescales. Applying the historical method to supplement the case study approach was not a one-off event. It informed our research activity throughout the research project as has been deployed at multiple occasions often triggered by new insights gained from ongoing data collection activities. Another criticism of the case study approach is its apparently insufficient capability for generalisation. Being a bottom-up approach generalisation is based on specifics of a limited number of cases, or even one case as in this study. This "may result in narrow and idiosyncratic theory" and misses the grandeur of theories such as resource dependence, population ecology or transaction costs (Eisenhardt, 2002, p. 30). However, a case study approach aims at a different level. Generally, multi-sited approaches have been earmarked for contributing to a better understanding of the space between micro and macro-scale theories, identified as the middle range of theory (Hine, 2007). In contrast to 'statistical generalisation' where inferences are made about population based on samples, the case study approach draws on 'analytical generalisation' which, comparable to individual experiments, allows for testing, validating and advancing of existing theories (Yin, 1994). Applying the 'Biography of Artefact and Practices' perspective in line with theories of social shaping and social learning increases the validity of our approach and outcomes as we base the methodological approach on existing knowledge and contribute to its further advancement.

4.2.3 Ethnography and participant observation

The definitions of participant observation and ethnography can be ambiguous and sometimes are used interchangeably (Delamont, 2004). Both terms describe the practice of studying a group of people by immersing in their culture and social environment and by exploring the nature of social phenomena over an extended period of time (Atkinson & Hammersley, 1998; Bryman, 2004). The definition of ethnography, however, can range broadly from a philosophical paradigm to a research method (Atkinson & Hammersley, 1998). Its prevailing feature is that besides describing the method of research it also refers to the written outcome of a research (Bryman, 2004). At the end of the day, ethnography is "a theorized account of the culture studied with ethnographic methods" (Delamont, 2004, p. 207). In this study we draw on the method of participant observation with its ethnographic elements for it covers a mixture of observation, interviewing, note-taking and document analysis (Delamont, 2004). The ethnographic approach played a major role in facilitating the interaction with the case study strategy and the historical method. New findings discovered in the field informed the further application of the other strategies. For example, interviews that uncovered the participation of another organisational player initiated an exploration of the history of that new player. Historical findings, on the other hand, deepened understanding and allowed more detailed questioning in the field.

The level of immersion is also the boon and bane of this strategy because ethnographic data can be susceptible to specific weaknesses. Particularly talk-based data can be misleading in several ways. Interviewees can provide false information by telling lies or, if they are not aware of being lied to themselves, mislead the interviewer by giving incorrect accounts of facts and events. Further, the researcher can be misled because informants can be unaware and unreflective about certain aspects of their own activities. These potential methodological pitfalls have been described as the 'ethnographic illusion' to remind the researcher of the multiple layers of mediation a piece information can pass before being written up (Van Maanen, 2002). Maintaining distance to the object of study is another challenge for the student of ethnographic methods. A researcher unfamiliar to a social and cultural setting generally has fewer difficulties in spotting interesting aspects worth closer inspection (Delamont, 2004). Because we had privileged access to the case study organisation due to prior engagements, it was more challenging to be critical and analytical in our approach. It is likely that our analytical struggle to narrow down the focus was connected with our familiarity of the case study organisation study – an issue that had been somewhat resolved by expanding the scope of the analytical focus to cover the overall technological project rather than narrowing down on a specific feature within it.

4.2.4 Historical method

The previous two strategies address primarily matters of space. The case study approach delimits the organisational boundaries of this study while the ethnographic approach locates our position within the cultural confines of particular groups of actors. With the use of the historical method we are stressing temporal concerns pertinent to this study. Time can be divided into three parts: the past, the present and the future. Historian John Lewis Gaddis (2002) prefers

> "to think of the present as a singularity [...] through which the future has got to pass in order to become the past. The present achieves this transformation by locking into place relationships between continuities and contingencies: on the future side of the singularity, these are fluid, decoupled, and therefore indeterminate; however, as they pass through it they fuse and cannot then be separated." (Gaddis, 2002, p. 30)

Continuities are defined as patterns that extend across time, whereas contingencies are phenomena that do not from patterns. When the present is viewed as a process that zips up continuities and contingencies, then structure is the survivor of passed processes (Gaddis, 2002). Further, if space is understood as the location where events take place, then the past is a landscape and the historical method the effort of mapping out what happened when and where (Gaddis, 2002). In this sense, the historical method supports an ecological understanding of reality. Mapping historical events enables the analyst to examine how individual events interacted with each other across time and space. This historical-ecological perspective takes into account qualitative changes over time and provides more insights than merely looking at the sum of all parts (Burgelman, 2011).

Some argue that a key difference between historians and social scientists is found in the origin of data (Goldthorpe, 1991). While social scientists are privileged in being able to generate their own data, historians are bound to what has been preserved over time, e.g. archival documents, or what relics are being discovered, for example, by excavations, sometimes by chance as in the recent case of a thirteenth-century slab and the skeleton of what is believed to be a knight or other nobleman that have been discovered during the demolishment of a car park nearby our research institute.

What history and social science have in common is that research remains an interpretive enterprise (Tuchman, 1998). There is no "true" or "objective" meaning that can be uncovered with the historical method. Rather, the interpretation of historical information allows for multiple meanings to co-exist. Historical sociology is an approach to combine the historical method with methods from social sciences. For example, applying ethnographic methods to elicit events of contemporary history where eye witnesses are still accessible, MacKenzie (1990) produced one of the exemplary account of social shaping of technology in the case of guidance systems of nuclear ballistic missiles, a development that started in the post-war era.

Our case study covers a period between the 1980s and the 2010s in which the first two decades are only examined from an historical point of view. We apply the historical method to map out the landscape, and the timescape (Gaddis, 2002), in which the technological development is embedded and by which its unfolding is influenced. The historical perspective complements our ethnographic approach and helps locating the technological development concerned in the broader context of recent corporate history.

4.2.5 Researcher's role

A qualitative research approach relies on the interpretive competence of the analyst. This entails an element of subjectivity and biases that can affect the interpretation and analysis process. A way to mitigate such effects is to be aware of these influences and to reflect upon them (Creswell, 2009). In this section we highlight personal circumstances that had a significant influence on this study.

Despite our preference to use the plural pronoun for narrative purposes, this thesis has been written by a single individual with a personal history that affected the outcome of this research study. The most significant influence was our previous entanglement with the case study organisation. Prior to the doctoral research we have been working part-time with the organisation for almost three years in parallel to our undergraduate studies. In particular, we were supervised by the employee who at one stage became the project manager of the technological project investigated in this study. It was due to this prior engagement that we selected the organisation as the site for the pilot study because we were familiar with the department and people involved. Our familiarity with the organisational context allowed us to align our academic research interest with the agenda of the industrial research team. Taking advantage of this strategic relationship was crucial for gaining access to the organisation and the people involved in the innovation process. In this case gaining access meant that we entered the project as an external contractor who was commissioned to support the industrial research team in their efforts of developing and implementing the technological artefact under development. From June 2010 to December 2011 we have been involved as participant observers in the technology project. Our role in particular was to support implementation efforts by identifying the training needs of new users and by developing training materials in cooperation with other collaborators.

At the same time, our familiarity introduced elements of bias towards this study. Knowing about norms and cultural expectations of the specific organisational context influenced our ability to recognise taken-for-granted assumptions and the ability to be critical about phenomena we observed and experienced. This challenge to gain distance has been already addressed above. Reflective discussions with the supervisory team and the development of an analytical framework were two approaches to counteract these challenges. However, other challenges emerged during data collection which made the reporting of data problematic. For example, at some point the implementation of the technological artefact was in a critical state due to interpersonal conflicts between key project members. The incident was addressed in one empirical chapter but carefully worded because information was made available asymmetrically in this instance as some interviewees refused to comment while others were keen to address the issue. This is also a good example to indicate how triangulation of data in terms of getting data from multiple individuals familiar with an event was helpful in validating empirical data.

4.2.6 An overview of the case study context: CarCo and the NetworkPlanner

The case study organisation selected for this research is a publicly-traded, multinational automotive corporation based in Germany with a historical timeline that dates back more than a hundred years. In the financial year 2014, CarCo was among the top 10 automotive manufacturers worldwide in terms of revenue (Statista, 2015). CarCo distributes a range of vehicles that are sold across multiple brands. It is structured in five business units of which four are concerned with the production of vehicles while the fifth business unit deals with financial services. The four operational divisions are differentiated by the type of vehicle manufactured. To distinguish these divisions in this study we refer to them as cars, trucks, buses and vans division, respectively. Each division operates independently but is accountable to the management board which manages the enterprise and represents it in dealings with third parties.

The technology concerned in this study, referred to as the NetworkPlanner, had been developed by a team of industrial researchers. This team was based in CarCo's research organisation which will be referred to as the research group. Although the research group provides services to all operational divisions, it was located organisationally within the cars division. Senior management of the research thus reported to the cars division management team. The team of industrial researchers was the main locale examined in this study. However, other departments within the operational divisions also played an important role in this case study. The technological artefact was developed for and implemented in strategic planning departments. These departments were concerned with conducting strategic analyses of production networks and site locations to inform decision making processes.

The NetworkPlanner is a decision support system informing strategic planning processes. In particular it supports strategic planners in the quantitative analysis of a large number of scenarios. It does so by analysing different sets of data including, for example, capacity details of manufacturing sites, transportation and manufacturing costs, bills of materials, market forecasts and others. Drawing on operations research methodologies the information system applies highly-specialised mathematical models tailored to CarCo's specifications to process data and to identify optimal solutions based on both the given set of data and the selected minimum/maximum function.

4.3 Data collection

Qualitative research is generally characterised as an inquiry paying attention to describe phenomena in relation to organisational contexts, to interpret processes and the meaning thereof, and to develop understanding about social phenomena (Silverman, 2014). This research was a qualitative exploration of events and developments of past times as well ongoing processes witnessed at that time. The research strategy section above outlined in generic terms the rationale of our approach to collected data about relevant events and processes in respect of this case study. Although we identified a set of three different approaches, they have much in common in regards of actual data collection procedures. We gathered different data from multiple sources and multiple perspectives to inform our interpretation of the social order and meanings of events and developments in relation to the innovation project. In this section we will discuss the multiple means by which we collected different data to explore the research problems described in the beginning of the chapter.

4.3.1 Participant observations

We begin with reporting on qualitative observations for it allows us to sketch the timeline of our exposure to CarCo. Collaborating with the team of industrial researchers we were granted access to the research department where parts of the NetworkPlanner were being developed – basic software components were coded by an external software house following instructions from the industrial researchers. The collaboration with CarCo ran from July 2010 to November 2011. During this time we spent different periods in the field varying from one to three weeks. Between field trips we returned to Edinburgh to continue with other research activities. Thanks to a direct flight route of a low cost airline between Edinburgh and a regional airport in Germany, it was possible and within budgetary limits to strike a balance between research work in Edinburgh and fieldwork. Drawing on an overview of flight records we estimate that we spent about 30% of our time during this period doing field work. The extensive and prolonged exposure to the case study organisation and individuals involved enabled us to learn about and "to reflect the detail, the subtleties, the complexity and the interconnectedness of the social world" under investigation (Denscombe, 1998, p. 149). Being part of the team made possible to see the technological project through the eyes of the insiders. We observed activities and events that would not have been captured had we not physically been there. We learned to understand the (technical) language of our research subject and to map the contexts of various social settings.

Our initial struggle of finding a clear research focus contributed to enriching our participant observation experience. Instead of narrowing down the focus on a particular process or aspect of the technological project we started out exploring various directions. Although in the beginning this was a tenacious undertaking it became more insightful the more was learnt about past events from both formal interviews and informal conversations with project members. The main locales for observation were the offices of the industrial research team. Besides frequent informal interactions on-site and off-site with members of the project we also were allowed to attend meetings and workshops with customers and collaborating partners. These were valuable opportunities to observe, for example, how the researchers, representing vendors of a technological artefact, dealt with current and potential customers.

Developing trustful relationships, we expanded reach beyond the research department. Nine months into the field work, we were granted permissions to spend ten weeks in total working on-site in three user departments. It provided the opportunity to learn about the user requirements which, on the other hand, enabled us to deepen our understanding about the technological artefact and its meaning from a different viewpoint. Additionally, we spent another week with a consultancy firm specialised in providing operations research-based services and solutions which was involved in the development and implementation of the technological artefact.

There are challenges that emerge from the immersive character of the method in the form of potential biases. The 'ethnographic illusion', as described by Van Maanen (2002), reminds us that unnoticed taken-for-granted assumptions and mediated interpretations of informants run the risk of skewing our own interpretation of reality. It is not possible to avert such risks completely but our awareness about such risks was an important preventive measure. Further, the collection of a mixed set of data was another way to improve validity of data. Drawing on findings from interviews and documents helped in evaluating data and to make judgments about the validity of our data and interpretations.

4.3.2 Interviews

Interviewing is among the most common methods in qualitative studies also because it is flexible in allowing a researcher to revisit data later assuming it has been recorded and transcribed (Yin, 1994; Bryman, 2004). We applied mostly an unstructured interviewing approach where we drew on a few notes to make sure that we covered a certain set of topics that we found the interviewee could be knowledgeable about due to her role in the project. Since this was an exploratory study, a structured approach would have been prescriptive leaving less leeway for the interviewee to expand on subjects that she was particularly aware of and which we did not anticipate. A challenge during the interviews was to encourage the interviewee to openly speak about her experience of the project while making sure that the interview did not go off track. All but nine interviews had been recorded and transcribed. Most interviews lasted between 45 and 60 minutes. Depending on seniority and availability, a few interviews lasted just about 15 minutes but provided essential information. Where recording was not possible or not permitted, notes were taken instead. Generally, notes were taken in all interviews to trace the topics discussed and to help advancing the interview. At the beginning of each interview, interviewees were asked to sign an informed consent form to confirm that they have been made aware of conditions of anonymity and that their participation in the research undertaking is voluntary. Nine interviews were held over phone. In these cases interview partners were send the form via email and then asked to confirm that they have read the form and acknowledged its contents.

In total, forty-four individuals have been interviewed. The majority of the interviews (34) were conducted in the first eighteen months after the collaboration with CarCo had been established (see Figure 4 for a time-line). Face-to-face interviews had been conducted on-site in the workplaces of interview partners with one exception when an interview was held on the road during a journey to a meeting with customers (the vehicle was driven by a third person). This improvised setting was due to the limited availability of the interviewee who was an external collaborator based in London at the time.

The last seven interviews were arranged with individuals who were not available during the main data collection stage. Mostly, these individuals had left the company. Their insights became necessary to provide details on the early history of the technological project and events that predated our participation and to triangulate other data.

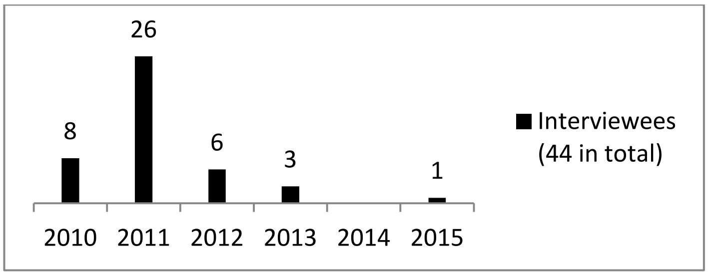

Figure 4 Timeline of interviews

Most interviewees, twenty in total, were recruited from the research department which was the main locale of the technological development. With a few exceptions we managed to interview all researchers involved in the development of the artefact at some point of time. The most significant person that we could not locate was the first team leader of the research team. This gap was compensated with interviews of his colleagues. The user departments provided for the other big group of interviewees which numbered eighteen (see Figure 5 for an overview of interviewees per group). The 'Others' group comprises individuals of external organisations, e.g. the consultancy or software house, as well as individuals who were remotely involved in the project including a professor in the field of operations research, an internal patent lawyer and the director of an engineering consultancy. The latter individuals contributed in shedding light on social contexts of the development. In particular, the director of the engineering consultancy provided valuable insights and helped triangulating data by contributing a critical and external perspective on the early history of the technological project. We note that roles and job positions changed across time. Employees and students working with the research team switched to user departments. We also note that two individuals had not been interviewed face-to-face but were interviewed in course of the focus group which will be addressed below. The overview in Figure 5 is not a snapshot of some point in time but a representation of the organisational origins of an interviewee. A current snapshot would see a reduction by five in the research group in favour of the user group.

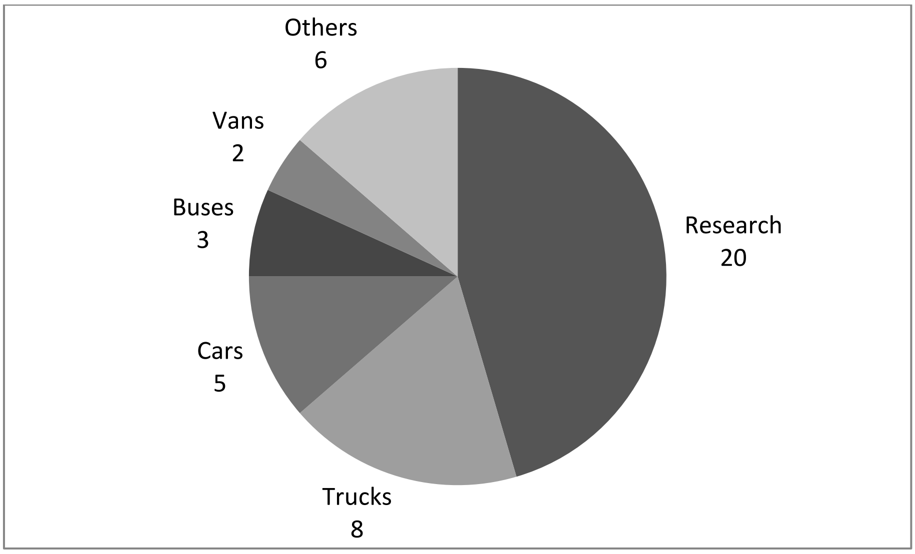

Figure 5 Overview of interviewees (per group)

To protect the anonymity of interviewees and, at the same time, to maintain the readability of the empirical chapters, we are applying pseudonyms to refer to the interview data.

The notion of the 'ethnographic illusion' reminds a researcher that information gathered from other people is susceptible to social and psychological flaws (Van Maanen, 2002). Besides the deliberate manipulation of facts, an informant can unknowingly be the provider of incorrect data when she herself was being lied to by others. Even if no foul-play is involved, understanding of events and facts can be misconstrued due to lack of information or analytical capabilities. Talk-based data can be the best source of information but has to be treated with care and needs to be corroborated with data from other sources (Yin, 1994). Another weakness of the interviewing technique is the intervention by the researcher in guiding the process. Interview data is manufactured data (Silverman, 2014). By framing questions researchers can manipulate the production of data. It thus takes a skilled interviewer to elicit the kind of valuable data that is sought after. Our advantage was that the first interviewees were students doing placements in the research department who were more patient and forgiving when we were struggling in the beginning to make sense of the complexity of the technological project.

4.3.2.1 Focus group

Originating from commercial market research the focus group meeting is a particular form of interview that comprises of a number of people who are questioned about a specific subject area (Silverman, 2014). What is the most interesting characteristic of a focus group is the chance for group interaction. Rather than aggregating opinions, interaction and the joint construction of meaning are the focal points (Bryman, 2004). Initially, a focus group was not anticipated in the research design as we deemed it unrealistic to bring together a group of professionals dispersed organisationally and geographically. However, the former manager of the research department in which the industrial researchers were based proposed to organise a focus group meeting. In fact, the manager had retired at the end of 2009 and took the chance to refuse our request for a face-to-face interview. Instead, he insisted on us organising a get-together of relevant project participants in his home with an opportunity for a focus group discussion. We note that our previous employment with the research department, a time when we had the chance to interact and work with him occasionally, probably was a beneficial factor influencing his willingness to support our research activities, although under his terms only.

The focus group meeting attracted eight individuals of which two had not been interviewed before. Three participants were researchers actively involved in the project at that time. Three participants also were involved in the project at some point but had moved on since or had retired, respectively. One attendee was from a user department and the remaining attendee was from a department providing legal advice to researchers. It lasted two hours and was recorded as well as transcribed. The discussion was organised in a way that each individual was given the chance to contribute his or her perspective. Because the attending participants represented project participants of different stages in the technological development, it was possible to arrange the discussion to follow a chronological order. We started the focused discussion revisiting the time before the project began and ended with the implementation as perceived by the only attending user representative.

Although the focused group discussion did not elicit any substantially new piece of information, its most important contribution was the opportunity to negotiate, retrospectively, a commonly shared narrative about the journey of the technological development. In hindsight, the outcome of this focus group event was a valuable set of data for the triangulation and validation of the general narrative of the innovation process that shaped the technological artefact. As this method also represents a talk-based data collection technique, it is susceptible to similar weaknesses as single individual interviews. However, the interactive approach mitigates such risks as participants intervene and negotiate about the interpretation of meanings. Also, the common risk of individuals dominating the discussion (Denscombe, 1998) was mitigated by the informal setting of the meeting and the diversity of attending participants.

4.3.3 Documents

Juxtaposing a document with the transcription of an interview one could argue that both represent written text and as such could be treated similarly. For this reason, a document is distinct from a transcribed interview for it is created without the intervention of a researcher (Bryman, 2004; Silverman, 2014). An overview of all documents collected follows below.

1) Materials on research programmes of public funding bodies. Documents and websites provided information on research programmes funded by public bodies including the European Commission, the German Federal Ministry of Education and Research, and the Wing consortium, an industry-led global collaborative programme to advance research in manufacturing-related subjects. Information on the Fifth Framework Programme (1998-2002), the thematic programme on "Competitive and sustainable growth" in particular, and announcements of the Federal Ministry about research grants, especially on the "Research for the production of tomorrow" programme (1999, 2000), informed the understanding about the wider context of the technological project examined.
2) Materials on publicly-funded projects. Information on the publicly-funded projects, SATFAB and LICOPRO, enriched understanding about the early stage activities of the researchers involved in the technological project. These were found on the websites of these projects, on the websites of institutions involved.
3) Internal events and meetings. Agendas and other documents of internal events, such as inter-departmental meetings, user community events and the launch event, supported the development of a chronological overview of the technological development
4) Functional descriptions of the artefact introduced technical features represented ideal states of the envisioned product. Interim reports on the development of the NetworkPlanner version 2 explained the modular functionality and use cases of the artefact. In contrast, a promotional document of a competing information system, GlobalDB, improved understanding about the functionalities of the technological development.
5) Student dissertations and internship reports. In total, 85 documents from master students, doctoral students and students on work placements were accessed.

Student-made reports provided details on functional development of prototypes. A few individual dissertations provided valuable insights into the process of strategic planning and other relevant organisational practices.

6) Internal archive of corporate newspapers and other media. The corporate intranet held archives of internal newspapers that documented special events and projects. Articles provided details on the public representation of the technology concerned and its application in larger projects. Further articles showcased the technological development when it was awarded the corporate innovation award in 2008. A particularly helpful document elaborated the global sales history of the company providing relevant information on historical strategic decisions.
7) Annual business reports. Publicly available annual business reports of the case study company shed light on historical organisational developments. In particular, these documents revealed details on the establishment and transformation of the corporate research organisation.
8) Social networking websites. Networking websites for professionals, in particular linkedin.com and xing.com, helped complementing chronological data on the involvement of individuals in the development, implementation and use of the artefact.
9) Public archives on municipal developments. A report on the 20th anniversary of the science park, a cluster of R&D-focused firms and research institutions in the city of Ulm where CarCo's largest research facility was based in, provided insights into the formation of the research facility in this particular locale. A time-line of the history of the science park, available on the website of the city of Ulm, depicts the chronological development of the research facility.

We distinguished two sorts of documents in the data collection: documents about the organisation available in the public domain and documents for internal use only. The most relevant publicly available documents for us were annual reports of the overall organisation. We examined the annual reports of the last three decades to trace the recent history of CarCo, in general, and its organisation of research activities, in particular. The history of the overall firm was widely publicised. However, learning details about the organisation of its research activities required thorough reading of annual reports. Another relevant source on the history of the research facility was the documentation of the 20th anniversary of the science park where the facility was located at. Finally, from online archives of regional newspaper articles we gathered further data relevant to understand regional economic history. These public resources helped us to relate company-internal events and developments to regional and sectoral contexts and dynamics.

Documents produced for internal purposes were helpful in learning about corporate and project-related processes and events. Here we distinguished three kinds of documents. First, a selection of corporate-wide available documents provided us with a public representation of the research project. Since the team was awarded the corporate innovation award it was widely publicised in the internal newsletter and intranet. This provided information about how the NetworkPlanner and its capabilities were presented to a wider audience. Second, project-related documents provided technical details and insights into negotiation processes between researchers, external developers and internal customers. This allowed us to get an intimate understanding of past meetings and other events upon which relevant decisions were made. An internal network folder where most files were stored was the most important source for project-related documents with the exception that documents with sensitive user data where not accessible. Third, theses of students working with the industrial research team provided important insights into technical but also organisational details. Especially the one-page acknowledgement sections became a highly important resource for learning about relationships between students and industrial supervisors. Since we could not access databases to learn about employee details, the acknowledgement sections filled important gaps in our timeline. Thus, we were able to locate them on the time axis and we could trace their technical contributions to the shaping of the NetworkPlanner. Another supplementary source to fill this gap were online business networking websites like 'Linkedin.com' and 'Xing.com', its German equivalent.

Documents by themselves are not as useful as they are in relation to other sources of data (Yin, 1994). Just like interview data it can be inaccurate and biased since documents also are produced to serve particular interests (Denscombe, 1998). Therefore, they are helpful in corroborating or contradicting other data if used carefully.

4.3.4 Pilot case study

A research project requires a serious commitment of time and resources. A pilot study gives the chance to explore areas of uncertainty or to learn about interesting areas that one has not been aware of previously (Janesick, 1998). Generally, pilot studies allow for testing the research design before fully committing to the research project as they "may reveal inadequacies in the initial design" (Yin, 1994, p. 52). Based on the performance of the pilot, researchers can recognise inadequate methods or flawed assumptions and modify the design accordingly. Selection criteria for a pilot case study can be based on reasons of convenience including access and geographical proximity (Yin, 1994). For ease of access and familiarity with the organisational context we decided to approach CarCo, a former employer of ours, to test the research design and to learn more about our field of interest. After all, the initial research proposal was inspired by our previous work experience with this firm.

About six months into our studies, in the first half of 2010, we reached out to former colleagues in a research department at CarCo. We managed to gain access to the organisation as a guest to collect a first set of data on the case study organisation. At this time we had not committed to a particular technology or research focus yet. By definition this approach was “much broader and less focused than the ultimate data collection plan” (Yin, 1994, p. 75). Before and during the pilot study we attempted to reach out to individuals working in departments that appeared particularly relevant for our research interest at that time. However, we failed to attract sufficient interest and the responses were negative. As a result the research design required modification. The resolution for this problem was relatively easy thanks to the contacts to our former colleagues. Instead of looking elsewhere in the organisation we modified our research interest according to the research activities pursued by the industrial research team we were most familiar with. Thanks to the previous decision to take a more general stance on the technology/society relationship it did not pose a big challenge to adapt our research approach and was still in line with the previous literature review.

To summarise, the pilot study was a pivotal element in this research undertaking. It elicited problematic issues early on in data collection and, therefore, allowed us make necessary adjustments to the research purpose and design. It contributed significantly to shaping the research agenda as it required us to reconsider our situation and the range option available at that time.

4.4 Data analysis

Data analysis is the process of making sense of the data collected in a way to elicit evidence to support meaningful and conclusive findings. Two general strategies for qualitative data analysis are identified: analytic induction and grounded theory (Bryman 2004; Blaikie, 2010). Grounded theory emphasises theory-building in iterative steps which alternate between data collection and analysis. A central feature of this approach is the role of data as the ultimate foundation on which theory is built. In the analytically inductive approach, theory building starts out with a hypothesis informing the analytical process in which the examination of deviant/non-deviant cases guides further analysis. However, our case study approach afforded the application of another specific analytical strategy which is the reliance on theoretical propositions (Yin, 1994). We relied on theoretical propositions suggested by concepts deriving from theorisations of the social shaping of technology and social learning. These concepts guided our analytical gaze by foregrounding some processes and phenomena over others.

Besides understanding how the technological artefact had been developed and implemented, a central question of this study was to understand 'why' all these processes happened and how they related to each other. Thus, we were led by a strategy of 'explanation-building'. This is an analytical approach in narrative form that is supported by theoretically significant propositions (Yin,1994). Its process is characterised by gradually building explanations as a result of a series of iterations in which case study data is examined and theoretical positions are revised in turn.

The analysis process was supported by the codification of data, which is the central activity in the analysis of qualitative data (Blaikie, 2010). It aims to reduce the complexity of raw data and allows its arrangement in a meaningful order. Documents were analysed following the principles of source criticism (Tosh, 1991; Kalela, 1999). Instead of analysing documents for their contents only, we took into account the role and intentions of the authors to put into perspective the reasons for producing those documents. Documents intended for public or wider audiences provided valuable contextual information. Internal documents were produced with certain political motivations and thus were treated with care. However, they were particularly useful to provide insights on technical details and specifics of the artefact and to triangulate other data.

Rather than focusing on linguistic features or utterances of particular details, we applied grounded theoretical approaches to analyse the contents of the interview data (Strauss and Corbin, 1990). In a first step, open coding was applied to break down the interview data and to find meaningful categories. This provided an overview, for example, of the range of categories about activities and events individuals were involved in or occurrences they knew about. In a second step, axial coding was applied to align categories in a meaningful order. Linking categories with each other produced an insight into chronological occurrences of events and other causal and otherwise meaningful relations. This multi-stage coding process helped categorising events and actions of individuals and collectives and linking these to wider contextual developments. The coding process was facilitated by Nvivo, a qualitative data analysis application.

Another important process that guided our analysis was the development of an extensive timeline. Yin (1994) addresses the use of time-series and chronologies but relates them to quantitative analysis. Our timeline, on the other hand, was an attempt to relate and to align a mixed set of qualitative features along a time axis. Figure 6 shows a corkboard representation of the timeline which has been primarily developed in a spreadsheet format. The timeline spreadsheet became a crucial point of reference that helped in getting an overview and comprehensive understanding of the complex ecology of actors involved and events marking pivotal moments in the innovation project (for an aggregated version of the timeline spreadsheet see Appendix A). Furthermore, the timeline allowed developing a spatial map that helped making visible changes in spatial relationships, i.e. the ecological landscape, over time between the research group and other units of the company. Although the spreadsheet variant contained more details, the physical variant was developed as an additional iteration in order to get a different perspective – it also made for a better visual representation than the snapshot of a spreadsheet. Beside the first two markers, which remind of two decades of corporate history, each blue marker in the top lane indicates a year, starting with 2000. Each horizontal white strip (of tape) represents the involvement of an individual actor while the black strips separate organisational units. Significant events are marked by pieces of paper. The threads attempted to indicate spheres of influences of an individual over others.

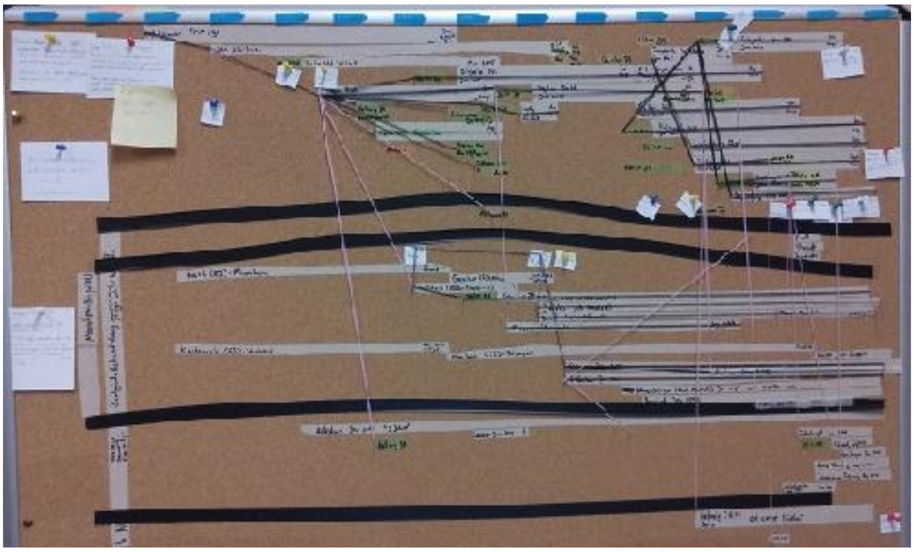

Figure 6 Visual representation of the case study timeline (corkboard variant)

The visualisation is indicative of the different stages through which the technological project passed and, more generally, of the complexity inherent in the case study. It played an important role in reconstructing and ordering historical events. The timeline was also a helpful tool for triangulating data from other sources.

In course of the data analysis process, we have attempted to interpret the timeline in various ways. The timeline represents the participation of individuals by plotting their periods of involvement along a temporal axis. This provided us with a small set of quantitive data which allowed us to experiment with various quantitative analysis tools. Before eventually settling with the spreadsheet representation, we tested other time-series analysis applications. In particular, we tested the two open source applications TimeFlow[6] and Gephi[7]. Both applications provided functions for the visualisation and analysis of quantitative data (for preliminary visualisations see Appendix B). While TimeFlow supports journalistic enquiries, Gephi was created to analyse larger sets of quantitative data. Despite Gephi's focus on large data sets, it provided a timeline function to visualise change in data sets over time which was useful for our purpose. Our attempts in quantitative analyses did not follow a systematised approach. However, these experiments helped us in getting a better understanding of the interrelatedness and simultaneity of events and developments across multiple locales. Although we did

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[6] https://github.com/FlowingMedia/TimeFlow/wiki

[7] http://gephi.github.io/

not focus on the use of these quantitative tools, the experience contributed to the further analytical process and the elaboration of the detailed timeline spreadsheet. We continued experimenting with the quantitative data drawing on functions offered by the spreadsheet application (for examples see Appendix C). Biographical studies that draw on larger data sets with time periods could probably make better use of such quantitative tools and elaborate appropriate methods for timeline analysis.

4.5 Validity and credibility of research

Validation is a process by which we make claims about the quality and trustworthiness of data collected, e.g. its reliability (Yin, 1994), and our interpretations thereof (Kohler Riessman, 2002). Since terms such as validity and reliability carry connotations of quantitative research, alternative criteria have been proposed to do justice to the requirements of qualitative research including concepts such as credibility, transferability, dependability and confirmability (Guba & Lincoln, 1994; Bryman, 2004). We will draw on the four latter criteria to argue for the quality and trustworthiness of this research.

Why is our account of reality better than that of our informants? This is a major question to test the quality of procedures to collect and to analyse data. It addresses the credibility of the data we produced and interpretations we made thereof. Two techniques to test credibility are respondent validation and triangulation (Bryman, 2004). The first technique describes the procedure whereby the researcher asks informants to give feedback on produced data or, if available, preliminary findings from analysed data. The second technique describes a procedure in which multiple data sources are used to corroborate or to contradict information to build a coherent account of reality. The focus group we organised at the end of the main data collection stage inherently applied both techniques at the same time. Drawing on our understanding of the main themes of this case study, we were able to get feedback on preliminary findings from multiple participants. The attending informants negotiated about a joint interpretation of these themes and thus corroborated findings during this process. More generally, since our prolonged study is characterised by a multi-local and multi-perspectival approach, we can argue that the research design allows catering for the credibility criteria by default. We note, however, that some authors question these techniques because, in their view, the 'situatedness' of actions in particular contexts cannot be accounted for appropriately even by drawing on multiple methods and sources (Silverman, 2014).

How can we apply findings from the case study of a German car company to other companies or institutions? Transferability raises issues of generalising findings from one context to another. In general, the case study approach has been questioned for its ability to making generalisations, mostly by critics who themselves operate in logics of statistical inference (Blaikie, 2009). In response, other forms of logics have been proposed for case study methodology including analytic generalisation (Yin, 2003; Blaikie, 2009). Analytic generalisation allows to link between case studies and, thus, supports theory development and testing. Our approach followed and contributed to the tradition of theorisation of the social shaping of technology. Consequently, we have drawn on a robust set of theoretical principles which have been applied and tested in numerous other studies examining technological projects in a variety of national and cultural settings. In that sense, we have applied methods of logical inference to increase replicability and validity of our approach by emphasising linkages to other theoretical and conceptual accounts (Mitchell, 2006). In summary, we argue that our findings offer valid theoretical contributions that can be generalised to other cases of technological developments which have similar empirical features, e.g. large organisations in the private sector.

How can we trust in that the data was produced following commonly accepted operational procedures and that conclusions have been drawn free from personal biases? These questions of dependability and confirmability call for transparency in methodology and for reflection on our personal role in the research project. To address these issues it is suggested to adopt an auditing approach (Lincoln & Guba, 1982; Bryman, 2004). This approach aims to establish that research has been conducted "rationally" and that it represents a "fair" account of the phenomena observed (Lincoln & Guba, 1982, p. 5-6). In this chapter we elaborated the research design and the operational procedures according to which we conducted this research undertaking. We have done so to be transparent about the process and circumstances of how we generated data and how we drew conclusions from it. We also reflected in detail about the contingencies that patterned the unfolding of this research project and our personal involvement in the case study organisation. Opening this study for an audit and providing an overview of the applied methods also corresponds to the intention to make available a guideline for other students of technology to follow.

4.6 Ethical issues

Above we have discussed matters of credibility to underscore our claims for the trustworthiness of this study. In this section we want to address ethical issues which underscore the integrity of a study (Bryman, 2004). Social research may constitute an intervention into the lives of individuals and social life in general (Blaikie, 2010). The consideration of ethical issues intends to avert the possibility of informants being put at risk due to their participation (Creswell, 2009). Since we studied an industrial context populated by highly skilled individuals, we did not work with vulnerable people like children or patients. Regardless of the status of participants, we took measures not to expose informants to any harm that could result from our activities.

External research students were a common sight within the industrial research context and the technological project in particular. There was no need to hide our intentions or research activities. Thus, all participants and other collaborators had been made aware of our dual role as project member and participant observer throughout the data collection process. Being open about our status helped avoiding the risk of someone disclosing confidential material without knowing about our research interest (Denscombe, 1998). Besides, before we could engage with CarCo we were required to sign a non-disclosure agreement which prohibited us from disclosing any confidential material in the first place. Confidential material in this case concerned data of business cases that had been evaluated with the technology under investigation. For reasons of confidentiality, we also committed to not disclose the name of the case study organisation. Instead we draw on the pseudonym 'CarCo' to refer to the organisation throughout this report.

To inform participants about their rights and to reassure them about efforts to protect these we handed out informed consent forms (Creswell, 2009). We prepared a form that provided our details, outlined the purpose of this research project and highlighted that participation was voluntary. Further, we guaranteed the anonymity of our informants and assured that the interview can be interrupted at any time. Our multi-local approach led us to conduct interviews at different locales. Thanks to the opportunity to do placements with different organisational units, we were granted access to different departments and the respective members of the technological project. In addition to asking project members for interviews, we approached relevant gatekeepers, usually their line manager, to get the permission to conduct an interview in the first place.

5 Empirical chapter 1: Historical transformations and contextual dynamics

The motivation of this thesis is to understand how the technology concerned had been developed and, most importantly, why the technological development came about in the first place. In order to comprehend the origins of the development we have to go back in time and to other locales to examine events that preceded events and episodes involving the technology project. In this first empirical chapter, we will examine historically the dynamics and events that led to the initiation of the technological development (see Figure 7 for an overview of the empirical data discussed in this chapter).

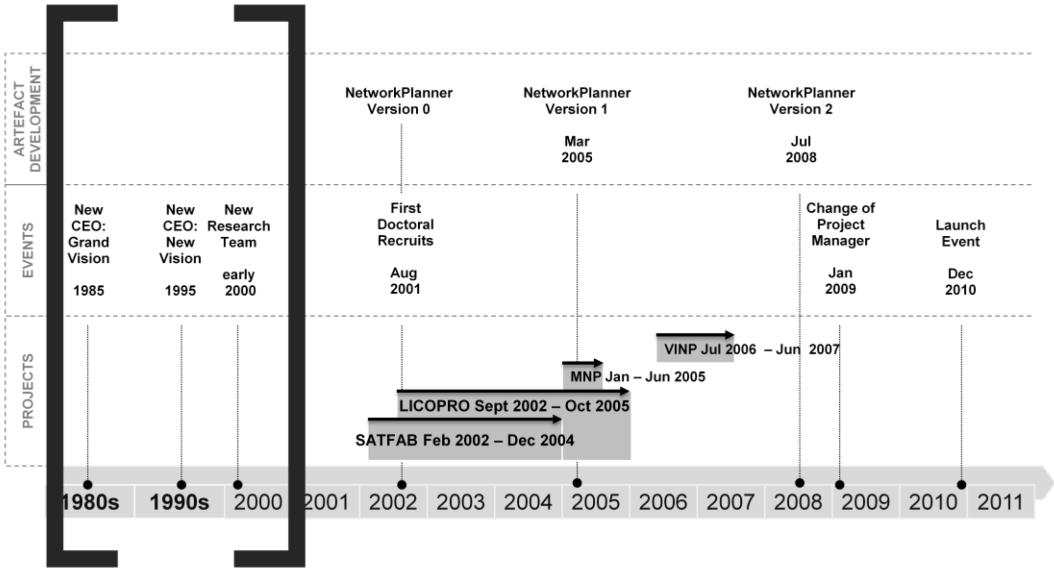

Figure 7 Overview of the innovation process addressed in chapter 5

The first of the three sections in this chapter examines the corporate history of recent decades. It sheds light on how the struggle of implementing a grand vision shaped CarCo's organisational landscape to the extent that the research group faced a difficult situation when a new grand vision was put in place. The second section reports how the research group created a new team to deal with organisational tensions. Finally, the third and last section describes how this team adapted to the tense situation by extending its activities to access resources from funding bodies outside the company. Next, we will begin with reporting how the research group was established as an organisational unit in the first place.

5.1 Historical context of CarCo's research organisation

CarCo's research was not centrally organised until the establishment of a dedicated organisational unit in 1986. The circumstances of why and where the research division was established and how it was managed thereafter established crucial structural conditions that patterned later events. It was due to historical and local contingencies, involving not just CarCo but also regional and local administration and a higher education institution, that allowed a situation to arise in which a few individual researchers were assigned to work on subjects that later afforded the development of the strategic network planning system. An important historical precursor for these events was the appointment of a new CEO in 1987 who set in motion a momentous transformation of the company.

In mid-1980s CarCo embarked on a journey to transform and expand its organisational landscape. Until the end of the decade, several companies were acquired that extended the range of products offered by CarCo. Further, a new CEO was appointed in 1987 who pushed to transform CarCo. His vision of an integrated technology company was informed by the idea to diversify CarCo in terms of the products manufactured and markets where those were sold to. This diversity strategy aimed at reducing dependence on few single markets and at the same time reducing the risks of volatility in these few markets.

At the time when the new strategic approach was implemented CarCo had a homogeneous product portfolio focusing on passenger cars and utility vehicles. This narrow product portfolio made the company susceptible to the market volatility of the automobile sector.[8] To put the new vision into practice the new CEO set out to expand the competencies of CarCo. What followed over the next years was a strategy of acquisitions. Traditionally CarCo produced automobiles for roads. After several acquisitions CarCo's product portfolio comprised vehicles also for rails, aerospace and

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[8] Suddenly changing sales figures had an immediate impact on the overall performance of the company. Economic crises, such as the oil crises witnessed in the 1970s, reminded executives in the automobile sectors that political instabilities are a threat to their businesses. Diversification was a usual response to avoid single market dependencies and an opportunity to tap into new opportunities and to exploit previously inaccessible markets.

waters. Besides expanding its automobile products, CarCo also significantly expanded its capabilities to produce electronic goods.

5.1.1 Research and technology consolidated in new central department

After a period of rapid growth the landscape of CarCo had been strongly transformed. Newly acquired and integrated firms with different organisational structures extended CarCo's and challenged its executives to align everything according to an overall structure. These needs of realignment were met with internal reorganisation efforts. One of the significant internal changes was the establishment of a central division for research and technology in 1986 (Document: Annual Business Report, 1986). Besides organisational reasons there were also exogenous motivators to restructure the organisation. An important objective for CarCo's researchers was to address increasing environmental restrictions imposed by German and European regulators.[9] Car manufacturers bore the consequences of stricter emission regulations. Meeting new regulations required the development of more efficient combustion engines and other technical components that emitted less pollutants. Another impetus for centralisation of R&D was the increasing diffusion of new technologies into the manufacturing domain, information technologies in particular. [10] Thus, even prior to CarCo's organisational expansion, increasing legal requirements and the general advance of technology pushed CarCo's existing research laboratories already to their limits. With the acquisition of

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[9] The increasing awareness of environmental pollution peaked in the public debate of the causes for acid rain throughout Europe in the 70s and 80s. Particularly in Germany, the public was sensitive to the subject and demanded political interventions which came in the form of stricter regulations for industry.

[10] From an information-technological perspective, the 1950s are characterised by military inventions and developments spilling over to industry and businesses. Computers and information technologies found their way into workplaces and shop floors. Sites of manufacturing were first equipped with stock and inventory control systems in the 1960s. The development continued with Material Requirements Planning (MRP) systems in the 1970s and Manufacturing Resource Planning (MRP II) systems in the 1980s (Pollock and Williams, 2009). Similarly, other information technological developments occurred in different settings. Increasing volumes of international trade handled by customs in mid-1960s saw the emergence of Electronic Data Interchange (EDI) to speed up transfer of information and reduce costs. Emerging standards in the 1970s eased implementation and offered cost reductions to other industries dealing with vast quantities of materials and goods (Gifkins & Hitchcock,1988). These and other technologies challenged the principles of conventional manufacturing systems but also offered new ways to tap into new profitable opportunities.

firms, CarCo's research capacities to do and to manage research were further stressed. Particularly the acquisition of an electronics company contributed to great extent to a rapid increase of employees working in research laboratories. For this reason CarCo restructured its research organisation to consolidate all research activities in a single organisational unit.

For large, companies with distinct 'mechanistic' hierarchical structures, reorganisation and establishment of new organisational units is a common response to deal with change (Burns and Stalker, 1961). Changes to internal and external conditions are met with redefinitions of functions and responsibilities as well as reshuffling of capacities and resources. In this light, the consolidation of both research and technology into a separate organisational unit was a comprehensible move. The new division pursued three areas of activity. Firstly, it would host product and production-related research. Secondly, the division would be responsible to deal with information technology by tracking and, if applicable, exploiting technological opportunities. And finally, it would coordinate centrally the utilisation of technical facilities within CarCo.

A year after the establishment of the new division, research executives were looking for a way to harmonise the diverse research activities undertaken within the transformed CarCo organisation. In pre-diversification times, research activities in predevelopment departments were both located closely to production plants and aligned closely to the requirements of specific business segments. With an increasingly heterogeneous range of products, research-in-progress did not reflect the more diversified research-needs of the new organisational landscape. In tandem with the establishment of a dedicated organisational unit for research and technology, a new facility was envisioned to provide a central home for current as well as future researchers. The idea was to consolidate CarCo's research also in a physical location. Thus, a visible landmark of CarCo's diversification and consolidation strategy was the construction of a new research facility in early 1990s.[11]

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[11] The decision to construct a new facility was also contingent on certain local and regional developments. The electronics company acquired by CarCo employed about 400 industrial researchers in the city of Ulm. Around the same time, this city was over-proportionally affected by an economic crisis triggered by closure of large manufacturing sites in recent years (Stadt Ulm, 2006). Local councillors were keen to attract new investments to fill these gaps and thus allied with the University of Ulm and

5.1.2 Open agenda for the new research facility

CarCo envisioned the new research facility as a space to yield synergy effects of a diversified company. However, the company had no experience yet about how to proceed and to develop a research agenda for a heterogeneous organisation in the beginning. It was commonly perceived that the research policy should not aim to fulfil the requirements of just one division. Indeed, it was stressed that CarCo's research, in general, ought to undertake cross-functional research that would produce outputs relevant for a wider set of products. Translating these broad requirements into a concrete research agenda was a piecemeal undertaking.

The annual business report (Document: Annual Business Report, 1990) published in the year when the construction of the research facility had begun, explained that the definitions of research foci and the qualifications of new researchers yet to be recruited were the next items on the agenda. In practice this early uncertainty about research objectives entailed enhanced privileges over funding and personnel, and increased freedom of decision making about the research agenda by the researchers themselves. As Patrick, the former head of a research department, recalled:

> "I remember, when I started to work in the CarCo's research, there was [a former head of research] who said 'Do cutting-edge research and come back in four years to show results'. […] many of the [research] subjects, which were started in our department, they did not develop because some director told us 'do that' but because they emerged bottom up" (Patrick, former head of the research department, focus group interview, 12 November 2011).

Such a free mode of operation was not arbitrary - large companies are rather known for strict hierarchical orders - but a consequence of the rapid increase of research capacities and the yet unanswered question of how to translate the vision of a newly-forged, integrated technology firm into a concrete research programme of a newly established division.

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the regional government of the Federal State of Baden-Württemberg to push for the development a so-called science park, an innovation cluster following the model of Silicon Valley, on the outskirts of the city (Stadt Ulm, 2006). Since the support of the regional government was bundled with public funding, CarCo accepted the invitation to take part in the undertaking and decided to locate its new research facility in the newly established science park.

The intellectual freedom of the early years was soon confined by initiatives of senior management to wrest control over research activities and to move these away from basic research towards a more business-related agenda. CarCo began to cultivate a culture of strategic and entrepreneurial thinking (Document: Annual Business Report 1992). It also encouraged their researchers to become "entrepreneurs within the enterprise" (Document: Annual Business Report 1993). In 1994, a control mechanism was introduced to assess the performance of research projects (Document: Annual Business Report 1994). Research projects were audited regularly in terms of their efficiency and effectiveness. To pass the audit, a research project had to prove that it met international standards and that it could match with competitors as well as demonstrate high potential for success. The requirement to implement this critical review process indicates that the performance of some research projects, which were initiated prior to the implementation of rigour audits, was in some way unsatisfactory. These attempts to influence and control research activities indicate the relatively loose alignment of research projects to the requirements of CarCo's operational divisions at that time.

5.1.3 Vision did not materialise and was succeeded by an economically oriented vision

After almost 10 years the vision of an integrated technology company did not prove successful in economic terms. Timing also turned out not to be in favour of risky undertakings as an economic crisis and a looming recession where under way in the early 1990s. Throughout the German automobile industry, operational efforts were targeted at implementing rationalisation measures. 'Leanness' and lean production was the leading management fashion among German executives (Benders & Bijsterveld, 2000).

Eventually a change in CarCo's board heralded the end of an era of organisational diversity in 1995. A new CEO was appointed who put emphasis on the shareholder value and de facto abandoned the vision of an integrated technology firm. CarCo's traditional core competencies in producing cars and other vehicles were again set as the leading corporate mission. This triggered yet another corporate-wide reorganisation to undo previous transformations. In the years to follow, parts of the company were scrutinised and evaluated according to their contribution to the new shareholder value-led vision. Many of the organisational units acquired and integrated in the past decade experienced substantial changes. Profitable units were consolidated. Problematic units were downsized or, if no other acceptable option was found, sold off or liquidated.

The research group was not exempt from this new wave of transformational changes. Although it did not witness dramatic structural changes as did other organisational units, it was affected generally by rationalisation programmes that were felt throughout the research group. An interviewee from the research team indicated that the mood among employees in the research group, who saw their privileges shrinking, darkened as a result of these rationalisation efforts.

5.1.4 From excellence to efficiency: change in the evaluation culture

For the research group and the new research facility these developments had particular consequences. Because the product portfolio was subsequently cleared of products not directly related to automobiles, the cross-functional research projects increasingly lost their anticipated realm of application. For example, advantages of economics of scope necessary for the cost-effective utilisation of a new technology were not achievable any longer in a smaller and more homogeneous company landscape. An indicator for the unsatisfying success of research activities was the low transfer rate of research outputs into products or the production system after the completion of projects in later years. Arguably, this low spillover was the result of a research programme that was relatively loosely coupled to the specifications of the automobile-producing divisions of CarCo, as the former head of the research department explained previously. However, blame for this apparent underperformance is not exclusively to be sought among researchers. This perceived lack of value of research outcomes is also to be interpreted in light of the changes triggered by the new direction pursued by CarCo's board of management.

The change in the management board did not only bring a new order in the social structure of decision makers but also a cultural change of how performance ought to be interpreted and evaluated in the entire firm. Under the previous corporate vision the research division was regarded as a bridge between the diverse operational divisions. The proponents of the integrated technology firm hoped that cross-functional research would provide equal benefit to all divisions. This belief manifested in expectations on research outputs. Konrad (2006) describes how 'collective expectations' influence generally the perceived worth of potential project outputs in favour of dominating evaluation criteria. Collective expectations implicitly shared by a larger group can persuade a sceptical individual to back an undertaking despite having second thoughts. The vision of the integrated technology firm perpetuated a culture where technological excellence was the dominating criteria. This created a protected space where research projects were evaluated and selected primarily based on promises of technological excellence. Thoughts about the ultimate application of research outputs and economic considerations were of secondary order. The new vision with its focus on shareholder value - a perspective that puts economic considerations at the fore-front - triggered a top-down cultural change reversing that order. Previously taken-for-granted assumptions about the value of research outputs changed and were replaced by new assumptions based on different expectations. Suddenly, technological excellence as criteria was degraded in favour of economic factors. The new evaluation regime affected how the worth of existing projects was interpreted. A project that was previously evaluated as worthwhile due to the potential excellence of its research output lost its worth due to the suddenly leveraged priority of economic factors.

5.1.5 Research organisation facing increased internal pressure

CarCo's strategic redirection and the later resulting low research transfer rate due to the change in the corporate landscape had a negative effect on the research group in the long run. The notion of research as a strategic advantage experienced a rapid increase in significance for the firm due to the vision of an integrated technology firm that directed CarCo's corporate strategy from mid-1980s onward. Investments into technology and research competences were regarded as an essential link to yield the benefits of the integrated technology firm. Newly acquired as well as existing capacities were consolidated to create a separate research group. All these costly acquisitions and investments in favour of the research group were made possible only by the profitable operations of the operational divisions in CarCo. This exemplifies the relationship between the research group and the other profit-generating divisions. Each profit-generating division is oriented towards the development, production and distribution of their products. From this point of view the research division was an organisational unit that did not contribute directly to producing profits for CarCo.

Generally, the research group followed a closed innovation system model as opposed to an open innovation approach, where a research and development department directly interacts with external actors and thus could generate revenue through licensing or selling its research outcomes to markets outside of the firm (Chesbrough, 2003). Instead, the research group was geared towards the operational divisions as the only internal consumers of their products and services. Therefore, the research group was accountable to the operational divisions and had to justify its expenditures by producing outcomes that could be transferred either to improve directly the value of the products or at least indirectly by improving the production of the products. If the research group did not deliver and thus failed to meet expectations of the operational divisions sufficiently, then further expenditures were at risk of being critically examined and probably called into question. With the old vision failing and opposition to the structural residues of the grand vision of an integrated technology firm increasing, the research group faced a changing reality where its legitimacy came under scrutiny.

Support from the operational divisions was an essential component legitimising the work of the research group. Sustaining and fostering this relationship became more important in a new evaluation culture where economic factors replaced the dominance of technological excellence. In this context, a low spillover from research into operations was particularly harmful since it endangered to strain the relationship even further. A major reason for this gap between research output and its successful implementation was found to be the inadequate consideration of economic factors during the research and development process. Concerned researchers and managers were aware about the methodological shortcomings when it came to the economic evaluation of their projects. Thus, an attempt to bridge this gap was the creation of a dedicated team that would provide missing economic skills sets and methods to support the consideration of economic factors in research undertakings. The next section will report about this team and the story that unfolded after its formation.

5.2 A new research infrastructure: the Production Management Team

The previous section reported how the corporate research infrastructure was established in the course of the grand vision of a diversified firm. Consolidating its research capacities centrally, CarCo built a new research facility to unite previously distributed research activities. However, a change in the corporate strategy and subsequent transformation of the firm triggered a slow-down in the performance of the research group. Eventually, after severe organisational transformations and a shift toward a culture of economically-oriented evaluation of performance, a low spillover of research outcomes into operations prompted the research executives to take action.

The following section elaborates how a new team was formed to address the problem of the low rate of research outcomes being successfully transferred into products or the production system of CarCo. However, the team of researchers struggled to enlist its fellow colleagues to collaborate as the structure of incentives turned out to be not in their favour. To compensate for underutilised capacities within the team, efforts were directed towards another venue which opened up thanks to participating in publicly funded projects. This new line of work branched into a novel field of research that proved rewarding for the research team and that resulted in the shaping of a technological artefact.

5.2.1 A new research team to address consequences of change

Among research executives a main reason for the low transfer rate was understood to stem from the neglect of 'soft factors' as one interviewee put it. After the centralisation of the research group and still in course of the old vision new research projects were initiated with little consideration of socio-economic factors. Instead, fulfilling the stereotypical tradition of German engineers, technological excellence was the main criteria in both conducting research as well as designing new car models. Thus, the criticism of some authors that a car newly introduced by CarCo in 1991 "was massively over-engineered and ridiculously expensive as a consequence" (Cooke & Morgen, 1994, p. 100) can be carried over to indicate the technology-led focus of some of the research projects undertaken within the CarCo research group.

When a research project approached later stages, issues regarding feasibility and applicability of its output became apparent. It was perceived that it was not the technology but the neglect of socio-economic factors that caused the problem. Thus, the idea was to have a team of dedicated specialists that would cater for the socio-economic factors, or the 'soft factors'. These specialists would work with other researchers to address previous shortcomings. They would provide missing skills and capacities to conduct economic evaluations of technologies which were under development in the research laboratories. In the fashion of technologically deterministic thinking, the eventual though late consideration of missing socio-economic factors was expected to positively affect the successful transfer of research outcomes.

The new team was named the Production Management Team (PMT) and comprised fewer than five researchers in the beginning. It was allocated as a second team to a department with another team of scientists doing research on rapid prototyping methods and technologies. The programmatic direction and initial configuration of the new team reflected the primary objective defined by the research organisation. To get started the team got in touch with other researcher groups and enquired about possibilities to get involved and to support other research teams.

5.2.2 Social learning through interactions with other projects

Although this track of work proved to be less fruitful for PMT in the long-run, it was the first opportunity for the team to learn about difficulties in technology transfer endeavours. For example, one of these technological projects was the development of a high precision laser welding technology. From a technological point of view it was a technical challenge that would, if solved, contribute to a better quality of goods produced. A question that popped up only late in the research and development process was if the benefit of the technology could eventually be put into practice at all. A PMT member's task was to evaluate and estimate the productivity and costs of the implementation and use. Such an assessment would include the costs to install, operate and maintain the technology. Further, it would take into account social, organisational and environmental factors which were neglected in previous estimations. What skills would be required to operate the technology, and if so, what would it cost to train workers? Does the technology fit into the existing production routine or would the organisation of work have to be adjusted?

Because there were no pre-existing tools PMT could draw on, the researchers were required to develop their own sets of tools. Thus, PMT acquired special expertise on how to evaluate the feasibility and productivity of technologies in development. As indicated previously, the objective to collaborate with other research teams proved fruitless in the long-run but the expertise gained thanks to such engagements was practical for research activities in scope of publicly funded projects later on. Compared to their other research colleagues, PMT members were more exposed to operations for they had to understand about the requirements of potential users of the technologies. Increasing awareness and understanding of the operational side resulted in better comprehension of the different culture and principles prevailing in this, from the point of view of the research facility, rather distant but dominating part of the firm. This social learning process, a concept that emphasises learning by interacting with various social actors (Williams, Stewart & Slack, 2005), turned PMT members quickly to the most practice-oriented and best networked research team within the research group. The ability to generate outreach was acknowledged by the head of PMT's research department who noticed that in the end, the team leaders of PMT dealt with more managers in senior positions than he did.

5.2.3 A financial model with a flaw

A crucial factor turned out to be the funding model according to which PM's budget was allocated. PMT's budget comprised a mix of 50% fixed funding and 50% variable funding which was to be acquired from other research projects. This funding model was intended to encourage the team to seek collaborative relationships with other research projects in the research facility. The model required PMT members to regard the research group as a market on which they had to offer and promote their services. Such a model works well if the service or product is perceived of high value. When the team was established, senior managers assumed that PMT would successfully team up with other researchers who required their skills. However, this was not the situation that PMT encountered.

The internal market approach was taken up well by PMT's members. It was a relevant and successful incentive for PMT members to be creative and proactive in connecting with others. The problem was that no equivalent mechanism was arranged for on the other end of that relationship. As it turned out, other researchers were reluctant to team up with PMT members. Approaching their anticipated clientele, PMT members were not overly successful in raising high expectations of any benefits resulting from their services. One reason to turn down PMT's support was, for example, that at that late a stage of a research project no such services were required any more. If any social investigations or economic calculations were required, the researchers, so they thought and argued, could undertake those themselves. They would not need any outsider evaluating their work. In fact, other researchers were reluctant to disclose their projects to detailed scrutiny by outsiders. Thus, collaborative relationships were difficult to establish. It seemed the idea of creating PMT was good but not without flaws.

This fundamental problem was fed back to the senior management of the research group. However, PMT's small size resulted in the team's concerns not being heard by the research management. Establishing a new team is a political decision and takes negotiations to clarify details about resource allocation and other details. Undoing such a decision would again take effort and negotiations. Thus, a decision to change the situation was delayed and not highly prioritised. As a new team they had no time yet to create a strong network of allies and as a result had no strong voice within the research group.

The newly-established Production Management Team faced a substantial threat after the business model of the team proved to be impractical under the given circumstances. Because the appeal to senior management was not immediately responded to, PMT had to find other ways to acquire resources. Indeed, this search did not take long because an opportunity arose not long after the establishment of PMT. An engineering consultancy approached CarCo with an offer to participate in drafting a research proposal to apply for a research grant from a German ministry.

5.3 Publicly funded projects

In October 1999 the German Federal Ministry for Education and Research (FMER) released the first announcement to introduce the framework for a funding programme titled "Research for the production of tomorrow" (Bundesministerium für Bildung und Forschung, 1999). The target of the programme was to fund research activities which aimed at strengthening producing industries in Germany. Research proposals that would benefit SMEs were particularly welcomed and preferred. The funding intended to create protected spaces where research activities and collaborations could be initiated which otherwise would not happen.

An engineering consultancy firm got notice of the call for project proposals and set out to submit an application. The firm was specialised in providing consultancy services to companies in the manufacturing industry. In course of its consultancy activities, it had an array of customers which it had worked with before. Drawing on experience from working with these customers the consultancy was able to draft a research proposal which addressed concerns and problems of its clients. For the consultancy, it was also a practical approach to strengthen relations to its customers. The consultancy approached a selection of its clients and invited to join in shaping the draft of the proposal as research partners. One of those clients was CarCo which confirmed its interest in participating and shaping of a potential research project. In particular it was PMT that responded to that call to engage in the collaborative work on drafting a joint research proposal.

It is important to emphasise the significance and contingent role of the consultancy as an intermediary that brought together this set of actors and research partners. The FMER funding scheme aimed primarily at SMEs in Germany. CarCo is among Germany's largest companies and thus was not among the preferred target group of the programme. In its intermediary role the engineering consultancy had links to various different actors including both SMEs and larger corporations. As such it was in a better position to enrol multiple SMEs to form a research consortium that largely met the requirements of FMER's funding scheme. Due to the research goals of the project, which will be described in the next section, CarCo was accepted as a representative of the customer of these SMEs. In hindsight, this moment can be pinpointed as the starting point of PMT's research on flexibility of production networks.

5.3.1 Project SatFab

The joint research proposal was submitted and eventually the funding was granted by the Federal Ministry for Education and Research. The project, titled SatFab, ran from February 2002 to December 2004 (Karlsruher Institut für Technologie, n.d.).[12] Short product life-cycles, increasing product varieties and fierce competition frame the ever rising challenges a factory has to cope with. Generally, flexibility in a production system is a concept to plan for instability and uncertainty in order to deal with the aforementioned factors (Slack, 1987).[13]

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[12] Its title 'SatFab' was derived from the German word 'Satellitenfabrik' which translated means 'satellite factory'. A satellite factory is a decentralised factory of a supplier firm which is located in proximity to one or more original equipment manufacturer (OEM) such as a car manufacturing plant.

[13] Because flexibility is an ambiguous term which is often used interchangeably with other concepts (Zaeh et al., 2005), it is important to delimit the context. In regards of a single factory, flexibility can be defined as an ability to master a given set of different states without altering the system. The concept of changeability, on the other hand, describes the ability to shift the production system with little investment to operate within a range of different states (Zaeh et al., 2005). For example, a factory that is able to select the product for manufacturing out of a variety of products of one family of products can be regarded as flexible. A highly changeable factory would be a factory that

The seven members of the SatFab project, comprising six industrial firms and the engineering consultancy, aimed to research innovative concepts and exemplary solutions to set up a satellite factory with a high degree of changeability. CarCo's role was to represent the customer that procures goods manufactured by the satellite factory of a supplier firm. The task was to elaborate approaches of how to co-design a production network and how to identify and influence parameters that affect the changeability of factories. The starting point for the project was the problem that supplier factories usually were designed to meet the prevalent requirements of a previously determined product. However, future requirements shaped by the continuous change of both products and production systems were not considered in the planning and design of a satellite factory. Consequently, supplier factories were rigid by default and unfit for change. Therefore, SatFab was set up to address that design limitation and to find novel concepts for a flexible and sustainable integration of satellite factories into the value chains of OEMs. The project promised to reconcile the conflict between the producer and the supplier firm resulting from tensions caused by the uncertainty and complexity of globalised and volatile markets.

5.3.2 From national to European level

The first call for proposals announced by the German Federal Ministry for Education and Research for its "Research for the production of tomorrow" funding programme contained a reference to a similar programme run by the European Union (Bundesministerium für Bildung und Forschung, 1999, p. 9). From 1998-2002 the European Union ran the 5th Framework Programme to fund research, technological development and demonstration activities among its member states. One of the four specific thematic programmes was titled according to its objective to foster "competitive and sustainable growth" (European Commission, n.d.). The German Federal Ministry pointed to the key action "innovation products, processes and organisation" that was similar to its own research programme. Because the Ministry's funding aimed at domestic actors only, this remark brought applicants' attention to consider submitting a proposal application on European level if the scope of the project was adequate for this purpose.

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is additionally able to select its produce from a different family of products with minimum investment of time and money.

Considering the limitations of the SatFab project (domestic focus, limited budget, no research institute involvement and supplier firms-oriented project contents) there were a number of good reasons for PMT to expand the scale of its research on flexibility. Particularly the opportunity to align a project's direction according to the needs and specifics of CarCo was a compelling reason. PMT took the initiative and set out to search for project partners and to draft a proposal. The particular researcher in PMT who was mainly in charge for SatFab was tasked to also engage in this activity.

5.3.3 Project LICOPRO

The project proposal was eventually granted and co-sponsored by both the European Commission under the 5th Framework and the 'Intelligent Manufacturing Systems' (IMS) initiative.[14] With a supranational scope this second project boosted PMT's capabilities further than the SatFab project in advancing its research activities in the subject of flexibility in production systems. The project was kicked off September 2002 and ran until October 2005. The project acronym LICOPRO was an abbreviation for "Lifecycle Design for Global Collaborative Production". While SatFab's unit of analysis was a single factory, LICOPRO covered the entire production network. Its overall objective was to "develop a comprehensive explanation model for lifecycle robust design of global collaborative production" with research outcomes including "reference architectures, methods and tools for strategy deployment, (re)configuration planning, and evaluation and design of information technologies for global collaborative production" (ETH Zurich, 2007).

5.3.4 Three levels of flexibility

The LICOPRO project was an important signal for senior managers in CarCo's research group to allow PMT's researchers to continue engaging with its secondary objective. The project's funding enabled PMT to expand its operational capacity dedicated to this task. As mentioned before flexibility in manufacturing is an ambiguous term (Zaeh et al., 2005). Depending on the context there can be different meanings of similar concepts.

[14] The IMS initiative was an "industry-led, global, and collaborative manufacturing RTD programme, supported by the governments/public administrations of most of the world's leading manufacturing nations, i.e. Australia, Canada, the European Union, Norway, Switzerland, Japan, South Korea, and the US. It involved large and small companies, users as well as suppliers, universities, research organisations, and governmental organisations" (Wing consortium, 2007a, p. 11).

Therefore, research on flexibility had to carefully take into account these differences. PMT's approach in line with the research project proposal was to recruit three doctoral students. Each student was tasked to do research on the same topic but on different levels. To resolve ambiguity surrounding the term of flexibility, the research problem was split into three levels ranging from the local to the global. The first level encompassed the assembly line focusing on the factors relevant for assembling a product including machines, equipment, workers and all related processes. On the next level, the entire factory was taken into account where different shift models and other factors played an important role. Finally, the network level focused on the interconnected network of manufacturing plants. Our empirical journey will continue following the developments that unfolded around the research activities focusing on the network level.

5.4 Conclusion

The thorough review of historical dynamics and events is an important precursor to put the local processes of the technology project in perspective with other events and dynamics within CarCo's organisational landscape. We have learned that the team of industrial researchers was put together to primarily deal with a particular purpose that was not related to the development of new technological artefacts in the first place. Indeed, the reasoning to establish a new team has been related to other dynamics that were influenced by struggles of organisational reconfigurations. Although the idea of forming a new team to address an urgent internal demand appeared to be reasonable to begin with, it was foiled partly by the decision to develop a business model that was dependent on the collaboration with other research teams. The design flaw resulted in the unintended consequence that the research team increasingly focused on other, in part, more lucrative because prestigious sources of funding from public bodies. This enabled PMT to transform the kernel of its research infrastructure to include researchers and resources set for the development of technological artefacts (as depicted in Figure 8).

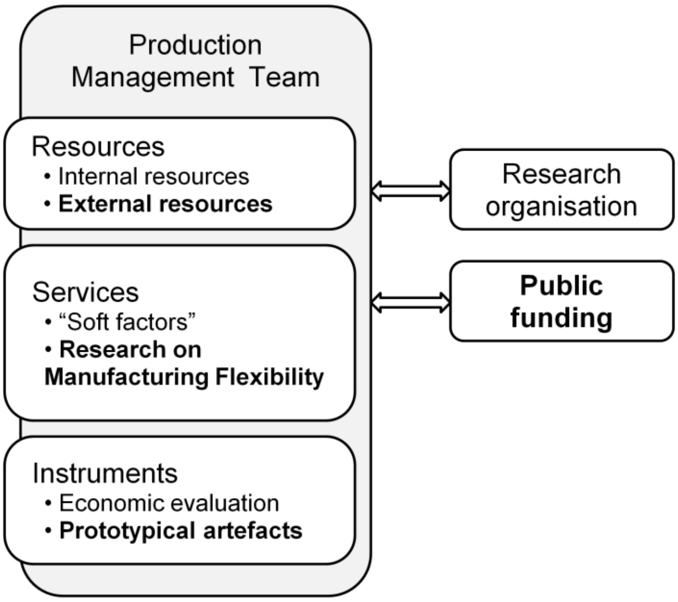

Figure 8 Transformed kernel after external funding was acquired (new elements are highlighted in bold)

The figure illustrates the flexible quality of the kernel concept. Rather than narrowing down on particular aspects of the technological change, e.g. the growing actor-network, it encompasses a range of elements involved in the innovation process. The next chapter will report in detail on local and agential processes that resulted in the shaping of the NetworkPlanner.

6 Empirical chapter 2: The shaping of a research infrastructure

The previous empirical chapter was an account of historical events and developments that transformed large parts of CarCo's organisational landscape. These transformations resulted in organisational tensions that affected CarCo's research organisation. A significant change of the corporate culture put the research group and its research undertakings in the spotlight of economic scrutiny and expectations about the production of useful outputs. A new research team was formed to address the low spillover of research outputs into operations. However, the team struggled to accomplish its objectives due to the reluctance of other research colleagues to collaborate. Facing a shortfall of financial resources, the team engaged with external organisation to acquire public research grants. External resources from two publicly funded research projects allowed the team to focus on a new area of research. In the course of this new line of research, the team began working on technological prototypes. One of the prototypes was the technological artefact investigated in our doctoral research project. This chapter will report on the events and developments that unfolded after the Production Management Team was formed (see Figure 9 for an overview of the empirical data discussed in this chapter).

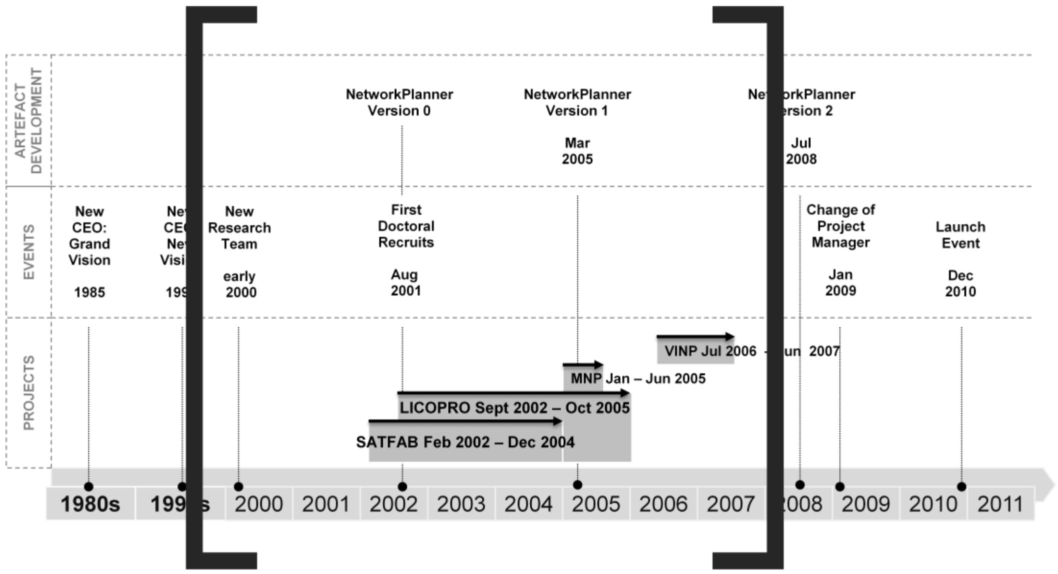

Figure 9 Overview of the innovation process addressed in chapter 6

While the previous chapter examined social phenomena from a distance, mostly due to the variety of locales and extended timescales covered, this chapter will focus on examining actions of individuals in a fewer number of locales. This will allow seeing how historical and contextual dynamics played out on a local level. The next sections will recount in more detail the early episodes of PMT's existence.

6.1 Establishing an infrastructure

As described in the previous chapter a research team was formed to address the problem of low transfer rate of research outcomes into operations. The formation of Production Management Team (PMT) was also the creation of a space in which the technological artefact under investigation would emerge eventually. We adopted the idea of the kernel of a research infrastructure to enrich the conceptualisation about this space and the elements belonging to it. The kernel concept allowed us to track how the team interacted with its broader social environment and how configurations of social, technical and institutional elements changed over time as a result of these episodes of social learning. PMT's actors were key agents of change but they were dependent on the set of resources, services and instruments accumulated over years. All these elements and the configuration to each other, however, changed in some way or the other throughout the years. Hence, it is the kernel that our analysis regards as the social entity that remained 'the same'. It is particularly because of the inherent flexibility of the concept of the kernel that allowed us to observe how the technological development and corresponding social processes of the NetworkPlanner artefact unfolded across time and space.

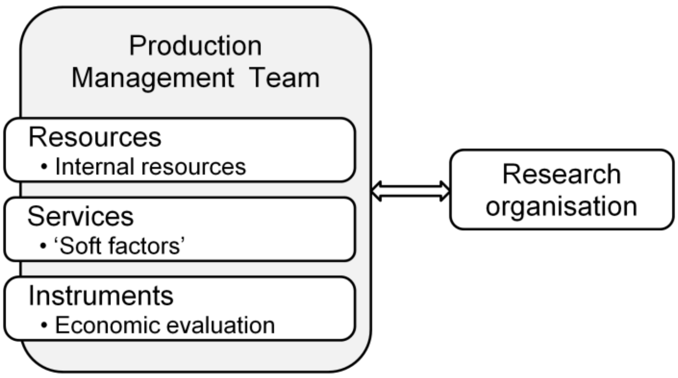

Figure 10 The kernel of PMT's research infrastructure

In the beginning, however, when the first members of PMT came together, there yet was little in place besides a mission statement (see Figure 10). Therefore, the actions of the first team members were decisive in setting the agenda and building capabilities of the team which were the basic elements of a yet emerging research infrastructure.

6.1.1 Building an agenda for the new team

When the Production Management Team (PMT) was created around 2001 there were less than a handful of members. Two of these members were of particular interest for this case study. The first team leader, Martin, was a visionary individual who was a driving force to get the team established. He was well connected to research executives within the research group and thus was aware of current concerns and organisational tensions. Among those tensions was the problem of the low transfer rate of research outputs. It was an opportunity for him to take control over a problem that was given significant attention to by the management. Martin was among the key individuals who pushed for the proposal to establish PMT to address the research transfer problem. His efforts were rewarded with him being promoted to be the leader of the newly formed team.[15] The other relevant and early member, Kai, was a doctoral engineering graduate who was recruited into the research group shortly before PMT was formed. His task was to support PMT and to work with other researchers in order to improve the chances for a successful transfer of technologies from research into operations. When the opportunity arose to work with the engineering consultancy to draft a project proposal it was him who was allocated to collaborating with the consultancy. In course of drafting the proposal it was among the first opportunities for him and PMT to get in touch with internal departments in operational divisions. This external engagement was to gather information about the needs and problems of practitioners in regards of flexible manufacturing processes and systems. Insights gained during several field trips to planning and other departments were fed into the drafting of the SATFAB project proposal. When SATFAB was kicked off in February 2002, PMT had already developed an understanding of flexible manufacturing system-related challenges and a number of contacts to internal practitioners who were interested in working with researchers who promised to address some of their problems.

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[15] Initially, another individual, Kate, was designated to take the role as PMT's first team leader but the candidate stepped down due to personal reasons. However, she will reappear as a project manager later in the story.

6.1.2 Local manufacturing site as a testing ground for ideas and methods

The second publicly-funded research project LICOPRO commenced in September 2002. Considering formal procedures, deadlines and the larger number of partners involved, it can be assumed that the proposal for LICOPRO was drafted around 6-12 months ahead of the project start. The seven months difference between the two projects allowed PMT to incorporate insights learned during the SATFAB drafting process and to further specify CarCo's particular needs in the project proposal for LICOPRO. At the time when LICOPRO started, PMT was several months into doing work on flexibility in manufacturing systems. During this period PMT was able to learn more about CarCo's production system, the organisation, locations, hierarchies etc. and respective problems dealt with by practitioners.

Coincidentally, one of CarCo's manufacturing plants was less than 15 km away from the research facility. This plant was one of only two large manufacturing sites of the Buses division in Germany. Because of its relatively smaller size and localised operations[16], the buses division and this site in particular were characterised by flatter hierarchies as compared to other divisions. These characteristics allowed for a faster decision making process. For example, the strategic planners in this plant covered a wider range of responsibilities. This included the planning of future production programmes as well as planning and overseeing the construction of new facilities abroad. In comparison, colleagues in the larger divisions were more specialised on subsets of these tasks. All together, these features made it easier for PMT to get access to relevant practitioners to introduce their work and to enrol them into their research projects.

Another reason encouraged practitioners of this nearby manufacturing site to collaborate with researchers. Although the legitimised distraction from their everyday work was reason enough for some, there was a competitive element that played a role in encouraging managers to allow their subordinates working with the researchers. The other large plant of that division in Germany was regarded somewhat a competitor to

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[16] This plant was added to the buses division when CarCo acquired a local motor vehicle manufacturer in 1995. Before the acquisition the company had been operating independently and thus had based most of its operational functions and related departments close to its main manufacturing site. Although some functions were removed and centralised at the headquarters of CarCo after the acqusition, this manufacturing site retained much of its operations locally.

this local plant. In times of over-capacities in the automobile industry, manufacturing sites compete against each other to maintain or increase their production volumes. Despite operating under the same brand the productivity of factories can vary significantly (Womack et al., 1990). When it comes to decisions of allocating production volumes, such differences can decide about the future of that manufacturing site and the responsible management team in charge of its operation. Some level of competition is encouraged by the central management to ensure that individual plants remain active in maintaining a culture where improvements and innovations are continuously sought after. Therefore, the practitioners of this manufacturing site were open for the fortunate opportunity to work together with researchers in the hope to gain an advantage over the other plant.

This manufacturing plant became an important partner for PMT in the early stage of its existence. Flat hierarchies, short decision-making processes and the willingness to collaborate were relevant circumstances that allowed PMT to access practitioners to enquire for their needs and problems, to test ideas and elaborate their methods. In sum, this manufacturing site was a crucial element in the early biography of the artefact concerned in this study. This manufacturing site was part of the protected space in which PMT was able to unfold its early research activities. It became a valuable ally and testing ground for the development of the first prototype.

6.1.3 Expanding research capacities: the recruitment of new student members

At the time when LICOPRO commenced, PMT had already established basic elements of a research infrastructure comprising an accessible network of people interested in their work, methods relevant for addressing their research questions and legitimacy granted by research executive to continue and expand their work thanks to positive feedback from collaborating practitioners. Positive feedback on PMT's progress was well perceived by senior research executives who appreciated opportunities to showcase successful collaborations between research and practice to their superiors. Many research projects were scrutinised by practitioners only in later stages when a technology was supposed to be transferred. PMT's approach, however, sought collaboration with practitioners at early stages. A way to engage with many practitioners was to have students work on the publicly funded projects.

The start of LICOPRO was accompanied by the recruitment of the three doctoral students mentioned in the previous chapter in context of the ambiguous meaning of the term of flexibility. Each of the three students was allocated to study different contexts or levels of flexibility. Three levels were distinguished: the assembly line, the factory and the network of factories. Research on the latter context gave rise to the artefact studied in this thesis.

Funding from the new research project and the recruitment of new research students expanded PMT's capacities significantly. Doctoral students are a practical instrument for an industrial research team. They are well-trained and motivated researchers eager to apply their theoretical knowledge in practice. At the same time, they are cheaper than a full-time employee and their limited contracts fit well into an environment where long-term labour commitments are difficult to arrange. Kai, the researcher who was chiefly in charge for drafting the proposal for LICOPRO, took the role of an internal supervisor for the doctoral students. Henceforth, he will also be referred to as the supervisory researcher to distinguish him from other PMT colleagues.

One concern over the doctoral students was that their work would not be distinct enough and that this would cause problems in terms of competition and lack of communication and interaction among each other. This was a particular concern in the first year when all three of them explored similar research areas. The student focusing on flexibility in manufacturing processes developed a distinct approach which interfered little with the other two and, thus, was not affected by this risk. The other two students, however, had a strong overlap in the early stage of their work as both their research topics related to factories as the unit of analysis. However, they differed in the quantity of factories involved. As it turned out, the two students developed a collaborative and interactive relationship in which they discussed ideas, helped each other out and shared resources. This high level of collaboration stimulated a coordinated division of labour and increased the pace in which methods were explored, tried out and either dismissed or elaborated further.

6.1.4 Division of labour: support by interns

SATFAB and LICOPRO defined work packages for which PMT was responsible. The work was shared among the full-time researchers involved and the doctoral students. However, the team was further supported by undergraduate or postgraduate students, who were recruited as interns for usually six months to work on small and clearly defined work packages.[17] Supervised mostly by the doctoral students, these students explored subjects which were relevant or of interest for the doctoral student's research topic. Therefore the students extended the capabilities of the doctoral students by looking into areas that the doctoral students were interested in but which they could not afford to investigate themselves. To distinguish the doctoral students better from supporting students, the latter will be addressed as interns henceforth. Interns were selected by the focus of their studies. If a task required knowledge of developing a technical artefact, an intern studying an appropriate technical degree was recruited. If the task required strong subject knowledge about finance or economics, an intern from a business school was selected.[18]

Interns were a valuable link to access and explore and to implement state of the art academic knowledge in technical prototypes. Over the years, strong links were established to a few expert academics and research centres which provided a platform to recruit new interns if required. Because all job offers and internships were publicised on CarCo's online recruitment platform in the internet, interns from outside this network were also able to join PMT. The incentive for interns was the opportunity to base their dissertations, or other kinds of reports they were expected to produce, on their work in

17 In Germany, internships are often integral parts of degree programmes in Higher Education. Internships are variable and can take place either in the middle of a programme or at a later stage. Additionally, students in Germany are encouraged to do their theses at the end of their degree with an external partner. Through these experiences students have the opportunity to gain practical insights in their anticipated sector to inform and pave the way for their future plans. The industry has well adapted to this system. Offerings for internships or industrial theses can be found in large multi-national corporations as well as local small and medium-sized enterprises.

18 No complete list of all interns ever contributing to the development was available but a folder on the network hard drive of PMT, used to archive dissertations and other reports submitted by students, allowed an estimation of the total number of interns working at or with PMT during the period 2005-2010. The folder contains 85 document produced by interns. Since most interns where in their final year of studies, the majority of these files comprised dissertations, "Diplomarbeiten", i.e. final year student dissertations. It is difficult to estimate whose work contributed directly to the artefact because only few state explicitly which of the several projects at PMT they were working on. Taking into account the interns found in the folder and additional interns identified via other data collection methods a list of 29 individuals was produced who worked on the artefact. Eight of those 29 interns became doctoral students themselves continuing their working with the strategic network planning application.

CarCo and to gain valuable experience for their future careers. The process of recruiting interns was an important element for methodological and artefactual developments not just in PMT but in the entire research facility. As already indicated, these cohorts of interns became the talent pool from which some future doctoral students were selected to continue research and development of the technical artefacts. Many of the doctoral students remained with CarCo after graduating, although most of them left the research group for non-research related positions in the other divisions.

6.2 Creating the artefact: NetworkPlanner, version 0

Soon after its formation the members of the Production Management Team started to investigate the research problems it was tasked to address and to identify possible solutions for. The seven months difference between the two public projects gave PMT time to conduct a review of literature and best practises. Findings of the preliminary review where gathered in a repository in the form of a slide show. Since CarCo used Microsoft's office package throughout the company, an initial repository on ideas and concepts about flexibility was stored in the MS PowerPoint format. Slides were an easy and practical way to gather information of different formats.

In the first months, when there was only the SATFAB project, the focus was researching concepts concerning suppliers, manufacturers and the relationship between the two. During the interview, Kai, the supervisory researcher referred to the repository as an interactive multimedia encyclopaedia which he titled 'SATFAB Navigator'. Indeed, name-giving was a typical characteristic of him as highlighted by other interviewees. He pushed the doctoral students in making their work comprehensible for outsiders, particularly practitioners in operational divisions. Giving prototypical artefacts a name was one method - it was also him who proposed the name for the strategic network planning system under which it became known throughout the company, NetworkPlanner as referred to in this thesis. Kai came up with many proposals to simplify the technical prototypes. It was among his ideas in the early stages to add a map as a visualisation layer to enrich the user interface of the planning system.

6.2.1 Configuration of spreadsheets

Based on the slides of the 'SATFAB Navigator' the doctoral students worked on interpreting the general concepts and methods and looking for ways to apply them in a way relevant for CarCo's manufacturing system. In the first year the doctoral students explored the field to learn about existing literature and relevant concepts. While general ideas were stored in MS PowerPoint slides, the first approaches in putting concepts into practice were attempted using MS Excel. Its calculation and spreadsheet analysis functionality made MS Excel a powerful and versatile tool for quantitative analysis. It allowed for storage and manipulation of vast quantities of data. Further features made it a strong instrument to quickly develop technical prototypes. For example, Visual Basic for Applications (VBA)[19] allowed development of automated routines and to access data and other applications external to the spreadsheet itself. First prototypical spreadsheets were constructed to formalise and quantify a manufacturing system.

Spreadsheets are ideal tools for collecting diverse sets of data and for interlinking it with each other as one spreadsheet can contain multiple worksheets. For example, one worksheet stores the bill of material while another sheet contains data on materials and products. A third sheet links to the data stored in these two spreadsheets and calculates any information demanded depending on the purpose. Following this approach a model of a manufacturing system was represented by building a complex set of interlinked spreadsheets.

Developing and elaborating meaningful and practical models of an automobile manufacturing system was one of the first challenges for the doctoral students. The doctoral students were encouraged to elaborate general models first before defining specific constraints typical for the automobile industry. Thus, the first models could have described manufacturing processes of cars, bicycles or refrigerators. This level of generality allowed thorough exploration and learning about relevant concepts to model a manufacturing system and about appropriate methods to process data for deriving meaningful information.

6.2.2 From a set of spreadsheets to a configuration of spreadsheets with a map

Gathering and processing manufacturing-related data in an innovative but generalised manner in spreadsheets was an interesting task for a researcher but not yet sufficiently interesting for a practitioner who has to deal with highly-specialised data sets and

19 Visual Basic for Applications is a programming language implemented in multiple Microsoft Office applications.

objectives. Kai encouraged the students to go beyond the researcher's perspective and to consider the point of view of planners in practice. Chris, the doctoral student working on the network-level characterised Kai, his supervisor, as someone who

> "[…] always tried to develop Excel solutions further, so that it is more generalisable, so that you can apply them as a tool. He always thought about tools. […] And he always was 'we need a tool that can be marketed well and such'". (Chris, doctoral student, interview, 9 May 2011)

It was the Kai who approached Chris and presented him a sketch of an idea where he used the graphics application Microsoft Visio to draw a map and link it to a spreadsheet. Microsoft Visio is an application for drawing diagrams and vector graphics. Being part of the Microsoft Office package, it also comprised a VBA interface and, hence, enabled rich interaction with MS Excel. What the map achieved was displaying a graphical representation of a production network. Previously, it was represented only in the spreadsheet's tabular format. The map rendered simple outlines of water, land and territorial boundaries. Further, MS Visio allowed displaying other data including notations or data about relationships between individual plants (e.g. transportation costs between two plants).

With a 2-dimensional spreadsheet a person without prior knowledge of the problem would struggle making sense of data and their relations to other cells in different worksheets. It can be tedious work to make sense of an unfamiliar spreadsheet. Furthermore, explaining contents and structures of a spreadsheet can be tricky. Presenting contents of spreadsheets to others when there is little time to introduce meta-information about a spreadsheet like the name of different columns, relationships to other worksheets etc., is a difficult task. Taking the viewpoint of the audience, the presentation of a spreadsheet does most certainly arouse the interest of a minority of people only. A visual representation, however, is easier to understand - an image says more than a thousand words - and helps making sense of a complex issue because a map is a familiar type of visualisation particular for spatial and relational data.

The introduction of a map was not immediately welcomed by Chris. Initially he was reluctant because the performance resulting from a technical configuration with MS Visio was poor and unacceptable for him. However, the potential benefit was apparent and he admitted that

> "There was an 'aha' moment". (Chris, doctoral student, interview, 9 May 2011)

A later doctoral student, John, used the description that the map was more "sexy" when addressing its effect on external people seeing the prototype (John, doctoral student, interview, 7 October 2010). For the time being Chris agreed that he would pursue this idea further but under the condition that the technical side would be improved significantly. This early MS Visio-based prototype of the NetworkPlanner was the first that combined analytical capabilities with visualisation techniques. It was to become a model for later, more elaborate versions. To distinguish this state of the technology from later, more mature states, we call this prototype the NetworkPlanner, version 0.

6.2.3 Visual representations

Extending the technical configuration by a graphical feature was in some way a departure from the previous approach. Due to the large quantities of data necessary to model a network with its numerous elements, spreadsheets can become complex configuration. For a researcher, who tinkers with these spreadsheets and its contents on a daily basis, the credibility of the configuration is a taken for granted fact. The researcher has a good understanding about the origin of data and algorithms inherent in the technical artefact. Any outsider, however, who is confronted with the artefact for the first time, does not have a prior relation to it. There is no prior knowledge except of what has been told about it either directly by the researcher or by other colleagues. Basically, the artefact would appear a black box for any outsider being exposed to it.

The introduction of the map was the most significant addition that appealed to the need of those actors without prior knowledge of the black box or the methods at work inside it. A map is a familiar instrument and transmits recognisable information about spaces and relations. An unfamiliar actor would pick up important information quickly when looking at a map. An experienced planner would immediately recognise the meaning if nodes placed on a map indicating location of plants. An edge between two nodes would also be interpreted as relationship and hierarchy within a production network. The map was the first element resembling characteristics of a boundary object that became part of the overall technical configuration of the artefact. A boundary object is defined as having different meanings in different domains but still having a common enough structure that allows for recognition (Star & Griesemer, 1989). Thus, the map functionality reduced the threshold for interaction between researcher and practitioner by introducing an element of mutual understanding. A boundary object further advances interdisciplinary interaction from the discussion about classification and morphology towards a discussion of process and function (Star & Griesemer, 1989). Although initially seemingly trivial in its technical implementation, the map helped both researchers and practitioners to reduce the epistemic gap between each other. The map expanded the rhetorical repository, the collection of technical vocabulary already acquired through previous research activities, by spatial and referential vocabulary, i.e. it was easier to talk with each other and to understand each other's perceptions about difficulties and challenges yet to overcome.

Most notably, the researchers benefited from this new capability to engage with practitioners without starting to explain basic features of their black box. This became an important feature to reduce uncertainties and to increase visual appeal when presenting the strategic network planning system to practitioners. Particularly individuals in management positions appreciated the simplicity of visual features in general. The map was just a starting point. Later, the system was supplemented by other visual representations, in particular graphs that displayed results of data analyses. Especially visualisation techniques that presented results of the complex calculations caught the attention of managers, who were looking for qualified information to make business decisions or to justify those already under way.

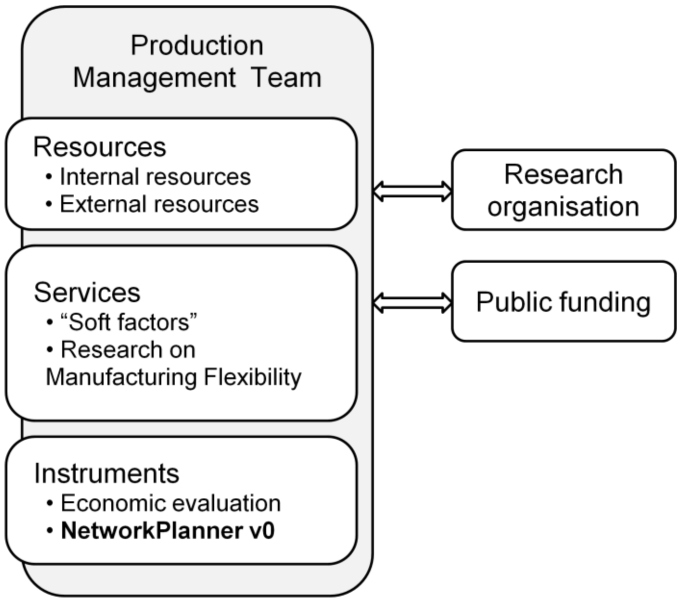

Figure 11 NetworkPlanner version 0 gains shape as practical expertise and technological capabilities increase

The additional resources from public projects allowed PMT to engage with the evaluation and development of methods to address the practical problems that strategic planning practitioners faced. The initial prototypes helped in scoping the research problem and testing different approaches towards potential solutions. They also served as medium to test different means of communicating expectations to various audiences including researchers as well as internal and external practitioners. (Bakker et al. 2012). The growing set of technological and practical capabilities inherent in PMT's kernel, i.e. the increasing number and quality of resources, services and instruments available to members and partners of PMT, enabled the team of industrial researchers to engage with other audiences that moved closer in a social manner.

6.3 Expanding the infrastructure

After the exploration stage, when basics about flexibility concepts and methods were learned and tested in the first prototypes, contact was made again with the nearby manufacturing plant of the buses division. The plant was a valuable gateway for PMT to discover needs and concerns of practitioners during the stage when the research project proposals were drafted. Yet again, the plant was approached for collaborating with PMT members in scope of their flexibility research. The local practitioners responsible for production planning were willing to work together with the researchers to co-develop methods and to validate them using their business cases. In return the researchers supported them in doing some of the calculations and evaluations required for their ongoing projects.

6.3.1 Gaining practical expertise and elaborating the prototype

A challenge in early collaborative engagements between researchers and practitioners was the cultural difference. Although both parties worked for the same company, they did so in fundamentally different functional areas characterised by different objectives and modes of operation. Particularly in the beginning, PMT's work on flexibility was based on a systematic approach that underscored generalisability and theoretically solid methods. In contrast, practitioners tend to follow a pragmatic and practical approach typical in a business environment. This divide was apparent in the difference in methods applied to solve problems. Despite having conducted preliminary research about the needs and specifics of practitioners, the researchers yet had to work with abstract problem cases. In contrast, practitioners in the plant had to deal with concrete cases which were driven by short-term objectives and affected by uncertainties. While general approaches might be helpful to explain to some extent the complexity of processes and dynamics taking place in the plant, the social setting of local actions rendered every local situation differently.

A core achievement in working with practitioners from the nearby plant, was to acquire data for real-life cases and, even more so, to get exposure to their mode of operation. Regarding the mode of operation, the strategic planners of that division were complying with standards defined centrally by respective authorities within CarCo. In particular, standards of financial assessments were set by controlling departments. Financial controllers are responsible for gathering financial and non-financial information about the performance of the organisation to inform and support managers in their decision-making process. The profession of financial controllers uses standardised practises to gather and to produce relevant data. There is no right or wrong practice, but a range of methods depending on the sector, functional area, level of aggregation etc. Thus, every company and functional area develops an individual set of practices that proved useful and workable over time.

Working with strategic planners from the nearby plant allowed PMT members to learn in detail about these practices. Further, this experience was encoded and implemented in the prototype to produce various standardised key performance indicators, which are commonly used throughout CarCo and to some extent expected by decision makers. In the course of these engagements with strategic planners, the researchers undertook analyses on behalf of the practitioners, while the latter evaluated the results. For a technical software prototype it is typical to have bugs, i.e. errors in the code of a software programme. The practitioners checked the results and hence helped spotting errors and de-bugging the code.

This loose but fruitful collaboration was maintained for several weeks as long as the practitioners were in need for another pair of helping hands in their projects. When the projects were finished, the collaboration ceased. Later, when another doctoral student tried to reinstate the interaction, he was rejected because of a change in the planning premises of the division. At some point, the senior management made a political decision in favour of a harmonic capacity utilisation throughout the division's manufacturing plants. Instead of optimising the best production programme, it was fairly distributed between the two plants. In other words, the objective of the strategic planning department changed to the extent that there was no more need for a system as the NetworkPlanner.

6.3.2 Gaining legitimacy through exposure to external audiences

Enrolling practitioners from the buses division was eased by previous interactions and by the proximity of the plant. Nevertheless, it remains a delicate undertaking to establish collaboration even when such mitigating factors are at play. Originally, PMT's motivation to seek out business opportunities stemmed from its financial problem to generate income to fill its financial gap. In time, other reasons for interactions with operational departments arose. The longer the development continued and the artefact matured, the more important it became to find a final host for a sustainable long-term solution. The public project granted so much funding only. It was for PMT to arrange for a sustainable situation after funding ceased. Engaging with the buses division was the first attempt to find a host. The yet immature state of the artefact and the weak demand for it in the buses division deemed this solution insufficient. Thus, the search continued.

Irrespective of other divisions, there is always an opportunity to approach actors outside of CarCo's boundaries. Technology firms, such as Cisco, Intel or IBM are examples of how research outputs can go both ways in an open innovation model (Chesbrough, 2003). They acquire interesting technology from outside to integrate it into their products. At the same time, they do not hesitate to sell or license their in-house developed technologies and research results to other firms, if they cannot make use of it to gain a competitive advantage or if there is a worthwhile business opportunity. The doctoral student, Chris, had presented his work at a conference, when he was approached by a senior manager from Siemens, a German multinational engineering and electronics company. The manager was intrigued by the capabilities of the artefact at that time and offered to either buy the artefact or at least to license it to address a current difficult business challenge he was facing. However, CarCo research management rejected the offer as the open innovation model was not a strategy pursued in the research group. However, this incident caught the attention of research executives and put PMT research activities in the spotlight. This indicated a slight shift in the senior management's thinking about the research in flexibility conducted by PMT. Paraphrasing this shift in thinking among senior research executives, Chris indicated how sparsely PMT's activities were appreciated by them in the beginning:

> "Oh, maybe this is not just a student's science fair project". (Chris, doctoral student, interview, 9 May, 2011)

This encounter with the Siemens manager can be broadly interpreted as a trial of strength where an authoritative representative of an interest group is persuaded to accept claims made by a spokesperson to be objectively valid (Latour, 1978, p. 78). Presenting preliminary results and a prototype at a public conference, an opportunity facilitated by the fact that this was a publicly funded project, exposes previously private research to external public examination. A positive response like the approval by other researchers, or practitioners as in this case, confirms the objectiveness and legitimacy of a research direction and a potential worth for others. Rejecting someone else's research, however, denotes it to the work of subjective individuals who do not have anything important to contribute to the community. Thus, the presentation of the artefact and the research approach in general to a public audience was a successful trial of strength for PMT.

Not every trial of strength results in a clear case of success or failure. Another such trial was the anecdotal confrontation of PMT with another research team which could have ended PMT's approach right there on the spot. There was a team in a research facility in Berlin doing similar research on production networks but drawing on techniques of simulation as compared to PMT's approach based on mathematical optimisation. Upon learning about PMT's research undertaking, the other team tried to intervene because it felt being under threat by PMT. The Berlin research managers demanded for PMT to cease their research justifying this with the claim that research on manufacturing flexibility was under their jurisdiction. Indeed, the decision to cease PMT's research on flexibility in production networks had been confirmed by the research management in Ulm. However, Jürgen recalled, the order to abandon this branch of research was just

> "not executed immediately". (Jürgen, team leader of PMT, focus group interview, 12 December 2011)

He further explained:

> "They had the strategically better levers and they said 'this is our core subject, you are not allowed to continue'". (Jürgen, team leader of PMT, focus group interview, 12 December 2011)

Their strategic lever was that the managing researcher had a higher rank than the Kai, who represented PMT during that confrontation. Organisationally, a situation such as this one would have usually been resolved by abandoning the subject and allocating resources to another project. This is relatively easy in cases when there are only full-time employees involved. However, because the technological project involved doctoral students, a simple reallocation of resources and employees was no viable solution, at least not without jeopardising the fate of the student's doctoral dissertation. Thus, a compromise was made along the methodological divide between the two research teams. Because simulation methods was the field of expertise of the Berlin team, it was decided that PMT's doctoral student in Ulm would be allowed to continue his work only if he would not cross this methodological line. For PMT and the doctoral student, this compromise was easily acceptable. Their research tended to lean towards the specialisation in optimisation methods, anyway. And after probing this subject previously themselves simulation was found not to be an interesting branch of research for their set of objectives.

Despite the methodological differences between the two research teams and the success in averting the conflict, the episode highlighted the weakness of PMT's political status. At this moment it was secondary which method was superior. A political decision weighted more than any technical argument. If it was not for the peculiar configuration of PMT's research infrastructure, which generally consisted of a mix of full-time employee, doctoral students and interns, this claim for jurisdiction by another department could have ended the development of the artefact. An interpretation of this incident allows drawing the conclusion that the social-technical configuration and particularly the diversity of the research infrastructure proved stronger than the political power of another department. Jürgen compared this incident with a wave under which they had to dive under:

> "For a moment you hold your breath and wait for the wave to pass over you. As soon as the threat has passed, you surface again and continue your work". (Jürgen, team leader of PMT, focus group interview, 12 December 2011)

After this particular trial of strength, PMT was confined to a narrower selection of future methodological choices. However, as they ruled out this path anyway, it only reassured their determination to focus on optimisation methods.

6.3.3 Soliciting business and growing the network of contacts

The Production Management Team was different than other research teams in that it was a fundamental requirement for its members to seek collaboration with others to generate income to fill a financial hole in their budgets. For Kai, the supervisory researcher, and Chris, the doctoral student, this detail was not much of a burden on top of their everyday work activities. Several interviewees highlighted their skills in dealing with other actors and that both became a good team in presenting their team's work and particularly the potential of the artefact under development. Especially Kai's skill to present a subject to any audience was singled out. Patrick, the manager of the department which PMT was reporting to, recalled a particular anecdote to describe his skill set:

> "[Kai] was a gifted marketing person and a genius in some way. When we were driving from [the research site] to [a production plant], we had no slides with us. I was driving and he made slides and presented them convincingly. And I was sitting on hot coals thinking: 'Gosh! We have not prepared anything'. 'I will take care of it', he said. A PowerPoint artist; and he could put things across convincingly". (Patrick, former head of the research department, focus group interview, 12 December 2011)

Confronted with this term during the interview, Kai rejected the notion of marketing or selling in general as "misleading" (Kai, team leader PMT, interview, 22 June 2012). From his point of view it was a combination of empathy and "reasonable collaboration" (Kai, team leader PMT, interview, 22 June 2012). It was important to understand the requirements and problems of the user side in order to progress collaboratively. Also, he did not miss to point out that "a bit of fun also generates the motivation, more freedom" for successful social interaction (Kai, team leader PMT, interview, 22 June 2012). This strong personal trait, characterised by a collaborative and transactional approach, in contrast to an authoritative regime not uncommon in a hierarchical and bureaucratic organisation such as CarCo, contributed to arousing curiosity of various audiences and eventually to a successful acquisition of new users. His skill was very valuable when he teamed up with Chris to introduce the technical prototype, the NetworkPlanner, to potentially new users.

The acquisition of a new user followed a common pattern with three general stages. Firstly, a user working on projects with production network-relevance had to be identified. Previously, PMT identified such users by pro-actively approaching relevant departments. But thanks to an expanded network of contacts and collaborators within CarCo, PMT members were informed about interesting projects which were under way elsewhere. For example, in one case PMT was informed about an important project by the partner of one of the doctoral students. She was working at that time for CarCo's internal engineering consultancy. In this position she learned about many projects taking place in different places throughout CarCo.

Secondly, a meeting was arranged with members of the targeted department, ideally including the manager responsible for granting the permission for collaboration. It was a situation like that, when the complementary duo of the supervisory researcher and the doctoral student could make use of their combined presentation skills. An intern remembered one occasion when he witnessed their performance at one meeting with potential users. The supervisory researcher would deliver a general introduction about the kind of projects managed by PMT and the expertise available in the team. The doctoral student would then take over and introduce the planning tool. Their performance was so persuasive, as the student described, particularly because both performers convincingly conveyed the message, that they were strong believers in the value of the technical artefact and even more so in its capability to solve the problems which the target group was dealing with. Of course, the artefact was up for the task, so they assured. It would only take a few minor adjustments. Both the researcher and the student exaggerated the existing capabilities of the artefact to accommodate the requirements of the users and to raise their expectations. Thanks to a strategy of translating the needs and requirements of their audience generously in favour of their abilities, they won the trust of their audience and got the opportunity to demonstrate that they truly were able to deliver what they promised.

Thirdly, once they had their foot in the door, they would continue interacting closely with their clients to make sure that the users were happy with their services throughout the engagement. Keeping up users' interest was a critical and important concern. Kai referred to this as an "art" to keep them interested despite the bugs and raw results in the beginning (Kai, team leader PMT, interview, 22 June 2012). He emphasised that it is not always the practical and technical value that was critical. Social factors were also carefully catered for. For example, individual users were invited to the research facility for focused discussions or knowledge sharing sessions. Alternatively, the researchers visited the users and spent a few days in their offices to get to know the business cases and problems first hand. This high level of openness and engagement reduced the cultural distance between researchers and practitioners and facilitated sustaining long-term relationships.

The collaboration with the buses division followed this pattern before it was ceased due to a political decision. This was not too much of a setback for PMT because, by the time, the cars division had already indicated their interest in learning more about the capabilities of the NetworkPlanner. This division was the largest of all divisions in CarCo. Having gained substantial insights into real business cases and, thus, having improved the artefact correspondingly, the cars division was a welcome opportunity to test the artefact, which still was just a prototypical configurations of appropriated technologies built by an engineering student, in a new business environment.

6.3.4 Applying the NetworkPlanner in a new social setting

At the time, when attention switched from the buses division to the strategic planning department the cars division, the technical artefact was a complex construct of multiple worksheets interlinked with each other via numerous and complex formulas. Further, the configuration was extended by a map functionality based on MS Visio. On one hand, this resembled an improvised but operative artefact capable of solving highly specialised business cases in the domain of strategic network planning. On the other hand, however, its downsides were manifold due to its exploratory and opportunistic style of development. Improvisation comes along hastily integrated components, inefficiently coded algorithms, makeshift workarounds and unfriendly user interfaces. As long as the prototype was operated by an expert, of which there was only the doctoral student who assembled the configuration, it was a useful artefact. Except for Kai and fellow doctoral students in PMT, the NetworkPlanner, version 0, posed a puzzle for everyone else consisting of multiple worksheets with a map attached to it. As soon as one tried changing a parameter, the chance that the configuration would just collapse was very likely. In other words, it was basically useless for non-expert users without the concierge-like service offered by PMT. For this reason, Jürgen, the later team leader of PMT, referred to this version 0 as a demonstrator, rather than a prototype.

The opportunity to work with the cars division emerged about a year after Chris started his doctoral work on the project. It was not only the opportunity to work with a new customer, it also marked the appearance of the first intern who was under Chris's supervision. She was an industrial engineering and management student joining PMT to do her final year dissertation and she was recruited to deal with the new cars division collaboration. The strategic planning department in the cars division enquired for PMT's participation to demonstrate the capabilities of their artefact, the NetworkPlanner, version 0. PMT readily complied with the request and allocated the first intern to work with the planning department. She was as a representative of PMT and served as the bridge between the research group and the strategic planners who were located an hour's drive away at the headquarters of CarCo.

With a helper on-site, the Chris could assign complex tasks to her. Her close distance to the customers allowed her to directly interact with the strategic planners to collect relevant data necessary to operate the NetworkPlanner. Although Chris also spent much time with the planners of the cars division, she was a valuable assistant to collect data and to interact with practitioners to clarify issues and solve emerging problems on the spot. Her participation sped up data collection and helped the researchers to come to terms about the specific requirements of the cars division quickly in order to adapt the NetworkPlanner appropriately.

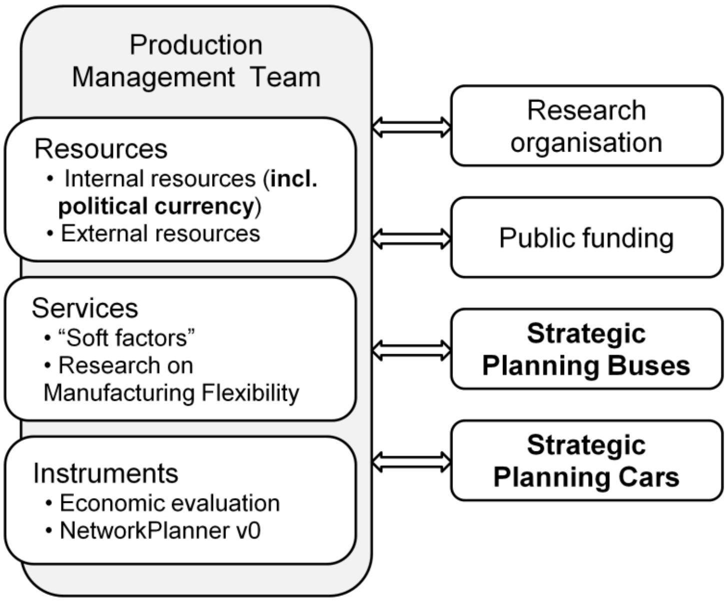

Figure 12 Additional resources from internal departments also bring new political currency to the kernel

Thanks to the engagements with the two strategic departments and the brief interaction with external audiences, i.e. the Siemans manager, PMT was granted access to new resources to expand the kernel. Although the financial reward was welcome, PMT gained immensely from the political currency that was attached to the internal funds (see Figure 12, changes to the previous kernel figure are highlighted in bold). However, despite the effort, this collaboration eventually turned out another dead end.

MS Excel was a common application allowing for the development of complex tools for quantitative analysis of large quantities of data. Strategic planners made extensive use of such tools and therefore were skilful experts in creating their own purpose-built solutions. The strategic planners applied the NetworkPlanner in a project to learn about its capabilities and to compare its results with an internal MS Excel-based solution developed by them. Although the actual results produced by the NetworkPlanner were useful, it was found that the benefit to implement the NetworkPlanner did not justify the overall effort. The financial commitment alone, comprising a significant six-digit figure, was too high a threshold to continue any attempt to adopt the artefact. Despite another setback, the PMT researchers were not discouraged to continue their work since they were sure that strategic departments were definitely the right location for the NetworkPlanner. It was just that the circumstances had not been in favour of the researchers so far.

While a political decision had rendered the buses division unfit, the strategic planners at the cars division found that the NetworkPlanner was providing no added-value in comparison to the MS Excel-based methods they got accustomed to. The reason why the NetworkPlanner did not provide any added-value compared to its MS Excel counterpart was that the business case it was used for did not comprise a minimum level of complexity. The advantage inherent in the application of the NetworkPlanner was the increasing integration of higher order mathematical methods drawn from the field of operations research. To take advantage of these effective methods it required a project that posed a challenge with a minimum level of complexity involved. Here, complexity refers to the interconnectedness of high numbers of factors including products, production plants, markets, and other parameters. At the time of the encounter with the cars division, the planners were dealing with problems which yet were below the minimum level of complexity that would justify the application of the NetworkPlanner. It does not mean that the planners were dealing with simple problems. Far from any such claim, their business cases represented complex problems on multiple dimensions. Nonetheless, the NetworkPlanner was deemed to be of no use for the cars division.

Again, the situation was not in favour for the NetworkPlanner. Despite having a large and globally operating organisation, the cars division was organised in a way that all relevant problem cases could be analysed adequately relying on bespoke MS Excel solutions created by the strategic planners themselves. The engagement with their customers ceased once again and PMT had to move on searching for another potential sponsor for their development elsewhere.

6.4 Elaborating the artefact – NetworkPlanner, version 1

Similar to the experience with the buses division, the interaction with strategic planners in the cars division was, although unsuccessful after all, a valuable opportunity for having had access to a real business case and social environment. The artefact was not adopted but it proved to be a useful and appropriate tool for evaluating production-related network projects and providing meaningful results to inform decision-makers. Viewing the experience as a failure in finding a host for the artefact is one possible interpretation. But as an experiment in the field, it was clearly a success case that advanced the project to prepare it for its next business case application in the trucks division.

6.4.1 Improving usability and visual appeal

Although finding a host was an important objective, it was not yet a problem PMT had to address immediately. The collaboration with the cars division lasted from mid-2003 to early 2004. Funding from both public projects kept the research on the artefact afloat but the end of the SatFab project was on the horizon in December 2004.

In mid-2003 efforts were directed at improving the technical foundation of the artefact. The artefact to that date was mostly an improvised configuration developed opportunistically and shaped strongly by experiences made at different occasions and under varying circumstances. In fact, Kai, the supervisory researcher, indicated that Chris was not really into doing technical work on the artefact. Chris was eager to delegate this task to another intern who was recruited in August 2003.

A chemical engineering student from Spain was looking for an opportunity to do his final year dissertation somewhere in Germany. He found the description for the internship interesting because the requirements demanded experience and skills in programming. Chris recruited his second intern and delegated all technical responsibilities to him in order to free himself up for working on methods and dealing with practitioners at the cars division at that time.

At the time when technical development was delegated, the artefact was a configuration made of MS Excel spreadsheets and a MS Visio-based map. The objective was clearly set on finding a way to improve the technical configuration and, most importantly, the visual interface of the artefact. In hindsight, Ricky, the former intern from Spain who was working in the production programme planning department of another car manufacturer at the time of the interview, realised the importance of improving particularly the visual appeal of the artefact:

> "I can realise, after the years, in order to have success in this kind of tools, it has to be like everything was like all top things in the world, that it has to be good and it has to look good. When another manager in the company would hear about [the NetworkPlanner] and it would be presented to them, if it was easy to use and a nice visualisation it would be better. So I think that is the point they were taking that much effort in doing this visualisation". (Ricky, technical intern, interview, 18 December 2012)

Thanks to the work of the intern, the integration of the map was subsequently improved and enriched by further functionalities and more interactivity. User-friendliness became an explicit requirement besides the never ending improvement of the code and methods. However, at some point, the limitation of MS Visio became apparent. It was an application to draw diagrams which can be enriched with a limited degree of interactivity. But not to the extent demanded by the researchers. Therefore, a professional software firm was commissioned to support the intern's technical work by developing a bespoke graphical user interface (GUI). The bespoke GUI had the advantage to provide a level of interactivity unachievable with a MS Visio-based solution. The intern emphasised the connectedness between the map and the spreadsheets as one of the core functionalities. For example, a factory created by clicking on the map appeared automatically in the spreadsheet. Such and other automation features made the map and thus the artefact more intuitive and easier to be used by non-experts, at least on a superficial level. This was much progress compared to early states of NetworkPlanner, version 0. Indeed, the new development drive, which saw the substitution of components by more effective and integrated modules, changed the face and capabilities of the NetworkPlanner. This greatly improved artefact, in particular the new GUI and its more elaborate integration, is what will henceforth be referred to as the NetworkPlanner, version 1.

6.4.2 Further configuration of concepts and methods

Among the concepts integrated in the NetworkPlaner was the Gozintograph (see Figure 13). This concept exemplifies the kinds of ideas that were being implemented in the artefact over time. The Gozintograph represents the production structure of a manufacturing process (Loos, 2001).

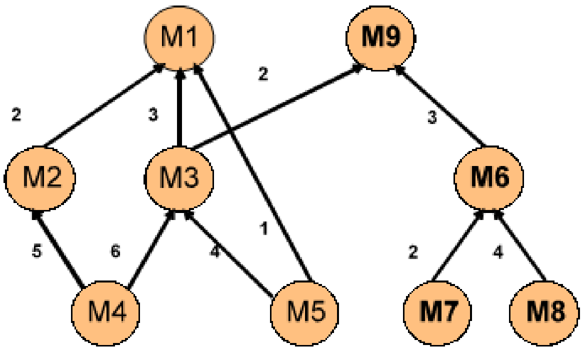

Figure 13 Gozintograph - graphical representation of production structure of a manufacturing process (Loos, 2001)

It organises the bill of materials by displaying what number and what type of material ‘goes into’ (from which the term ‘Gozinto’ is derived from) what product. Individual concepts, like the Gozintograph, are informative but limited in its application. It is the integration and combination of numerous concepts and methods which gradually increased the capabilities of the prototype. For example, the significance of Gozintograph was strongly enhanced by combining it with sales forecasts. Forecasts are a relevant type of information regarded as future demands by strategic planners in their network-related projects.[20] Knowing or forecasting how many products will be sold in a particular period allows calculating the demand on materials for the same period. These and other calculated figures allow planners to evaluate different scenarios and network configurations.

20 Car companies forecast sales figures by drawing on various sources including estimates reported from their car dealers. Salespeople are closest to the customer and therefore are among the best to estimate future sales performances by evaluating recent sales figures in the light of current circumstances and potential future trends. Forecasts are collected by a central department in CarCo and enriched with other data, e.g. product life-cycle information, before the figures are made available to other departments like strategic planners. Sales forecasts are represented by concrete figures which are split up according to markets. A market can be a single country or a region comprising several countries. Although these heuristics to estimate future demand are not particularly reliable - an average difference between forecasts and actual sales was measured to be about 40% (both + and -) at US car company General Motors (Jordan & Graves, 1995) - it is a methodological approach to derive a figure to work with. The German car company BMW’s horizon for long-term strategic planning is twelve years (Fleischmann et al., 2006). For a network analysis project at BMW, thus, the demand for a product under investigation would be fixed for the twelve year planning period.

A network analysis comprises the evaluation of not one but of numerous network configurations and scenarios. The level of complexity jumps significantly when flexibility is the subject of a network analysis. An analysis of low-level flexibility in a solitary production structure, i.e. one product is produced by one factory only, can be handled by a spreadsheet solution with confidence as practised at the cars division at that time. The advantage with solitary production structures is that the amount of potential configurations to investigate is manageable. However, when a higher level of flexibility is investigated, a manual spreadsheet analysis based on conventional methods can become a balancing act where the capabilities of an individual strategic planner are stressed to her limits. Complexity of a network analysis increases exponentially the more flexibility is taken into account. Basically, conventional spreadsheet solutions developed by strategic planners, who are experts in using spreadsheet applications, are not scalable to meet the requirements of complex network analyses. This is where methods of operations research as promoted by PMT promise tailored solutions.

Two approaches to solve complex production network-related problems in the field of Operations Research were described in the anecdote about the conflict between PMT and another research team in Berlin. PMT chose to investigate methods of optimisation while the latter researched simulation as a method to analyse a production system.[21] First experience with simulation was gathered by PMT with an intern who worked on a simulation-based approach to investigate potentials for cost reductions in a press shop network. Supervised by one of the full-time researchers in PMT, this student was employed almost at the same time as the three doctoral students. The early experience with simulation techniques informed the decision to pursue optimisation methods as the way to go forward in the subject of flexibility in a production network. Getting to the

21 Optimisation and simulation are distinct methods to address problems of complexity with different approaches. The method of optimisation, e.g. linear programming, requires a descriptive model that abstracts reality into a function with constraints and variables. Solving a linear function allows to determine an optimal solution, e.g. minimum costs or maximum profits. For a simulation, a behavioural model is developed with a set of rules to simulate different behaviours and states of a system. Simulation allows investigating unpredictable events and thus is useful for a situation where a system is not understood entirely and an analytical, descriptive model is difficult to obtain.

point of having a functioning optimisation module integrated in the NetworkPlanner was a complex undertaking, however.

6.4.3 Developing an optimisation module for the NetworkPlanner

The cornerstone for PMT's strong focus on operations research, in general, and on optimisation methods, in particular, was laid by the first generation of doctoral students working on the subject of manufacturing flexibility. After overcoming, firstly, technical challenges of designing a working prototype and, secondly, social challenges of finding cases for application and extensive learning, Chris intensified efforts to increase the methodological capabilities of the artefact. While an intern was assigned each to deal with the technical and social challenge, a further two interns were recruited at the end of 2004 to address the methodological challenge. To distinguish these two interns by the order of recruitment, they will be referred to as the first OR intern and the second OR intern, respectively. Since we conducted an interview with the first intern, we will refer to him also by the name Jörg.

The two interns were not recruited at the same time but their placements overlapped to large parts so that one student could inform and expand on the findings of the other. A major contribution is credited to Jörg, the first OR intern, whose assignment was to test different optimisation methods to identify a best practice approach for the kind of problem dealt with by PMT and its customers. His recruitment was a good example for the teamwork between the doctoral students Chris, who focused on the network-level, and Matthias, who focused on the factory-level. Initially, the first OR intern applied for a job offer posted by Matthias. However, when Jörg embarked on his assignment, he was given a choice to work on a different subject with Chris. Because the specifics of working on methodologically-oriented rather than a technically-focused subject were more appealing to Jörg, he gladly accepted the offer and switched to the other topic. For Chris this was a lucky coincident, for he was successfully establishing links to strategic planners of another division, the trucks division, at that time and he was in need for interns to take on the incoming workload. At the same time PMT also engaged in a further undertaking with practitioners from the buses division again. The second OR intern was assigned to work with the buses division. It was after this project that buses division made the decision to harmonise its production programme to equalise capacity utilisation among its plants. This move basically terminated the need for any network optimisation as offered by the researchers. Meanwhile, PMT was commissioned by the trucks division to support them in conducting a network analysis to determine the future production programme of a follow-up product. The trucks division was the second largest business unit of CarCo and, thus, a highly-lucrative customer.

To this point at the end of 2004, the artefact was not yet capable of deriving mathematically optimal solutions based on optimisation methods. This capability existed by means of a manual capability of the researchers involved but its integration into the artefact was yet to be achieved. So far, the artefact was capable of managing relevant data of network-related problems and of representing it practically on a map. But its actual data processing capability was rudimentary and yet not close to what was promised to practitioners. However, the roadmap for expanding methodological capabilities was set and Jörg was assigned to work on the methodological challenge posed by the new network problem from the truck division. One of his first tasks was to identify the best methodological approach on developing a descriptive model to represent the network problem. Only when a problem is abstracted into a descriptive model, can it be solved. However, research on manufacturing flexibility in the field of OR was still developing at that time and the availability of appropriate models was scarce.

It was the 'seminal work' by Jordan and Graves (1995) that marked an important milestone in that subfield of OR that focused on production networks (Volling et al., 2013, p. 250).[22] Their model became a template and inspiration for other researchers to apply and adopt their approach for similar problems in various industrial contexts. PMT's researchers also recognised it as an interesting model to address the kinds of research problems they encountered in strategic planning departments. Volling et al. (2013) also indicated that, over time, PMT grew to a significant player in the application of OR methods in the field of global production networks.[23] But in 2004, when OR was

22 Jordan and Graves developed a descriptive model to represent a product-to-plant assignment problem and to prove that even a limited state of flexibility already yielded many advantages of a fully-flexible production network in contrast to a solitary strategy production system (Jordan & Graves, 1995).

23 Volling et al. (2013) reviewed research on OR methods and applications in the domain of global production systems. Among others, this review presents a table with 27 publications including both doctoral dissertations by Chris and Matthias. Their listing

just being explored at PMT, there was only one intern struggling with developing the first model. Supervised by Chris and supported by Matthis, the first OR intern learned from available models and used them as templates to incrementally create a bespoke model representing the business problem encountered in the trucks division. The descriptive model gradually grew from a relatively general model to a complex model that incorporated more and more of the factors and details relevant in the analysis of a production network reflecting the specifics of the trucks production system.

While the problem of modelling the business problem was incrementally solved, another challenge was to run algorithms efficiently. With a descriptive model and with the support of a calculator, one can solve a particular problem using pen and paper. But a network analysis comprises the investigation of numerous configurations with varying sets of input parameters defined as scenarios. Each configuration would require completing one calculation procedure and would result in determining one local optimal solution under the given parameters. A network analysis increases in robustness the more qualified configurations are analysed and eventually compared with each other to find a solution that meets a diverse set of requirements. In the end, a strategic planner aims to find a global optimum among all the locally optimal solutions derived from analyses of single configurations and scenarios. The robustness of a network is measured in its ability to cope with uncertainties of markets, currencies and other socio-political circumstances. A production network that generates profits in cases of both high and low demand is more robust than a production network that generates higher profits in cases of high demand and higher losses in cases of low demand. Undertaking such an extensive network analysis manually would be not only an uncomfortably monotonous activity but also one prone to human error. The purpose of the NetworkPlanner was to automate these calculations - a capability widely promised by Kai and Chris to their customers, but which yet was to be delivered. Having a model of the problem, or at least being on a promising track, therefore, was just one of two problems solved.

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indicates the significance of their final research outcomes in this particular niche. The list also comprises works of five other doctoral students who worked with PMT at later stages. For the sake of completeness it also is mentioned that two other publications listed were lead-authored by former interns that worked with PMT.

Once again, Jörg, the first OR intern was not required to re-invent the wheel but to look out for existing technologies. Several commercial software solutions were available on the market to fill this gap. These software solutions, so-called solvers, comprised algorithms to solve mathematical problems, which are formalised in a generic form readable by the solver. Three software providers were short-listed and contacted to get more information. Some vendors visited PMT to discuss the requirements in person. Selecting one particular vendor and implementing its software solution was an important milestone in the overall undertaking, as Jörg recalled:

> "I think this was a crucial point, that I eventually compared three different vendors to automate the problem-solving. So, I was able to entirely focus on the mathematical description of the problem. Eventually, I found a black box which I could feed and which would produce a solution in the end.[…] Subsequently I mostly focused on modelling the problem and on gradually increasing the complexity of the model. That means, to include more and more restrictions, customs, multi-level supply processes. That means going from the simple model to a more complex problem". (Jörg, first OR intern, interview, 13 February 2013)

After finding a solution to the second problem and developing a solver module for the artefact, Jörg conducted performance tests to find out about the limits of the solver. Although computer capacities are immense nowadays, an ineffectively modelled problem can easily crash a solver.[24] The developing and testing went in parallel to the work on the actual business problem posed by the trucks division. Users were encouraged to install the software at their workplaces to use it themselves, but typical problems of early stage applications rendered its use problematic because numerous errors continuously interrupted the work flow. Chris as well as the interns frequently provided customer support services when users experienced problems with the NetworkPlanner.

The successful development of a functioning model by the first OR intern was significant in enhancing a strategic planner's interest in the NetworkPlanner for it allowed automation of a usually complex problem. The automation of this part of the strategic

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24 A crash of the solver is a welcome response because it immediately terminates the automated process. Otherwise it could end up computing the problem in a seemingly endless loop or at least for such a long time that the costs of time render the model useless.

planning process unfolded prospects previously unthinkable for practitioners involved in the process. For PMT this achievement was an absolute necessity because after many sessions of promissory meetings with potential users, the team eventually was able to deliver a technology that met the high expectations of users, at least on the methodological side of the artefact. It the beginning it was yet only a feasibility study embodied as separate prototype developed by the first OR intern. The next step was interweaving this methodology as an OR module into the artefact. However, parallel to the methodological development, a second major technological development regarding the artefact was under way.

6.4.4 Poor performance

From about the end of 2002, when the doctoral students began doing research on manufacturing flexibility, up to mid-2005 the artefact endured incremental as well as radical changes. Spreadsheets were created, elaborated and supplemented by a map representation. The map was later replaced by a GUI with enhanced interactivity features. Although the artefact became clearer in its shape, the overall performance remained unsatisfactory. Spreadsheets were the format in which data was stored and manipulated so far. The advantage of MS Excel as a technical foundation was its availability throughout the company and its ease of use, even for more complex applications. This is practical for an experimental stage where prototypical development requires much tinkering and improvisation. But a spreadsheet is not the best technology to manage data efficiently in the long run. A spreadsheet is like a plain playing field on which data can be dumped and handled with ease. But the more data is amassed and linked up with each other the less dynamic and manageable it becomes. Besides a separate editor for programming in Visual Basic for Applications, the MS Excel environment does not offer much specific functionality to a software developer. Generally, MS Excel provided a rich set of functionalities but, overall, its performance was lacking. What was missing was an ability to deal with data flexibly and efficiently. This was a functionality provided only by proper database management systems. Particularly in light of the need to use an external solver application, it became obvious that MS Excel was a poor foundation and that it turned to a reverse salient, a subsystem that delayed the progress of the overall system (Hughes, 1983). Thus, the technical foundation of the artefact required a redesign, it was found. MS Access, another software application from the Microsoft Office Package, was selected to replace MS Excel and to serve as the underlying database management system.

As of that date, Ricky, the intern from Spain who was responsible for the technical development, had already graduated. However, he had continued working with PMT as a self-employed technical consultant.[25] This was by far an easier alternative to maintain a working relationship than attempting to employ them directly. Budgets were tight and new faces appeared mostly due to organisational reshuffling rather than new recruitment. Indeed, of all the doctoral students working with PMT only one student was ever employed after his funding period ended. Overall, only three interns remained with the project for a period longer than 12 months. All three of them were responsible for the technical side of the artefact, i.e. coding basic functionalities, developing data management and processing components, expanding data analysis features, improving usability etc. Two of these three interns worked with PMT for two years, one of them part-time as he had continued studying in the city where the research facility was located. The other intern remained with PMT for 18 months. This latter intern, an industrial engineer named Karl-Heinz who will also be referred to as the technical intern henceforth, was the successor for Ricky, the intern previously responsible for the technical development. Their work overlapped for less than four weeks giving the successor less time to be trained about artefact than he was comfortable with.

The new recruit was assigned to swap the spreadsheet foundation with a proper database, MS Access in that case, and to reintegrate the other existing components. Karl-Heinz summarised his task as follows:

> ”[m]y main focus was, principally, to turn this spreadsheet-construct into a database, which was underlying the GUI, and, at the same time, to integrate all calculation and optimisation algorithms into the Access database, and, when all the data was collected, to shape it in a way that the Access database could be regarded as a second module in which data analyses could be undertaken”. (Karl-Heinz, technical intern, interview, 7 June 2012)

25 After graduation, interns could not be employed under the same conditions. To keep them involved as long as necessary, and as long as they wanted to stay involved, they were commissioned as self-employed consultants.

Another task he inherited was to continue overseeing and coordinating the work on the GUI which was still under development. Generally, he perceived the state of the art of the technology as unfinished, mostly because the integration of the different components was not tight:

> "Well, it was not really mature. It really was only the ideas which existed in the minds of [Chris] and all other OR experts; somehow represented by Excel spreadsheets which, linked up with each other, resulted in a fairly mazy construct for an outsider. Well, in principle it did deliver results, but not applicable for everyone". (Karl-Heinz, technical intern, interview, 7 June 2012)

It is of little surprise that Karl-Heinz, the artefact appeared somewhat chaotic when he glimpsed at the interiors of the NetworkPlanner. Taking into account that his predecessor had to deal with ever changing early-state components, the GUI and the optimisation module, it was obvious that the state of the artefactual configuration mirrored the large extent of tinkering and improvisation. The slightly easier start, from which the new recruit started off, was that by now an understanding about a dominant design for the artefact had emerged. A good design depends to large extent from demanding users who continuously push the designers and engineers to deal with their peculiar requirements. A robust design, in particular, goes further and accommodates demands of yet non-existent but anticipated requirements (Gardiner & Rothwell, 1985). The NetworkPlanner acquired over time a fairly good and increasingly robust design by having regularly been exposed to problems in different user locations where the problems encountered were similar but different in details – a learning process termed as Social Learning (Williams et al., 2005). All the effort invested in working with various users had paid well off in terms of gaining a diverse set of knowledge from user interactions. This continuous social learning process was characterised by tight and yet flexible intervowenness of actors, spaces and resulting improvised problem-solution-configurations. Although the overall result of the social shaping process was an unfinished and buggy artefact, it was, nonetheless, a bespoke solution for a tiny but needy and important niche in a large organisation. Putting all together to a neatly integrated configuration was the desirable objective posed to Karl-Heinz, the new technical intern.

6.5 Embedding the artefact in a new social setting

Around the end of 2004 and the beginning of 2005 was a period with important achievements and events. The methodological approach was significantly substantiated and a redesign of the technical foundation was under way. But another trail of events was just about to unfold thanks to the involvement of the trucks division. This division turned out to be the home for the artefact, which the PMT researchers had been hoping and looking for. It later claimed ownership over the intellectual property of artefact and engaged in funding and pro-actively promoting its diffusion throughout the company. Understanding the reasons for this intense engagement requires a brief historical analysis of the trucks division and especially of the departments housing its strategic planners.

6.5.1 Pilot project at the trucks division in Team A

Previously, the work of an intern was reported who successfully developed a descriptive model based on the production network of the trucks division. His participation on the project was made possible because PMT successfully negotiated access to strategic planners at the trucks division. This negotiation process was not at all straight forward but very much a hard-earned achievement. In the interview, Chris remarked that it was a difficult and politically sensitive undertaking for researchers to approach higher ranks in operational departments in order to promote PMT's services. What was so sensitive about this approach was that they basically were poaching in territories under jurisdiction of other functional departments. Particularly the head of financial controlling was unpleased when learning about PMT's activities in his division and especially in his arena of responsibility. It was only due to the intervention of the head of planning of the trucks division that they were granted the permission to get involved in yet another network project anyway to demonstrate the feasibility of their technological project.

In the past there were two network planning departments in the division which later were merged to one in July 2006. To distinguish the two sets of strategic planners, the department where the NetworkPlanner was applied first will be termed Team A. Team B will play an important role later in the story. The first pilot project in the trucks division, which PMT was granted to work on, plays a crucial role. It will be referred to as Major Network Project (MNP). Following a similar approach as with the cars division, an additional intern, Karsten, was recruited to work closely with the practitioners. Since the recruit joined in January 2005, the kick-off of MNP can be dated back to the end of 2004. The role of the new intern was to facilitate the application of the NetworkPlanner at the customer side. Different to other interns he was a mature student with a background in business administration. Karsten re-enlisted to higher education to gain a second degree in mechanical engineering and applied for the job at CarCo to do his final year dissertation on a practical project. To distinguish this intern from others, he will be referred to as the planning intern. Instead of being recruited by PMT in the research group, the planning intern was recruited directly by the strategic planning department at the trucks division and was, therefore, reporting directly to the strategic planners.

The collaboration between Karsten and members of PMT was quickly established and well maintained throughout the pilot project. A first introduction of the NetworkPlanner to the planning intern was supervised by Chris. Aware of the opportunity posed by the collaboration with the trucks division, Chris was often present in the department to be briefed on MNP and its progress as well as to explain the use of the planning tool and to address any problems arising. Thereafter, the planning intern was responsible for applying the planning tool at the trucks division. The collaboration intensified quickly because many bugs and errors hampered the work flow and required much interaction with PMT. Reflecting on the state of the artefact when Karsten came in touch with it, he described the artefact as being in a stage prior to that of a prototype. He located it somewhere between a prototype and the next lower level of a demonstrator. His inputs became an important point of reference for PMT to debug the software as well as to implement new feature requests that emerged due to the planning intern's practical work with the tool. Karsten was the first key user of the NetworkPlanner outside of PMT. His views were not clouded by a forgiving developer's perspective. Facing the clearly defined task to contribute to a running network project, he had to comply to the MNP deadlines and objectives. Researchers found in him a demanding but helpful collaborator who helped shaping the user-friendliness and usability of the artefact.

The technical auxiliary student in charge, Karl-Heinz, remembered how busy it was at this time as user requests kept floating in regularly. A problem that was difficult to get hold of remained the poor performance of the tool. Much time in the beginning was spent on learning how to use the artefact and, especially, the descriptive model to represent the problem. Performance problems were caused initially by inefficiently designed models. Although a general descriptive model was developed it yet required trial and error approaches to find the best way in representing an actual network problem. Calculations by the solver either took an unsatisfactorily long time to finish or crashed in the process due to lack of computational capacities or hidden flaws in the model. Increased experience slowly resolved these kinds of problems thanks to better modelling of the problem. Other technical problems were addressed one by one increasing the reliability of the tool over time. Performance problems, however, remained a problem for many years particularly because the expectations of planners were very demanding, if not to some extent unrealistic. Network problems are complex and require a considerable amount of computation time to be solved. Nevertheless, these performance problems were regarded as a necessary evil and the struggle abounded with it was not reflected to the decision makers in upper ranks. This low profile about operational problems with the artefact helped creating an external image of a well working tool.

Another challenge that emerged was a concern with the financial controlling department in the trucks division. Although the presence of the researchers was tolerated thanks to the temporary mandate given by the head of planning, it did not go as far as coercing financial controllers into accepting the NetworkPlanner. Thus, their initial scepticism posed a problem for they remained an important element in the general strategic planning process. A strategic planner's job was to manage a network project analysis. In brief, a strategic network analysis included the identification of a set of possible solutions, liaising with practitioners working in the plants, gathering data relevant for assessing potential solutions, conducting necessary quantitative assessments to get representative results to, eventually, report a set of recommendations to decision makers. In the strategic planning process, the role of the financial controllers was to conduct detailed profitability accounting of those possible network solutions that were short listed by the strategic planners. From their point of view, the NetworkPlanner threatened to dispute their jurisdiction in this process and, in the long run, to push them out of the planning process.

To mitigate this problem, the researchers and the users in the strategic planning department, henceforth we refer to the combination of these two parties as the NetworkPlanner community, approached the controllers to address their concern. The

NetworkPlanner, as far as it was perceived by the NetworkPlanner community, was not intended to replace the involvement of financial controllers. Its purpose was to enhance the capabilities of a strategic planner. This enhancement did not make planners independent from controllers but allowed planners to make higher numbers and more thorough analyses to derive more robust results before handing them over to the financial controllers. In fact, if the development of the artefact had been adapted accordingly, it could have had the potential to incorporate a larger extent of the work usually conducted by financial controllers. After all, the concerns of the financial controllers were reasonable to some extent. However, the willingness to adapt the NetworkPlanner to that purpose was not there at the time also for the reason that, in the end, it still required a user experienced in financial controlling to legitimately conduct such an analysis. At a much later stage in development of the artefact, this route indeed was probed by undertaking a network project in collaboration with financial controlling within their domain. Meanwhile, the trust of the financial controllers had yet to be earned by the NetworkPlanner community.

Financial controllers voiced their scepticism by criticising the validity of results produced by the NetworkPlanner. Not being briefed in detail about the internal workings they assumed that calculations were not in compliance with the division's standards. Much effort by the NetworkPlanner community went into aligning algorithms and calculation methods to fulfil the requirements of financial controlling. Fortunately, a harmonisation of methods had already been undertaken in an earlier stage when PMT worked with financial controllers at the buses division. Therefore, the researchers readily disclosed the details of how the NetworkPlanner made use of relevant key performance indicators and how it produced its results. This allowed financial controllers to scrutinise algorithms to evaluate the artefact's methodological validity. To support the trust building effort, the NetworkPlanner community undertook network project analyses drawing on existing input data used by financial controllers for previous projects. Results produced with the NetworkPlanner were juxtaposed with results produced manually by the financial controllers. This comparative exercise convinced the financial controllers that the NetworkPlanner complied with internal accountancy standards. Eventually the division's head of financial controlling gave the NetworkPlanner his blessing but only after winning the reassurance that financial controlling would keep its role in the strategic planning process when it came to detailed profitability analyses. Finding a consensus with financial controlling was important to pave the way for the further implementation of the artefact. Otherwise, this organisational department could have been a powerful opponent in the coming struggle to diffuse the artefact in the rest of the division.

Having satisfied financial controlling and stabilised the link to the trucks division, work continued with gathering data and computing results expected by the strategic planners in respect of the MNP project. The operations research-based methods were an innovative approach for the strategic planners to undertake a network project. However, it was still a black box for them. Thus, it was necessary to explain these strategic planners how these methods worked so they in return were able to understand how the results came about. A difficulty for each planner was to learn the basics of OR methods to trace the mathematical process because in the end it was them who presented results to their superiors. Presenting results of strategic network analyses to their superiors, they were usually expected to explain their recommended solution and to stand detailed interrogative questions. Eventually, all steps of the strategic planning process had been taken successfully and a decision was made to proceed with putting MNP into practice. The successful application of the NetworkPlanner in the pilot project with Team A was among the most important milestones in the long development of the artefact for it was a valuable acknowledgement of the high practical value of the artefact for the strategic planning process.

In the midst of MNP, when the success of the collaboration between researchers and practitioners was looming, an important actor-related transition occurred. Chris, the doctoral student responsible for the artefact development saw the end of his contract with PMT approaching. This raised two issues. Firstly, a succession plan had to be put in place. And secondly, he had to plan his next career step. The first issue was addressed by looking for a candidate who could continue the work on the artefact. In the stage where the development was at, the ideal candidate was supposed to have sufficient knowledge about OR as well as software developing. Thanks to the constant involvement of interns and close collaboration with universities, there was a pool of well-qualified candidates to choose from. The successor student selected was an intern who had been recruited previously to support Chris in regards of OR-related challenges. He was a student of business informatics with a focus on OR methods and thus was an ideal candidate to continue work on the artefact. The second issue regarding Chris's next career step was also quickly resolved as it was aligned with his recent activities in the trucks division. He became the assistant to the head of planning at the trucks division. It was the same manager who arranged for the researchers to participate in MNP after another senior manager had raised his objections. The student's transition from research to the position of assistant to the head of planning was a fortunate move, not only for him individually, but for the further diffusion of the artefact in general. The former doctoral student became a strategic ally with direct access to a senior manager who held decisive power over the fate of the NetworkPlanner.

Another significant detail of this truck episode was that the LICOPRO project finished in October 2005 (SATFAB finished almost a year earlier in December 2004). This was about the shortly before the student moved to a new job and after the pilot project came to fruition. The pilot project at Team A, therefore, was still benefitting from the financial cushion that was provided by a public funding body. Figure 14 illustrates the kernel as it looked shortly before the end of 2005. PMT's members continued to work on their initial objective and to collaborate with other research teams. But they also continued focusing on growing the successful kernel by elaborating the artefact, which had reached version 1 by then, and expanding to other users.

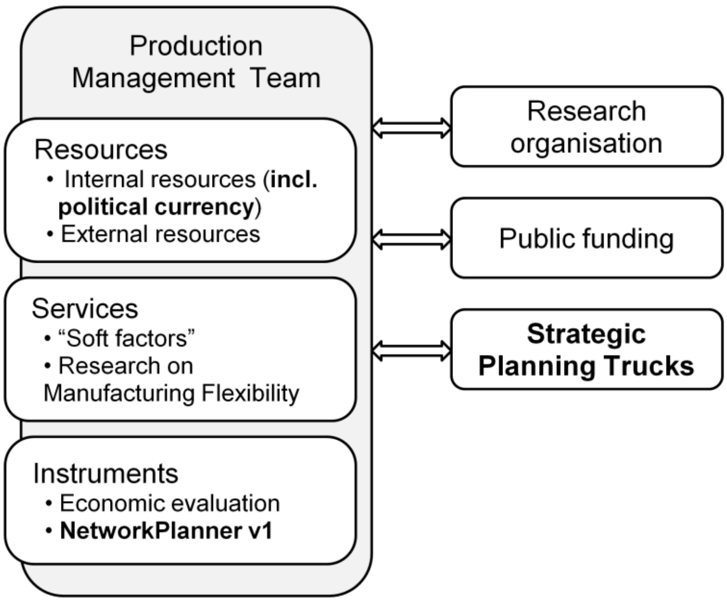

Figure 14 PMT's kernel after successful accomplishment of the first pilot project in the Trucks division at the end of 2005

Having improved internal representation of the NetworkPlanner, it was an ideal moment for a subtle follow-up campaign to diffuse the artefact to other strategic planners in the division. As noted above, the team of strategic planners which PMT worked with in course of the pilot project was only one of two teams responsible for strategic planning in this division. To put the next stage in the diffusion of the NetworkPlanner into perspective, a historical detour will shed light on the organisational setting of strategic planning in the trucks division and explain the co-existence of another strategic department.

6.5.2 A historical detour: two strategic planning teams in competition

By the early 2000s two strategic planning departments had emerged in the trucks division. The twofold organisation stemmed from the spatial separation of a major component plant from the headquarters. The plant and the headquarters of the trucks division were more than an hour's ride by car away from each other. The component plant produced engines for domestic production as well as production abroad. The plant's production volume and the significance of the component, the engine is the single most expensive component in a vehicle, as well as the relative size of the engine production network justified having its own strategic planning team, Team A, located close to the actual site of manufacturing. The team based at the headquarters, Team B, managed the final products as well as other major components. Further, the two departments were also distinguished by different philosophies in their approaches. The team in the headquarters, Team B, adopted a somewhat holistic approach, also characterised as "strategic-visionary" by an interviewee (David, strategic planner, interview, 9 May 2011), while the other team was project-oriented, tackling problems practically as they arose. The origin of the latter philosophy is explained with a tradition strongly influenced by a senior financial controlling manager at the trucks division. His philosophy was to minimise expenses and to avoid investments in production capacities whenever possible. Instead, this philosophy encouraged the reuse of existing infrastructure. In regards of component manufacturing, this was easier to accomplish than with finished goods. If more of a component X was required then plant Y was capable of delivering, than plant Z would produce more of the same component to satisfy the surplus in demand. Any surge in demand at one location can be relatively easily compensated by drawing on available capacities of another under-utilised plant at another location. Components are suitable for such compensatory tactics but less so are finished goods, i.e. commercial vehicles in this case. Shipping a finished good to satisfy unanticipated demand elsewhere, however, quickly carries extra hurdles in the form of customs or other tax penalties besides immense transportation costs. Thus, the planning team in the component plant tended to solve problems by rerouting material flows based on available capacities in other plants rather than increasing capacities of a bottleneck plant through costly investments. The planning and coordination of existing capacities and material flows in the production network required thorough financial evaluation of specific and complex business cases. The NetworkPlanner, therefore, offered a functionality that was more welcomed in Team A as it fit better their mode of operations: it was project-oriented, i.e. specific data had to be collected anew for every new project, and was capable of a thorough analysis of large and complex sets of data.

In contrast to that, the team at the headquarters pursued a holistic approach. This is most evidently observed in its attempt to develop its own information system that embodied the described characteristics. This information system was intended to be a database holding information on the global production network, thus it will be named GlobalDB for reference. GlobalDB should store all information about the production network that was relevant for strategic network projects. This included production-related information about production capacities, capacity utilisation as well as basic details on the address of the plant, products, plant layouts etc. Its purpose was to serve as the reference system for any network-related project so that the data had not had to be retrieved anew for every emerging project. Different to the development of the NetworkPlanner, GlobalDB was fully developed by an external software house and coordinated by a strategic planner in Team B with a background in information technology. The requirements for the system were relatively well defined and did not accommodate complex mathematical methods, although a secondary function was to provide for limited analytical capabilities. Development on the system started in 2003, about a year later than the work on NetworkPlanner. After a successful pilot project the development was commissioned to a larger software house. The collaboration with this company turned out unsatisfactory and so the smaller software house, which had developed the artefact for the pilot project in the first place, was again commissioned to develop the full system. This was about the time when the researchers entered the arena to compete against GlobalDB. Generally, both artefacts served different purposes. GlobalDB stored information for general use while the NetworkPlanner was a specialised tool for specific use cases. In principle, they did not necessarily compete against each other in terms of functionality. The opposite seemed to be true in that both systems filled gaps in different niches. It was rather social and practical reasons that turned both into competitors. The competition set in only after the NetworkPlanner was successfully applied to support the strategic planners of Team A in the Major Network Project.

After NetworkPlanner's success in one department, the strategic planners of Team A themselves tried to introduce the tool to their colleagues in Team B. At first, this happened occasionally via rhetoric means by praising the value of the innovative planning tool in the strategic planning process. However, these initial attempts failed clearly as the planners in fact were not able to demonstrate the use of the artefact or explain the details of its operation. Asked for a demonstration, they stumbled because they did not use the planning tool themselves but drew on the planning intern or the doctoral student to operate it. Thus, the strategic planners at the headquarters were sceptical about the grand claims and promises made by their colleagues. When the NetworkPlanner was officially introduced in a special meeting organised by the planning team who were involved MNP, the result was not as expected. Instead of being informed and convinced about the benefits of the artefact, the audience was left irritated. Max, who attended the introduction meeting, summarised the experience:

> "[T]he presentation was, in my opinion, a failure […] They introduced it as a mega tool… Super, super! But I did not at all understand what it was all about". (Max, strategic planner, interview, 7 April 2011)

What did impress him was the ambition and strong belief of the researchers in the value of their artefact. However, in this episode of diffusion to Team B, little ground was won. Learning about overly praised capabilities of the planning tool in a presentation, to which the planners of Team B were made to attend, is a different scenario than being genuinely interested and testing it on a real case. In the end, learning the use of a new software application is a time-consuming and not necessarily pleasant activity. Further, because the department was working on its own information system, which actually was not fulfilling its promises either, Team B was saturated with information technological innovations. Thus, the attempt to introduce the NetworkPlanner bottom-up by persuading strategic planners failed.

Besides the relative indifference of his staff, the manager of the strategic planning department of Team B was personally attached to GlobalDB. A reason why the manager kept holding on to GlobalDB was the fact that he himself became head of the department only a few months ago. Struggling with familiarising himself with the new job he was little interested in taking a strong position in a debate he was not clear about all facts yet since the development of GlobalDB was initiated by his predecessor. Thus, cancelling the development of that system could have had unintended consequences for him like the loss of trust of longstanding members of the team. Chris, now assistant to the head of planning at the trucks division, anticipated that as long as GlobalDB was an asset in Team B there would be no space left for another system. He therefore took advantage of his new position and intervened by convincing the head of planning to demand an official evaluation and direct comparison of the two information systems.

A technology assessment was eventually conducted and the result was clear in favour of the NetworkPlanner. The NetworkPlanner was a practice-proven, highly innovative and niche-tailored expert system that had been used in various business cases across different user locations. GlobalDB, on the other hand, was a general information system bespoke for a single user location. It was not fully operational and did not noticeably contribute to the strategic planning process yet. Even if the idea of GlobalDB had been superior to its competitor, it was in an underdeveloped state which could not compete with the already available capabilities of the NetworkPlanner. Actions were taken swiftly and GlobalDB's development was cancelled. Although the system had been around for a long time, its lack of strong support from the manager of the department and other staff members sealed its fate. After GlobalDB was out of the way, the NetworkPlanner won by default because its adoption was also an order imposed top-down by the head of planning. This order was an act of de jure standardisation, i.e. the NetworkPlanner was by authority declared the standard planning tool for strategic network projects. Coincidentally, soon after the victory of the NetworkPlanner over GlobalDB another internal development affected the two planning teams. An internal structural reorganisation in the second half of 2006 resulted in the two strategic planning departments being merged to one. Team A from the component plant was allotted to the head of Team B so that both teams were led by the same manager after all.

6.5.3 Pilot project in Team B

In light of the new techno-political configuration, with GlobalDB being removed and a top-down order being in place, a new approach to introduce the NetworkPlanner was undertaken by its proponents. The previously witnessed reluctance of the users was not necessarily due to individual strategic planners, but depended also on the dominance of the prior techno-political situation. In this new situation and after an initial struggle to adapt to the change, the strategic planners demonstrated that they were ready to give the NetworkPlanner another chance. This new attempt was largely facilitated by the coincidental emergence of a new important network project with a relatively high level of complexity.

Having acquired other companies in the recent past expanded the division's production network by new brands and several manufacturing plants in a major foreign market. The new network project was initiated because, as time goes by and markets change, the need emerged to consolidate the production network in this foreign market. The task was set to optimise the existing network to prepare it for present as well as future challenges. It was a major reassessment of the existing network of manufacturing plants open for considerations such as adding new plants or removing existing ones. Therefore it was an extensive network problem requiring the analysis of large structures and countless interrelationships - an activity difficult for manual analysis, as described above, but ideal for an expert system such as the NetworkPlanner. To simplify the narration and to emphasise the importance of the project, this project will be referred to as Very Important Network Project (VINP).

Chris, the assistant and former doctoral student, made the first move by approaching the two planners in Team B, who were tasked with analysing VINP, and convinced them to give the new planning tool a chance. He personally introduced the NetworkPlanner and explained its use to them. The beginning of this collaborative interaction was difficult and a particular aspect in the project was found that was not covered by the planning tool. To address this, the successor doctoral student, Tom, was called in. Being an expert in OR methods as well as software development, he was able to create a bespoke solution for that problem. Proving his competence and his willingness to put in extra effort, Tom quickly gained the trust of the two planners. As a result, he became involved in the planning process for VINP to support the planners and also to replace Chris who had to deal with other responsibilities and therefore could not afford being involved any longer. This was the moment when the transition of responsibility from one doctoral student to the other completed as Chris did not play an active role in the story any longer.

After getting on board the VINP, Tom quickly emerged to be a key actor in the project as well as the establishment of the planning tool for he had expertise to apply the tool and to develop it further every time a problem was identified. The project started to demand all his attention and a deal was made with PMT's research department manager to continue this intense collaboration. One of the two strategic planners remarked that the research department manager was very cooperative because he recognised that VINP had the potential to be the final breakthrough to transfer the tool out of research and into practice. The research manager himself had overseen the technological project ever since PMT started research into flexibility in respect of the public projects. Facing pressure to cease the use of resources for non-research related endeavours, the work on the NetworkPlanner was by then internally regarded as being at a stage beyond the responsibility of a research department, he was also eager to find a home for this outcome of years-long research.

Network projects can vary significantly. Some projects are repetitive and are done just in weeks when the problem is relatively small and data can be reused from previous analyses. But projects can also be intensive when problems are large in scope and complexity. VINP was an instance of the latter sort. Time is not necessarily a factor to measure the complexity of a network problem as smaller projects can take many months when frequent requests change the nature of the problem and hamper with results of previous efforts. However, in the case of VINP, the complexity of the problem stretched the project over a long period of time. The involvement of the planners started sometime in mid-2006 and lasted about one and a half years until the end of 2008.

This long period also marks a period when no significant development was made regarding the NetworkPlanner because the new doctoral student, Tom, was fully occupied by his work on VINP. Gathering data and operating the NetworkPlanner was one part of his task, another important responsibility was being the informal tutor to the two strategic planners in charge of the project. VINP was a hands-on experience for these practitioners to learn how the NetworkPlanner was to be used and how it worked internally. Particularly one of the two planners was dedicated to understanding the logic coded into the artefact. This is the same person who, as noted above, described his introductory meeting with the planning tool as a 'failure'. Because he turned to be a key actor in the later diffusion process, we will henceforth refer to him as the 'lead planner' to distinguish him from other colleagues. The term 'lead planner' does not refer to any special status within Team B. It is to emphasise his representative role as a lead proponent of the NetworkPlanner among all strategic planners and does not indicate any extraordinary capability to use of the tool compared to his colleagues. What distinguishes him from other users was that in course of the work on VINP he displayed strongest interest in understanding the reasoning behind the algorithms. He thoroughly scrutinised the results produced by the artefact and questioned Tom frequently and thoroughly:

> "And I got very interested in it and we discussed it frequently: why does it work, how does it work, why does it not work, what is a LP [linear programming], what is MIP [mixed integer programming] and so on. This interested my, personally. Like you would be interested in collecting stamps. Also it was not necessarily linked to any ends… I just found it fascinating. And I wanted to know more and more and more and so I got intrigued by that". (Max, strategic planner, interview, 7 April 2011)

Thanks to his strong personal interest in the subject, the strategic planner gained a better understanding of the methods designed into the artefact and learned to appreciate its contribution to the overall strategic planning process. An origin for his personal interest can been identified his sceptical view on the conventional methods of strategic planning in the first place. On this he remarked:

> "Well, it was not transparent. I mean, we did qualitative comparison of things. Sorry, but this was just pairwise comparison[26]. This probably was interesting around 1964 […] it hardly goes beyond common sense. Well,

26 Pairwise comparison refers to a general method known as Analytical Hierarchy/Network Process (AH/NP) (Saaty, 2008). This is a method to deal with complex problems that are difficult or impossible to quantify. Instead of relying on universal numerical order (1 is smaller than 2 is smaller than 3…), order is produced by assuming that one qualitative attribute is more important than another. Complexity is abstracted into aggregated and weighted factors which are in relations to each other rather than relating to deterministic data. Thus, one can derive a valid and methodologically sound solution taking into account subjective estimates for benefits, opportunities, costs and risks. This is regarded as a valid approach when there is no alternative to abstract a problem (Saaty, 2008).

> maybe it is ok, but for such complex problems it is not sufficient". (Max, strategic planner, interview, 7 April 2011)

In contrast to subjectively interpreted complexity, what the strategic planner referred to when speaking of complexity was the amount of interdependencies within a production network. These interdependencies are represented as flows of materials, costs of transforming materials into products and transporting goods from one place to the other, etc. With the support of sophisticated information-technological infrastructures nowadays, it is possible to get hold of the necessary information to quantify that complexity. The strategic planner was intrigued by the NetworkPlanner because he realised the potential to leverage transparency and, in consequence, to improve the strategic planning process.

As work on VINP progressed and first results were produced by the planning tool, the strategic planner and doctoral student spent much effort in delving into the details of those results. Together they traced the logic why a particular result was produced. For example, the economic situation for commercial vehicles was tightening around the time and under conventional economic considerations a particular manufacturing plant would have been closed down. The NetworkPlanner-facilitated analysis of the interdependencies of the plant in context of the relevant global production network, however, surfaced that closing this plant would have had a significant negative effect in the case of an economic recovery. Closing the plant had been a solution to a temporary and acute circumstance and thus depicted a local solution. In contrast, the NetworkPlanner-supported analysis considered the role of the plant in the overall production network beyond local circumstances. The recommendation to sustain the plant was based on the extended analysis which took into account not only the temporarily negative circumstances but also likely positive effects in the future. In this case, although the plant was not profitable under given circumstances it was highly relevant for other plants connected to it in times of economic upheaval. Thus, the NetworkPlanner juxtaposed multiple local solutions to help deducing a global solution. Tracing and discussing the reasons for these kinds of results helped the lead planner and his colleague to learn how the planning tool operated.

After more than a year of data collection, modelling and thorough analysis NetworkPlanner-deduced results on VINP were delivered to the decision makers. As usual, the planning team was thoroughly questioned by senior management about the data and their recommendations. Responses from the lead planner were well-prepared and well-informed thanks to his extraordinary effort to learn about the mechanics of the planning tool. The decision makers, which included the head of planning of the trucks division and superior of Chris, were pleased about the innovative method and particularly the transparency of the strategic planning process. The prior success case of MNP and the subsequent disposal of GlobalDB culminated in an official statement by the head of planning to declare the NetworkPlanner as the standard planning method in the trucks division. At that time, this authoritative de jure standardisation statement was important to set a direction for future developments. It was, however, only after the success with VINP that standardisation was accomplished de facto because a critical mass of strategic planners was eventually convinced about the value added by the planning tool. Subsequently, efforts were undertaken to teach remaining colleagues to apply the planning tool in their projects whenever the artefact was applicable to the problem. The successful accomplishment of VINP also had a decisive impact on Tom's who had worked on VINP. After finishing his doctoral thesis he transferred to the trucks division in January 2009 to start working in the strategic planning department under the supervision of the lead planner.

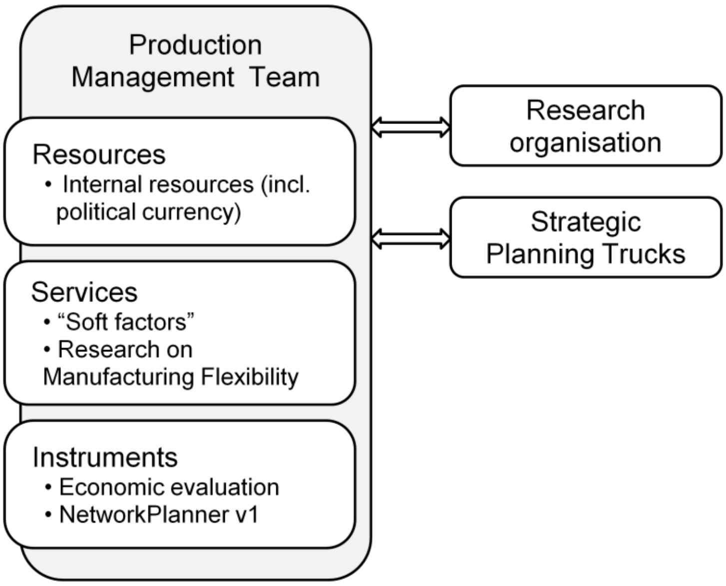

Figure 15 Kernel of PMT's research infrastructure after the second pilot project at the Trucks division

Before moving on, we briefly take stock of how these developments at the Trucks division reported above had shaped the kernel of PMT's research infrastructure (see Figure 15). A major difference between the episode with the first pilot project, MNP, and the episode with the second pilot project, VINP, is the shortfall of public funding from PMT's income stream. However, the financial security of the research team was no longer at risk as it was in the beginning of PMT's existence. A structural change in the way how CarCo's R&D was funded internally improved the situation of PMT. Political influence and justification became the most important currencies to sustain PMT's research activities. The disappearance of the public projects from PMT's ecological terrain, therefore, was not as disastrous as it would have been at an earlier episode. The kernel stood on solid ground at the end of 2008.

6.5.4 Decision to redesign the artefact

In the beginning of 2008 the situation looked far more prosperous for the researchers than in the past. Chris, the first doctoral student working on the NetworkPlanner, switched to a position close to the head of planning of the trucks division from where he was able to campaign in favour of the NetworkPlanner. The planning tool itself had been successfully applied in several network projects including two major projects that attracted much attention from relevant decision makers in that division. Subsequently it had been declared a standard for the strategic planning process in the trucks division. More important than that it was accepted and adopted by some strategic planners who were eager to promote it to other colleagues within their team. Another highlight in 2008 was the news that due to the success case of the Major Network Project the NetworkPlanner artefact had been nominated for CarCo's internal innovation award. To incentivise excellence in research and technology, CarCo rewards outstanding research projects with an innovation award. In December 2008, the NetworkPlanner team eventually won the innovation award in the category for process innovation.[27] All in all,

27 The December edition of the monthly internal newspaper features a picture of the 'Team [NetworkPlanner]' including Jürgen, team leader of PMT, Max, the lead planner from the trucks group, Karsten, the planning intern of Team A in the trucks group, Chris, the first doctoral student, Kai, the supervisory researcher, Tom, the doctoral student succeeding Chris, and John, another doctoral student involved in early development. An article describes the artefact as 'enabling PC-based and quick analysis of changes in production and logistics networks and [...] a valuabe decision support for management'. (Document: Internal research newspaper, December 2008)

it seemed an ideal situation for the NetworkPlanner. What was missing from the view of PMT was a last concerted effort to transfer the planning tool for good.

At the end of 2006 and in the early stage of VINP, Kai, the supervisory researcher, left PMT for another position within CarCo. Kai became team leader of PMT in January 2005, when the previous team leader left. Kai's departure, on the other hand, allowed Jürgen to become the new team leader. Jürgen consequently inherited the responsibility of dealing with the task to initiate the transfer of the planning tool. The main driver behind the idea to transfer the NetworkPlanner was the senior management of the research group which regarded the development of the artefact as accomplished and no longer as an object for research. Thus, any subsequent action related to the artefact was interpreted as consultancy-like activity that was outside the realm of a researcher.

For PMT's new team leader, the time was ripe to finish the work on the NetworkPlanner and to begin the transfer of the artefact for good to embed it in the operational departments. However, he recognised that the state of the artefact still did not meet the requirements of a mature standalone application. Every network project so far had required strong support by a doctoral student and several inters from PMT to deal with numerous technical and other practical problems. Considering the state of the artefact from a sustainability point of view, he deemed the artefact not transferable because it was yet immature for this step. Indeed, he doubted that the artefact was sustainable at all if the resources invested in it would have been withdrawn all of a sudden. The best option, he concluded, was to initiate a final redesign of the artefact to stamp out its weaknesses and to prepare it for its existence outside the research group.

A redesign of the artefact, however, required the support of the trucks division as it was the key user at that time. Therefore, he approached the manager of the specific strategic planning department to introduce his idea. It did not take much to convince him of his proposal:

> "[The manager] recognised early on, after I conveyed my view on the matter, that [the NetworkPlanner] was a vial tool for him and his troop, which stood on shaky grounds, namely, it strongly depended on [the doctoral student]. And after he realised that, it was not complicated any more. It is to say after [the manager] got cold feet, he said 'If it really stands on shaky grounds, as I am told, then it has to be stabilised as soon as possible'". (Jürgen, team leader of PMT, interview, 20 May 2011)

In contrast to the practitioner, the idea to start over again was met with strong objections by other researchers. In the focus group interview the team leader recalled that with this idea he

> "basically fell out with everyone involved in the project". (Jürgen, third team leader of PMT, focus group interview, 12 December 2011).

In the individual interview, he was more specific:

> "Everybody had an argument for why [I] had a screw loose with my interpretation. One felt personally degraded regarding the quality delivered after I said that [the artefact] was not yet the ne plus ultra. The other said 'Oh, dear, if [Tom] is busy with a redesign, then he won't be available to me for half a year. Everyone had a good argument. [Another planner] said that software projects never work out anyway". (Jürgen, team leader of PMT, interview, 20 May 2011)

Despite the resistance, he began with commissioning the development of a technical specification of the artefact. His intention was to preserve status quo just in case that for whatever reason the project is

> "frozen that we know that we can rebuild it anytime when we get it out of the box again". (Jürgen, team leader of PMT, interview, 20 May 2011)

Writing a technical specification for software or maybe any technology in general is not an appealing activity. It is perceived as a tedious task free from creativity which is shunned by most developers and engineers. The team leader correctly anticipated lack of participation by PMT members and therefore commissioned a consultancy firm to engage with the task. For about two or three months two employees of a management consultancy, of which one was previously an intern with PMT, analysed the software, spoke to those involved in its development and wrote up the functional specifications of the NetworkPlanner.

The funds for the technical specification of the artefact were advanced by PMT. In general, the situation in terms of funding had changed fundamentally since the time when PMT had to participate in the public projects to generate extra income. The funding structure within the research group had changed to a system that provided PMT with a full budget. With more financial resources at hand, the PMT team leader decided to advance the funds for the technical specification also to indicate to the trucks division that they were willing to continue supporting the artefact during the transfer process.

In hindsight, as confirmed by many interviewees, the resulting specification was regarded poor despite the consultants' detailed work to describe how the artefact and its algorithms worked. The technical language of the functional specification missed to unfold and explain all technical and methodological intricacies in a comprehensible manner. For these reasons, the technical specification did not play a relevant role as a point of reference in the further redesign undertaking. However, it was a good way to get the redesign project going.

6.6 Conclusion

The previous chapter examined from a meso-macro perspective on how CarCo interacted with other institutional actors. As a result of socio-political dynamics and occurrences a research team emerged that explored the subject of manufacturing flexibility. This chapter elaborated in more detail how the research team grew and expanded its socio-technical network consisting of researchers and researchers-to-be, complex configurations of technical artefacts and wide-reaching social ties to other individual and organisational actors. The artefact was frequently applied in real life projects in different locations. These application cases served as means for operational departments to test the applicability and functionality of the artefact to cope with the problems they were dealing with. For the researchers, these cases were essential to improve the design of the artefact to accommodate the demands of a diverse set of users.

Multiple episodes of innofusion, a repetitive process of innovation and diffusion, allowed the researchers to design, and thus, to couple features of the artefact closer to the specific features of its users and their organisational contexts. The innofusion process was a continuous cycle in which initially presumptuous promises were consequently transformed into artefactual qualities to meet varying requirements posed by its users. The greater the exposure of the artefact to players outside the research team was, the more recognition of its beneficial qualities was won. The innofusion process was accompanied by a credibility and reputation-building cycle that benefited the artefact's further advances. Different opportunities, in the shape of prominent network projects, increased the artefact's credibility and reputation to the point when it was rubberstamped as the dominant planning method in one business unit. Reaching apparently a peak time it was decided to redesign the artefact to make it fit for a transfer into praxis.

In hindsight the first five years went very well for the NetworkPlanner and the researchers involved in its development. At times, the team had been facing difficult challenges. Some challenges were overcome by hard working and enthusiastic individuals. Other difficulties, however, which were not in control by the research team, were resolved in favour of the NetworkPlanner only due to contingencies outside the control of PMT. This chapter attempted to highlight both these types of events that rendered the artefact's development process successful so far. An example, that revealed the arbitrariness of external contingencies, was the case of Matthias, the doctoral student who focused his doctoral thesis on the factory-level. Both Chris and Matthias started at the same time and spent the first year studying the same subjects. They collaborated closely with each other over the development of their artefact and debated frequently over the same methodological challenges faced by their common approaches. They were not only sparring partners, as characterised by John, another doctoral student involved, they temporarily even shared a flat with each other. Despite the strong similarities in the technological development and initially more successful applications in operational departments, it was only the network-focused artefact that made it in the end. Although the factory-level planning system was descriebd as promising and far advanced, it failed to find a host organisation that would lobby for the artefact as did the trucks division for the NetworkPlanner. One reason was also that Matthias did not transfer into a job position from where he could influence further take-up of his artefact as Chris did. A romantic but less informative explanation for the difference between the two artefacts would be to state that the failed technology was simply not loved strongly enough (see Latour, 1996). The reason why the NetworkPlanner seemingly enjoyed more passionate 'love' from actors involved is not be explained solely by studying the shape and contents of the artefact and the network of allies around it. Rather, as this chapter tried to foreground, reasons for the successful diffusion of the NetworkPlanner were often not under the control of any researcher or user directly involved. For example, it was thanks to a Siemens manager, who recognised the high potential of the artefact before CarCo's senior research management did, that the NetworkPlanner increased in reputation internally. Another example for a contingency that was crucial for the NetworkPlanner's success was that the trucks division's production network was dispersed globally and thus was inherently complex enough to pose a problem for strategic planners who relied on conventional methodologies and tools. In contrast, the cars division, a division with almost double the revenue of the trucks division, was not that interested in pursuing a cooperation with the researchers beyond one test project because there was no need for such a complex tool. The need did arise eventually, but the temporal delay in between could have been long enough to kill off any efforts of sustaining the development of the NetworkPlanner if it was not for the strong demand from the trucks division that kept it going.

The next chapter will focus on how the NetworkPlanner was redesigned and embedded in operational departments. This includes occurrences and developments of the following five years from 2008 onwards. The redesign did not proceed as anticipated and resulted, contrary to the initial intention, in the expansion of research activities. The chapter will continue highlighting how political decisions beyond the immediate network of the research team affected the fate of the technology significantly.

7 Empirical chapter 3: Redesign and transfer into operations

The previous chapter has reported on how a research team came about and began researching the subject of manufacturing flexibility. What started out as theoretical research in 2002, had evolved to a fully-fledged software development endeavour by 2007. The evolution of the activities of the research team was not following an overall rational strategic plan. Although rational decision patterned individual events and actions, the development was the outcome of multiple episodes of interactions with diverse actors that the researchers encountered and engaged with in course of their work. The social shaping of the artefact as well as the research infrastructure in which the development was embedded, was patterned by events occurring within the 'translation terrain' - "the immediate array of players with their historical and contingent concerns and capabilities, each trying to map out their strategy in interaction with other players and in the light of their broader social, economic and cultural setting" (Williams et al., 2005, p. 86). CarCo's ecology provided a unique translation terrain in which the events surrounding the development of the artefact unfolded. To learn how the artefact emerged in the first place, the previous chapter described how the artefact and its related actors manoeuvred in the given translation terrain and engaged with other players.

By 2005 the artefact had matured to an operational prototype which had successfully been applied in strategic production network projects. The same year, the researchers faced the problem that funding from public projects was about to run out. Up to that moment, public funding provided the Production Management Team (PMT) partial legitimacy to operate to large extent autonomously from directives guiding the research programme in CarCo's research group. This was reflected both in the improvisatory development of the artefact as well as in the loose organisation of those developing it. Contrary to the usual mode of operations within the research group, which saw researchers interacting with other organisational units only if necessary, PMT proactively monitored the translational terrain for potential users and reached out to other internal players to find users early on in the development process. This early exposure to user requirements allowed the researchers to gain both expertise in the domains of the users and a reputation of being competent collaborators. The positive reputation was important to find ways to continue the development when the public funding was running out. Continuous efforts of promoting and applying the NetworkPlanner resulted in the planning system being declared as the standard strategic network planning tool in the trucks division. After the planning system successfully stood the test of time in further network projects in its new home, the PMT team leader started promoting the transfer of the artefact in 2007 as the research group saw no more need for any further research activities. The transfer was intended to be an act of closure to bring to end a development that was met with increasing resistance by the senior management of the research group.

To transfer the artefact, so it was lobbied by PMT's leader, it was necessary to redesign the artefact from scratch to stamp out technical flaws that yet resided in the prototypical artefact. A small cross-disciplinary team was formed to coordinate the redesign project that was commissioned to an external software company. What started as a promising development, however, quickly transformed to a crisis-ridden undertaking. The act of closure unexpectedly turned to a new season of episodes in the development of the strategic network planning system. The following chapter will be reporting on the various episodes that occurred during and in the aftermath of the redesign undertaking. It will reflect on how the development stepped up in terms of formality of the project governance and resource commitment by the organisational players involved. The chapter, and consequently, the report of the empirical case study will conclude with the transfer of the artefact out of CarCo's research and its embedment into CarCo's operational divisions (see Figure 16 for an overview of the empirical data discussed in this chapter).

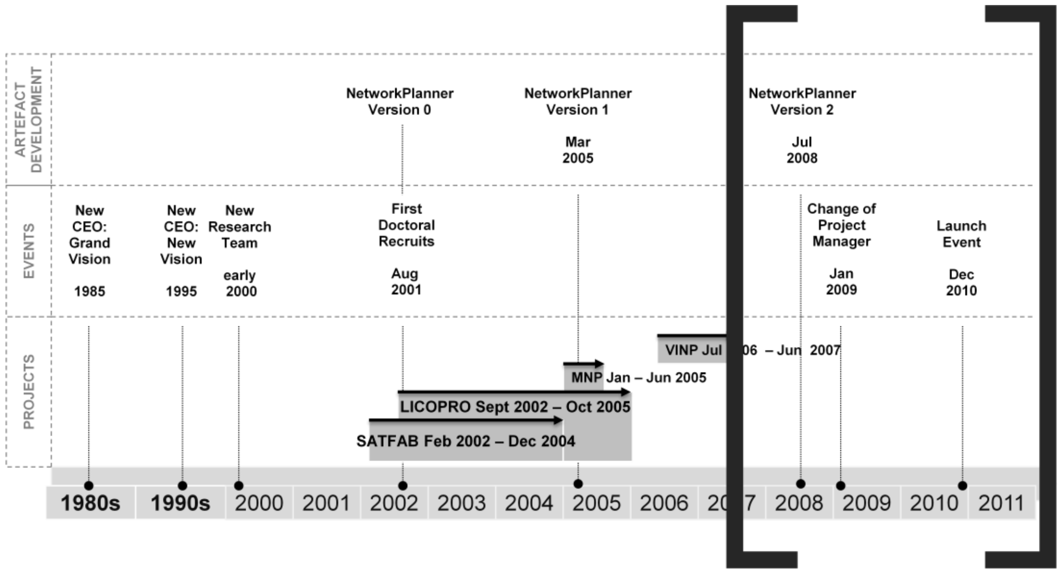

Figure 16 Overview of the innovation process addressed in chapter 7

The following section will start with describing how the project management team was set up before detailing the emerging struggles of the redesign project. The constituency of the team was insofar relevant as it was a reason why the crisis escalated to a point where drastic changes where urgently necessary in the end.

7.1 Redesigning the artefact

The redesign of the artefact was initiated in the first months of 2008. PMT and the trucks division's strategic network planning department, which was funding the redesign project, agreed to set up a joint project management team. The team consisted of a researcher representing PMT to deal with technical and methodological aspects and a planner from the trucks division to represent the users. The planner from the trucks division was also the same person who previously had supervised the development of GlobalDB. His work experience in developing database management solutions earned him the responsibility over the GlobalDB development in the first place. For the same reason he was allotted to supervise the redesign project. Due to his participation in the Very Important Network Project (VINP), the pilot project that helped the NetworkPlanner to win over Team B's trust, and subsequent projects that applied the planning tool he was familiar with the artefact from a user point of view. Additionally, he was supported by a member from Team A who used the artefact while working on the first pilot project with Team A on Major Network Project (MNP). This member was previously the planning intern in Team A. After the successful accomplishment of MNP he had been offered a full-time position as planner in Team A. Together these two planners contributed long-standing expertise in strategic network planning, in general, and expertise in the application of the NetworkPlanner, in particular. The researcher representing PMT, however, was a new actor who had recently switched from an internal engineering department outside of research. He was an industrial engineer with a focus on software development. Although he was not familiar with the artefact or previous developments, it was expected that he would be able to catch up soon after getting started.

7.1.1 An external software company and its proposal for a generic framework

Since the redesign project intended to turn the prototypical artefact to a professional tool, commissioning the technical development to professional software developers was an elementary part of the project. Negotiations with internal as well as external IT service providers were undertaken to find a qualified partner. Among CarCo's internal organisations was an IT service provider that offered in-house services including IT consultancy, provision and maintenance of IT infrastructures, and the development of software applications. Asked to provide a quote for the redesign project the conditions offered by the internal service providers, however, were not acceptable to PMT: the development time was too long and the costs too high. In hindsight, as a former doctoral student and later researcher at PMT remarked, their offer probably was "too honest" (John, doctoral student, interview, 7 October 2010). Based on a recommendation by other PMT researchers not involved in the NetworkPlanner development, an external company was finally selected which was known to the PMT from other projects. The software house had collaborated with PMT before and thus was regarded as reliable and competent project partner. Negotiations began early 2008. The kick-off event took place in July 2008. For the purpose of simplification, the software house will be further referred to as CodeMaker henceforth.

This first steps were to explain to CodeMaker's representatives what the NetworkPlanner was about and how it worked. Basically, CodeMaker was represented by a main software developer in charge of the technical development and his line manager who dealt with administrative matters. The previously described technical specification was a starting point for the software developer to learn about the requirements. However, after looking through the document themselves, CodeMaker's software developer found the technical specification to be "too vague" (Tayfun, external programmer, interview, 26 October 2010). A detailed over-the-shoulder demonstration by the project manager from the planning department was helpful for him to see how the artefact was used and operated in practice but it accomplished little to shed light on how it functioned internally. Despite the technical specification and live demonstrations, the software developer found it difficult to grasp the details of how this peculiar piece of software worked. The situation was unintentionally made more difficult for CodeMaker when the users of the NetworkPlanner raised ideas about new features and concerns over existing features during these initial interactions. Those researchers that had worked on the artefact and who knew about its limitations did little to curb the flow of new demands. Indeed, the technical specification, which was developed under the supervision by PMT, itself contained vague suggestions about increasing the flexibility of the artefact.

The more CodeMaker's representatives tried to explore the task at hand, the more ideas and features were identified that would increase the benefit of a new version of the NetworkPlanner. What started as a clearly delimited redesign increasingly changed to the development of a product with new properties. Put simply, CarCo's representatives asked for a more powerful and implicitly more flexible product compared to the prototype that was presented as a template. One motivation for a more flexible planning tool was the outlook to transfer the artefact to other divisions in the long run as the lead planner from Team B explained:

> "Well, to me it was obvious; if we wanted [the artefact] then in the mid-term it had to be used by others as well, not just us. […] My motivation to bring others aboard, […] was always to say 'I need to set [the artefact] up on a wider base in the company'. Firstly, it is valuable for the company, not just for us. That is fact. We have to take into account the interests of the whole company. And secondly, if others use it as well, then we would have such a wide base that it could not fail easily. I am most certainly convinced that it is good and that way I tried to secure it." (Max, strategic planner, interview, 7 April 2011)

Discussing the prospect of a more flexible solution, CodeMaker was attracted to the idea of developing a flexible solution which would be interesting to other divisions at CarCo. In the best case, one project could lead to another, so it was believed. It seemed like a good opportunity to secure more contractual work in the future. After taking into account all information including these prospective opportunities, CodeMaker's representatives proposed a system with a so-called generic framework to replace the rigid and narrowly purposed design of the prototype. The generic framework promised easier handling of the descriptive model that was among the most important components of the NetworkPlanner. In the prototype, the model was deeply integrated with other components of the artefact. This was also a reason why it was difficult for CodeMaker to understand its internal workings in the first place. A key concept of the proposed generic framework was to separate the model to make it directly accessible for changes by the user. When applying the artefact in a different division, no longer had a researcher change any software code in the artefact. Instead, a knowledgeable user could use an integrated user interface to manipulate the model directly or even replace it with another template model. Thus, the proposed generic framework solution resembled a tool kit which offered different tools for different problems.

For PMT's project manager, Jan, the generic framework was a valid idea deemed doable and worth pursuing. He shared his positive interpretation with other researchers as well as the users at the trucks division. Reflecting the interests of the practitioners towards higher flexibility, the proposal was accepted by PMT's team leader as well as relevant users. Finalising the specifications with CodeMaker, a project timetable and a total budget with a lower six digit figure was agreed which, nonetheless, resembled a significant financial commitment for a single information system (Document: redesign project interim report). The timetable proposed a development period of about eight months from kick-off to the transfer of the new product into operations. What the interim report also reported on was the software development method that was chosen to overcome the initial problem of vaguely defined requirements. An 'agile development' approach was taken to ensure close fit of the product and user requirements (Kai, team leader PMT, interview, 22 June 2012). Agile development is a common methodology when user requirements are volatile and emergent. Instead of rigorously planning all details in advance the method takes an exploratory approach with multiple iterations of planning, developing and testing. This dynamic method is characterised by close collaboration of the developer and the user where early exposure to prototypes of the artefact give users the opportunity to provide feedback and to clarify their own interpretations and requirements early in the development process. The timetable for the redesign project showed four intermediate release dates when the user would be given first prototypes for internal testing purposes every two months.

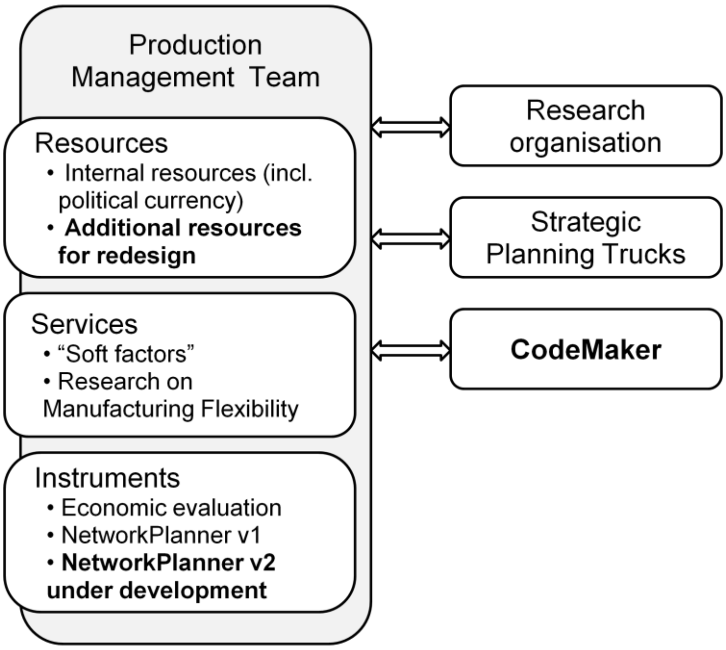

Figure 17 Changes to the kernel in scope of the redesign undertaking

Once more, we briefly take stock of the changes to the configuration of PMT's kernel in light of the redesign. The trucks division was persuaded to provide additional funds to support the development of the NetworkPlanner version 2. The new monies were used to commission an external software house with the technological development. As it turned out, this configuration of actors did not perform as expected.

7.1.2 Emerging problems

About two months into the development first signs were spotted indicating that the project was running into problems. It emerged that CodeMaker struggled with implementing the operations research-related components. The project manager from PMT explained that CodeMaker

> "completely underestimated [the project] […] due to lack of experience".
> (Jan, redesign project manager, interview, 14 February 2013)

As it turned out, CodeMaker's software developer and the respective manager underestimated the effort to create the generic framework. The development of the generic framework, which had no such counterpart in the prototype as developed by PMT, drew more resources than anticipated and began to affect the work on other components such as the graphical user interface.

An innovation emerging from the new generic system architecture was a new role system implying a division of labour designed into the technical artefact. Whereas the old prototype knew only one type of user, usually a planner knowledgeable in OR methodology, the new framework envisaged two kinds of users: a modeller and a planner. The modeller was basically the same type of user who was able to operate previous versions of the NetworkPlanner. The planner role was a novelty in that this user was able to operate the planning tool without the need to be aware of the intricacies of complex OR methods. A modeller user's essential role was to use an integrated editor to create and amend a descriptive model with clearly defined elements and boundaries. Based on this model a planner would find a predefined set of building blocks for use when modelling an actual network problem. The new division of labour largely separated OR expertise from the planning task and allowed planners to use the artefact without the need to learn about OR methods. Herein lay the front-end innovation of the generic framework. Generic in this context meant that a modeller knowledgeable in OR methods could develop a model to address any kind of problem. Referring to the generic capability, an interviewee explained that you can model the behaviour of an ant colony if you so like. A modeller could create a model for solving the path-finding problem of an ant on its daily forage for food (Kate, redesign project planner, interview, 16 September 2011). Drawing on the template prepared by the modeller the remaining task for the planner would be to define the name of the ant, the type of food and its distance to the colony. In a nutshell, a modeller would define the nature of the problem while a planner would work on solutions for particular instances of the problem.

Configuring the complex relationship between the modelling interface and the integrated mathematical solver was a massive problem for CodeMaker's software developer. This was a problem going beyond software developing skills and reaching far into the OR domain which neither he nor anyone else at CodeMaker was sufficiently skilled in as it turned out. Being an expert in software development himself PMT's project manager was drawn to the problem to work on a solution. This implicit prioritisation of the modeller perspective gave rise to another problem. Because both the PMT project manager and CodeMaker's developer paid most attention to the modeller component, less attention was given to the planner perspective which the major concern of the two users from the strategic planning departments.

During the regular project team meetings, most time was dedicated to address problems and requirements of the modeller components at the expense of the elements relevant for the planners. And because the urgent problem was very technical and specific, the two planners struggled to understand what the others were talking about. CodeMaker's software developer remembered misunderstandings over abstract technical terms such as "dimensions" and "dimensional values" which were important for a modeller but not for planner (Tayfun, external programmer, interview, 26 October 2010). Soon the two practitioners both felt left out and ignored in the regular meetings and in the development process in general. The project manager from the trucks group recalled:

> "You noticed that, what we told them was not implemented later in the software releases. We constantly had to follow things up and repeat them over and over again and to make Excel lists of what was not in accordance to what we agreed upon, what was not in accordance to what was defined in the technical specification and so on". (Robert, strategic planner & redesign project manager, interview, 6 May 2011)

The project manager from PMT misinterpreted the significance of the growing dissatisfaction and failed to act upon it. One reason why the researcher partly dismissed their objections and did not respond was because he saw the origin of their dissatisfaction in personal and hierarchical circumstances rather in the project-related technical problems. Instead of taking into account contributions from practitioners adequately, the acute technical problems fully drew the researcher's attention. As reported by several other interviewees, he preferred dealing with technical problems rather than with social nuances. For example, CodeMaker's software developer confirmed his lack of sensitivity when facilitating during conflicts (Tayfun, external programmer, interview, 26 October 2010). Jan, the project managing researcher, was offered support by both PMT's team leader as well as the lead planner at Team B when they noticed these difficulties. The lead planner explicitly offered him to intervene and to take the blame on himself. He recalled telling PMT's project manager:

> "Look, if you have a problem, let me deal with it, then I will be the bad guy, I don't mind, then you won't be framed for that". (Max, strategic planner, interview, 7 April 2011).

But the researcher did not make use of the offer. Instead, the dissatisfaction escalated to a point where the practitioners refused to continue the collaboration, as described by PMT's team leader (Jürgen, team leader PMT, interview, 20 May 2011). The redesign project turned to a crisis as the funding was running out while major technical flaws rendered the artefact dysfunctional and communication among participants stalled. The tension between PMT's project manager and the two planners was intense as indicated by the fact that both planners refused to provide details on this episode when it was addressed during the individual interviews.

Although personal frictions added another layer of problems it was a general agreement at the focus group interview that the reasons for the crisis were manifold and not to be found simply by pointing with fingers at individuals. Where the participants of the focus group interview agreed was that the project was flawed from the outset. Although the agile development approach was appropriate in light of uncertain and incompletely specified requirements the fixed price funding model was a deadlock in this configuration. Due to the unanticipated and continuing difficulties with the development of the generic framework CodeMaker had spent all budget before finishing the artefact. Facing empty pockets CodeMaker refused to continue any development. This was the tipping point when PMT's team leader decided to intervene. Against the advice of his department manager and other colleagues, he replaced the project managing researcher with another colleague from PMT. Lack of funding was a catalyst that forced the senior management of the software house also to intervene and to start contesting contract details. From the outset, it was unhelpful by the strategic planners to demand extra functionalities that were not implemented in the prototype and to keep issuing new requests the further the development advanced. Experienced PMT members who were involved in the development of the prototype also missed to contribute to the redesign project in order to keep it in line with the initial task of developing a productive implementation of the prototype. Instead they left it to the project manager, a relatively new member in PMT, to negotiate with developers and users to agree on the requirements for the new artefact. Interviewing the project manager, he admitted to having missed to recognise in time the complexity and CodeMaker's lack of experience to cope with the intricacies of OR methods. Reflecting on the idea of a generic framework he concluded

> "It was a big mistake, it overstrained everybody" (Jan, redesign project manager, interview, 14 February 2013)..

Further, he prematurely downplayed the significance of the practitioner's dissatisfaction with the project's progress and their perceived negligence of their role in the joint undertaking. Although the involuntary withdrawal of PMT's project manager initially caused further stir, it was a decision that saved the project at the end of the day.

7.1.3 New redesign project team organisation

The member of PMT who was asked to take over as the new project manager did not support the decision personally but followed her team leader's request to take up the role. The previous project managing researcher was not involved in the redesign project thereafter. Similarly, a change in the project management constellation was initiated at the trucks division. It was realised that having two project managers at a time was not an ideal situation. Therefore, project management responsibility was fully transferred to PMT and the lead planner was put in charge to represent the practitioners' interests.

The new project manager was not unknown to the planners at the trucks group. Months before the reshuffle of the project management organisation, she was assigned to familiarise herself with the artefact and its functionality. A strategic intention behind this assignment was to have another full-time PMT member ready to promote and diffuse the artefact. In the beginning she was still working on another project so the new assignment was of secondary priority. A few weeks before the reshuffle she was assigned to focus her work primarily on the artefact and the domain of strategic planning. To catch up with the assignment, she arranged for a placement at the strategic planning department in the trucks division. She intended to learn the requirements first hand by observing users in their workplace and interviewing them to learn about internal processes, requirements, limitations and problems in relation to the artefact as well as to their job roles. This ethnographic approach not only provided insights about the artefact and the organisational context where it was used, but also about the individuals at the trucks division. It was her exposure to the people as a participant-observer that enabled a smooth start into her new role and that reduced the social distance to relevant project partners:

> "I think it was a decisive step to create this good atmosphere, which we later had in the project. It is just about knowing each other, that one was out for lunch a few times together, that one conversed about private matters a few times." (Kate, redesign project manager, interview, 16 September 2011)

Good team work was a much needed quality for her first weeks as the new project manager. When the project management team was reorganised, the project still was at a critical point. The software house had spent all budget and still failed to deliver a working artefact. On the grounds of having spent all its funds CodeMaker refused to continue developing the artefact. Nine days after the new project manager accepted the new role, she sat in a room with CodeMaker's representatives holding "cancellation talks" as she called them, or "mammoth session" in reference to the day-long negotiation (Kate, redesign project manager, interview, 16 September 2011). During this session, they worked through a long list of technical details that caused conflicts in the development. It was a fierce negotiation over single features of the system and if they fell under the initial agreement or if they popped up after the development had started and therefore did not qualify as a deliverable under the existing contract. CodeMaker was put under "vehement" pressure as the lead planner explained (Max, strategic planner, interview, 7 April 2011). After all, CodeMaker signed a binding contract to deliver the artefact and thus was obliged to fulfil the agreement. However, another threat issued by the lead planner was a powerful instrument in the negotiation. He threatened the software house with a negative supplier rating in CarCo's internal supplier register. A negative rating could have had a significant consequence for CodeMaker because it would endanger future interactions with CarCo. Because CarCo was an important customer not just in this project but also in undertakings with other development teams at CodeMaker, the risk of losing the prospect of future contracts was a particularly strong argument.

Acknowledging CodeMaker's precarious situation both, Kate, the project manager and, Max, the lead planner followed a carrot-and-stick policy. They agreed on scrapping features deemed less valuable to make a concession but exercised pressure when features were considered crucial. At the end of the day, an acceptable compromise was found and the development continued but with strongly reduced requirements in regards of the final product. It was a significant achievement by both the project manager and the lead planner particularly in light of an economic crisis in Germany in mid-2009. As noted by the project manager:

> "2009 was a recession, nobody had a spare cent". (Kate, redesign project manager, interview, 16 September 2011)

The supplier grudgingly agreed and continued development at its own expense. After this incident, there were a few other meetings where CodeMaker revolted but CarCo's representatives got used to applying the effective carrot-and-stick policy by then. Indeed, the project manager identified herself as the good cop while the lead planner did not hesitate to act as the bad cop when it came to meeting the supplier.

After the continuation of the project was secured, efforts were directed at reorganising the work on side of PMT. Grasping the severity of the problems which the redesign project ran into, the project manager understood that the problems would not be solved just by fixing any technical deficits. The project had to be reorganised to reflect the problematic situation. Therefore, she reinterpreted her objective:

> "I did not conceive the assignment as a 'convert the software prototype into a professional software'-task but as a research subject. The subject was also titled 'cost optimal' or 'efficient and ecological design of production and supply networks'". (Kate, redesign project manager, interview, 16 September 2011)

A reason why CodeMaker ran into problems was the lack of OR expertise. In scope of the generic framework the software developer was creating an interface allowing users to work on the models directly. Developing the interface already was strenuous task for CodeMaker's experts. But their expertise stopped short of the ability to develop these models. Even if all technical problems would have been solved and a finished artefact was delivered, their lack of OR expertise and insights into the specifics of CarCo's production networks prohibited them from conceptualising descriptive models for the artefact. Because the artefact was a new creation, it could not draw on the prototype and simply copy the existing model there. The only constructive way to solve this dilemma was for PMT researchers themselves to engage in the development of the missing mathematical models. Eventually, it was the PMT researchers who were the experts in OR methods as well as in the application of these methods in context of CarCo's production networks. Extending the interpretation of the objective thus was another consequential and tactical decision to address a critical gap in the redesign project.

At the end of the day and with combined efforts, the new project manager and the lead user managed to find compromises that allowed the development to continue. The configuration between PMT, the strategic planning department and CodeMaker was maintained but at the expense of the quality of the artefact. Also the need for additional research work was identified that had to be addressed by PMT.

7.1.4 Ramp-up of the research team

In accordance Kate's interpretation of her task, regarding it as a research area to study rather than an artefact to develop, she expanded the capacity of the project by bringing in more members of PMT to support her in the project. An important circumstance made it easier for her to acquire more capacity. The financing model of the research division had changed compared to the time when PMT was formed in 2000. In its early years PMT was required to acquire extra funding from other departments to fill its funding gap. By 2008 this has changed significantly due to changes in how the research division was funded in general. Relative to its size each operational division paid its share into a general fund from which all research activities were funded. Instead of seeking for extra funding through direct collaborations with operational divisions, PMT could draw on a fixed budget that covered its basic costs.

The new funding model also affected the nature of collaboration between operational departments and PMT. Where PMT previously had to charge extra for their contribution, researchers no longer depended on such payments. In effect, researchers were more autonomous in their decisions who to work with. And the threshold for partnering departments was reduced as no financial commitment was required. These cooperation-friendly circumstances allowed the new redesign project manager to engage with a ramp up process in which she encouraged doctoral students she was in charge of to diffuse the artefact by contacting new potential customers.

When the new project manager took over, she was the only full-time researcher involved in the redesign project at PMT. Jan, the previous project manager, had additional support from two students working with PMT at that time. They supported him in testing the new versions of the prototype released by CodeMaker and in identifying technical bugs. Thanks to their experience and insights the new project manager got hold of these students to have them continue working with her on that project.

These two students were both doctoral students studying business informatics with a focus on decision support systems and OR methods. Both of them did their PhD in the same academic institution. Their expertise in software development was a highly valuable skill in that critical episode of the project. Although the Kate's background was in computer engineering, she followed a similar approach as Chris and focused on social and political activities while delegating technical tasks to other project members.

However, this was not yet enough support in her view. She approached other colleagues of whom she knew that they had capacity available to work with her on the redesign project. Talking to PMT's team leader and the department manager, she was granted permission to extend the team. The next person to join the redesign project was a doctoral student we will call Vince. He had been working with Kate on a previous project. He was assigned to the project soon after the project manager change. While most other students studied engineering, business, computing or a mix of those subjects, Vince was a student of mathematics. His new primary responsibility was to support the development at the core problem which was the development of a descriptive model that would be used as the standard model.

Another student joining soon after was a doctoral student in business studies who focused on strategy and management. We will refer to him as Moritz. His main responsibility was to test the validity of the calculus of the new model. The old prototype of the NetworkPlanner contained a specific built-in network model which evolved over a few years of time and which was validated for its compliance with corporate controlling standards in cooperation with controllers in the buses division. The model in the old prototype initially was used as the template for the new model that the redesign developers tried to reimplement in the new artefact. However, because of the technical complexity of the redevelopment the new model was at some point practically incomparable to the old model. Therefore, the emerging model had to be validated anew to be sure that it still complied with corporate controlling standards. To get the necessary approval from the controlling department, Moritz engaged with the controlling department responsible for the trucks division. Together they examined and tested the model to make sure that the model was compliant with corporate standards.

The validation process was again an opportunity for the controlling department to get to know the NetworkPlanner. Controllers working with the artefact for test purposes found that it held promising capabilities potentially relevant for their own work. Based on this experience, a separate collaboration was later initiated with the controlling department to probe the opportunity of adapting the model to solve network-related problems in that department. This episode will be elaborated in a later section.

Once again, interns also played an important role in this stage of the project. Two students were recruited within weeks after the project manager change: Anna and Alexander. Anna was a business administration student. Alexander was an industrial engineering student. A third student joined the group a few months later. Oskar was also an industrial engineering student but with a previous career in software development. Similar to the doctoral students, all three interns remained with the redesign project for a time that went beyond the regular time of an internship or final year dissertation. Their participation at the NetworkPlanner development was eventually their pathway to personal careers at CarCo.

After finishing her final year dissertation at PMT, Anna continued working with the NetworkPlanner community as doctoral researcher. The research topic addressed a particular challenge of global strategic planning faced by the trucks division and focused on the utilisation of the NetworkPlanner to find a solution. She was directly employed by the strategic planning department at the trucks division. Her supervisor there was Tom, the former doctoral student who succeeded Chris and who worked on VINP. Despite having been relocated away from the research facility she continued working closely with her doctoral fellows at PMT. She became the third research student who transferred from PMT to the trucks division, strengthening the bonds between PMT and the users in that user department.

The second intern, Alexander, also embarked on a doctoral research project but he remained with PMT focusing on the development of the artefact. This task was soon supplemented by coordinating and delegating activities and liaising with users in the operational divisions. His role resembled strongly that of an assistant to the project manager who herself readily delegated important responsibilities to her doctoral students. The project manager generally regarded and treated all doctoral students as equal colleagues rather than mere subordinates. Her management style greatly contributed to a friendly atmosphere in which the trustworthy and cooperative relations between members of the redesign project flourished.

Finally, Oskar, the third student, who was the only graduate from the local university where the research facility was located, continued his studies to do a Masters degree. He remained with PMT during the course of his studies as a working student. His previous work experience in software development was a valuable skill as he contributed greatly to the technical development of the artefact and the improvement of the user experience.

7.1.5 OR consultancy

An important requirement for the redesign project was, besides developing a new artefact, to create a sustainable solution which included long-term support. With CodeMaker failing to fulfil expectations, the project manager had to look for another strategic partner that could replace CodeMaker. Fortunately, another opportunity was already on the radar. Heiko, a recent doctoral student graduate who previously worked with Kate in another project, joined forces with two other doctoral graduates to spin-off a firm that specialised in OR consultancy.[28] The entrepreneurial idea originated from the founders' experience working as students on projects with industrial partners:

> "[We found] that the application of optimisation models or the research outcomes, which were developed in [our institution], is complicated. To begin with, clients are struggling with understanding what you can achieve with mathematical optimisation and, subsequently, how to provide for software implementation and software development. Back then we saw the gap that we as a firm should carry optimisation methods into the economy. And we still see us as a bridge to bring to attention to companies how they can achieve advantages through the application of optimisation methods, and eventually to offer to realise these advantages." (Heiko, OR consultant, interview, 11 January 2012)

Around the end of 2009 the project manager of the redesign project commissioned Heiko as external consultant to support the research team and CodeMaker in finishing the development of the new system. Being an expert in the field of OR, trained in software development and knowledgeable about CarCo, the consultant represented a welcomed

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28 Formally established in mid-2009, the new spin-off settled nearby the graduate school where the managing directors graduated from and which supported their enterprise from the outset. The spatial proximity resembled the close organisational ties with the academic institution and its staff. Members of the firm collaborated with the academic institution on various levels, including working jointly on a publicly funded project and offering students opportunities to work on real business cases. Besides pursuing academic activities, the firm also worked with industrial partners to develop and to implement OR-based solutions. One of these industrial clients was PMT at CarCo.

partner for PMT capable of dealing with difficult problems faced in the technological project.

The first assignment to the consultant and his consultancy firm was a major technical problem experienced with the artefact. The trucks division's users testing the early prototype of the artefact strongly complained about the overall slow performance of the new artefact, rendering network analyses in that current state an impractical activity. Therefore, the assignment detailed the improvement of algorithms to speed up the overall performance. Every time a commissioned assignment was delivered and implemented into the NetworkPlanner, another assignment followed up. Thanks to a chain of subsequent assignments Heiko had been kept involved in the development. For the project manager it was important

> "[…] that we had a partner, who grew with us, who was exposed to the tasks and who, over a long period of time, […] accompanied the project on different tracks, and who went along with us as supporters." (Kate, redesign project manager, interview, 16 September 2011)

As the development continued, the consultancy contributed to different aspects of the artefact and worked with different actors in PMT as well as the user departments. The firm later also became an important external partner for CarCo's users of the NetworkPlanner.

7.2 Growing the user base

The new generic framework, although being the cause of major concerns and technically not fully functional in early redesign episodes, made it easier than ever to modify the artefact so to accommodate specifics of diverse user requirements. At least so it was promoted to external parties. Also, in its unfinished state it was already flexible enough to demonstrate interested planners that it could be used to address a wide range of network problems. With new students joining the research team, PMT increased its capacity to collaborate with external departments. PMT members therefore engaged in customer acquisition activities to identify potential users and to arrange meetings to promote the NetworkPlanner.

It was, however, not only PMT's researchers who engaged in new user acquisition activities. The lead planner from the trucks division, who was previously described as being significantly more motivated in understanding the NetworkPlanner's functionality than other planners, also engaged in promoting the artefact. He played a relevant role to re-introduce the artefact to the cars and the buses division.

7.2.1 The trucks division promoting the artefact to the buses division

Max, the lead planner, engaged with network planners in the buses division to interest and enrol them in the use of the NetworkPlanner once again. The buses division was significantly smaller than the cars or trucks division. The size was also reflected by the configuration of planning department in the buses division. At the time of this research the team consisted of three planners and two architects. The latter profession indicates that this team was involved with more diverse activities as compared to the strategic planning departments at the larger divisions which were almost exclusively dealing with strategic planning activities. Since strategic projects occurred less frequently, the application of a tool like the NetworkPlanner was therefore also required less frequently.

The team leader of the buses division planning team, Jonas, explained this as the typical lifecycle of strategic planning in context of that division's production network (Jonas, team leader, strategic planning buses division, interview, 24 March 2011). Because of its relatively smaller size, strategically oriented network projects occur only every couple of years. After the strategic stage has finished, the team's activities change to an operational level supporting the realisation of the decisions made during the strategic phase. Therefore the team at the buses division dealt with diverse activities depending on the kind of projects on the agenda. The NetworkPlanner, thus, was required only in cases of strategically-oriented network projects.

In 2009 the planning team was tasked with the optimisation of the production network including the consideration to build a new production plant in an emerging market. This project description reads like a typical case for which the NetworkPlanners had been developed for. Indeed, various managers at the buses division had been aware of a tool specially developed to deal with such problems. Ever since winning CarCo's innovation award in 2008, the NetworkPlanner had been featured in the internal corporate-wide newspaper (Document: Internal research newspaper, December 2008). Everyone working in an area that remotely dealt with strategic planning had likely read about the tool or learned about it in another way. Members of the buses division planning team had another recent opportunity to learn about the recent version of the artefact due to an exchange with researchers at PMT in course of another project. Another team at PMT had been working on a different decision support system, also drawing on OR-based methods but with a focus on an operational level. In course of this interaction they were also introduced to the NetworkPlanner artefact and its team. In addition to that, Jonas, the team leader of the buses division planning team, had a personal relation to the strategic department in the trucks division since he had once worked in that department. Indeed, Jonas had worked with the Max before and thus knew him well. Thanks to these multiple interconnections planners of the buses division were able to get a realistic interpretation about the tool even before engaging with anyone directly involved in the artefact's development. With a new project on the agenda and a basic understanding about the artefact, it was only a small leap for the Jonas to approach Max, his former colleague, to find out more about the NetworkPlanner.

Max was more than willing to respond to the request. Around November 2009 the lead planner engaged in an exchange with his colleagues in the buses division to introduce and demonstrate the functionalities of the NetworkPlanner, version 1. The redesign project had just started, thus Max demonstrated the artefact he was most familiar with. Intrigued by the success stories of previous projects at the trucks division and eventually convinced by the demonstration, the Jonas was willing to use it for their network project. Together with the lead planner they adapted the prototype to meet the requirements of the buses division production network. Since the flexibility of the prototype was rather restricted, these changes were not significant but enough to accommodate relevant requirements. A reason why the existing trucks division-based model was compatible with the buses division production network was partly because of Jonas' origin in the trucks division's strategic planning department. Drawing on his expertise of the planning process at the trucks division he had carried over some routines and terminology to the buses division.

After the descriptive model was appropriated to meet requirements of the buses division, the planners started to collect data to feed the model. The actual analyses were run by the lead planner from the trucks division. Max convinced his colleagues from the buses division that it is not worth to learn the use of the old prototype. Instead he referred to the redesign project and promised that as soon as it would be released it would be made available to them. This division of labour was acceptable for the buses planners. It was maintained throughout the collaborative project. The network problem concerned was successfully solved with the support of the NetworkPlanner. Participation of various actors in other functional areas including production, controlling and sales allowed the introduction of the artefact and its methodology to all parties involved in the analysis of the network problem. It was the general aim to be transparent about what data was used in what way to develop a broad base of understanding for how the eventual decision came about. The NetworkPlanner was instrumental in forming this consent because the calculus for producing those results was traceable and thus explainable. Thanks to this participatory approach results were widely accepted, so was the methodology with which they were obtained. Similar to the pilot projects in the trucks division, the success in that pilot project helped the NetworkPlanner to gain a positive reputation among the top management of the buses division.

7.2.2 Vans division indicating interest

The vans division was the smallest of the four operational divisions at CarCo and also had production plants outside of Germany. Therefore, strategic planners in that division were interested in learning more about the NetworkPlanner. A joint project with PMT was undertaken to explore the potential for the application of the NetworkPlanner. As usual, a pilot project had been selected to test the artefact. In course of the project, however, the potential for the application of a tool like the NetworkPlanner was found to be little. The kinds of problems dealt with by planners in that division were different in their requirements regarding complexity and flexibility. The level of complexity and capability of in-depth network analyses supported by the NetworkPlanner was beyond what the division needed at that time. Planners in that division decided not to pursuit the adoption of the artefact as it seemed to provide little extra benefit. However, it did not mean that they lost interest either. Instead, they opted for staying in touch with the NetworkPlanner community. For the time being they remained with their existing spreadsheet-based solutions. If in the future the need arises to apply a more complex methodology, then they would reach out to their colleagues in other divisions.

In a previous section the team leader of the strategic planning team in the buses division was reported to describe a lifecycle of strategic planning. There is a strategic stage followed by operationally-oriented stages, for example, when increasing sales forecasts suggest the building of a new plant in a flourishing region. After a strategic stage has ended, the situation changes so that planners increasingly deal with operational concerns of implementing whatever decision had been made previously in the strategic stage. The lifecycle applied well in the two smaller divisions where the planning departments had a wider range of responsibilities. According to this theory, the vans division was in a non-strategical stage at the time when other concerns were dominant than those that would require the application of a tool like the NetworkPlanner.

7.2.3 Cars division re-enter the NetworkPlanner arena

The cars division first learned about the NetworkPlanner in 2004. At this time the first doctoral student, Chris, was working on the spreadsheet-based prototype. Strategic planning at the cars division was the second user department approached after contact was successfully established with the nearby buses plant. Although the researchers collaborated with strategic planners at the cars division over the course of a project, there was no further interaction beyond that one project. It was the lead planner from the trucks division who engaged again with his colleagues in the cars division.

7.2.3.1 Trucks division keeping the cars division in the loop

The strategic planning departments of both the cars division and the trucks division are located at the premises of CarCo's headquarter. Indeed, the strategic planning department of the vans division was also located on the same site. Only the buses division's planning department was located on another site. The strategic planning department managers of the two larger divisions made good use of the proximity and met up once a month for knowledge exchange purposes. During these exchanges both managers shared news and information on what was going on in the other division and discussed socio-economic developments occurring throughout the world that were strategically relevant for CarCo. Another item on the agenda was current as well as future network projects. At one of these occasions around early 2007, the trucks division manager gave an update to his colleague on progress made on VINP, the successfully accomplished pilot project that convinced managers in the trucks division to declare the NetworkPlanner as the standard planning tool. Intrigued by accounts of the most recent version of the NetworkPlanner the cars division manager asked to get more information on the current state of the artefact.

Another knowledge exchange meeting for the purpose of demonstration of the artefact was arranged between the two strategic planning departments. The demonstration was exercised by Max, the lead planner. Although it was an informative exchange, it did not result in any further interaction after this meeting. It was only three years later in 2010 that the cars division planners got interested in the tool again and, once more, asked to be informed about the current state of the artefact.

7.2.3.2 *Crisis in the belief of the dominance of conventional production strategies*

The renewed interest in the tool was triggered by a decision by CarCo's board of management (BOM) in the first half of 2010. It was decided to look into the option of shifting the production of a particular car model overseas. This BOM decision was also identified as the moment when a fundamental shift in thinking about the organisation of production networks set in. A strategic planner at the cars division explained:

> "The second contact was made after the board informed us about their decision, when the point was made that in the future we will have to think in networks because the network was shaped that way […]. And we saw where the future journey of [the cars division] was heading to, that instead of rigidly allocating plants to markets, we will have to think in networks in future". (Michael, strategic planner, cars division, interview, 15 July 2011)

In the past the cars division organised its production network according to a solitary structure where plants were equipped with little flexibility regarding the products they could produce. Allocations of plants and markets were relatively fixed and rigid. The BOM decision to reorganise the production network of a particular model was a first step to adapt the cars division according to changing external circumstances where the inflexible allocation of individual products to particular plants proved to be an outdated and costly strategy.

In this case, a shift in thinking is a severe disruption and comparable to a paradigm shift. Kuhn (1996) described a scientific paradigm as those elements that defined what was regarded as "normal science" including the nature of scientific inquiries, methods to observe phenomena and to conduct experiments and how results ought to be interpreted. What was accepted as normal science was replicated by and learned from canonical textbooks. When facing a significant anomaly that cannot be explained within the margins of an existing paradigm and that cannot be ignored any longer, a crisis emerges and eventually a paradigm shift occurs. A paradigm shift shakes the very foundations of normal science. Preexisting knowledge is challenged and revaluated. Methods and instruments, previously marginalised or even discriminated, are put in perspective as they seem to offer solutions where conventional approaches fail. Similar was the process that triggered the BOM decision. In context of a car company, missing out on opportunities to gain profits when markets shifted can be broadly interpreted as the equivalent of an anomaly that leads to a crisis in existing knowledge, or in the belief of the dominance of certain production strategies, respectively. Lack of flexibility of production plants barred the cars division from switching from one product to another to react in time to market fluctuations. The BOM realised that solitary strategies of the past, including the methods and tools to derive such strategies, were no longer fit to address challenges of the present and the future. Thus, new solutions and approaches were sought that helped overcoming the limitations of solitary product allocation strategies. This was the moment, when the NetworkPlanner was recognised, or rather remembered, as a promising solution that offered the ability to explore new strategies.

7.2.3.3 Diffusion to the cars division

A planner from the cars division, Michael, was tasked to engage with PMT to learn more about the NetworkPlanner and to find out if it was a viable tool in light of a new network project. In mid-2010 he was referred by his colleagues in the trucks division to the researchers at PMT who promptly and positively responded to the cars division's enquiry. A doctoral student, Alexander, supported by an intern, Oliver, engaged with the Michael to learn about the specifics of the network project and to introduce the NetworkPlanner to the strategic planner. Interested in learning about the capabilities of the tool, Michael provided data so that the researchers could adapt the standard descriptive model to the requirements of the cars division's production network.

An important role was played by Oliver, the intern. He was supervised by Alexander who supervised the work of two other interns at that time while working on his own topics as well as coordinating the testing of the prototype under development. Oliver was responsible to feed the model with the data provided by Michael. The strategic planner provided a spreadsheet that he created in scope of a previous network problem. Drawing on the spreadsheet and advised by the doctoral student, Oliver transferred the data into the model. Close interaction with the Michael was required to clarify details or to fill gaps which the spreadsheet left open. Within just a few weeks the researchers were ready to present Michael an appropriated model that was ready for running analyses of different network configurations. The quick response time as well as the high level of expertise was positively acknowledged by the strategic planner:

> "And, in my opinion, I came across an incredibly high level of competence. Very quick and smart people in research who absorbed and grasped [the problem] although they were not from the auto world. I was surprised that they transferred the problem correctly into the NetworkPlanner. And we were quickly able to derive conclusive results. I liked that". (Michael, strategic planner, cars division, interview, 15 July 2011)

The quick and competent response from the researchers was important in convincing the planner, that the package of both the artefact and the people involved deemed a proposition well worth to explore further. Interested by the positive results and in need to provide results in scope of the network project, Michael decided to dedicate his full attention to quickly catch up with the artefact. For this reason he spent a week at the research facility to shadow the intern and to learn-by-doing. Together they worked on the network problem and analysed different configurations. The strategic planner emphasised that this straightforward collaboration was a crucial investment of capacity by PMT to convince him about the high potential of the NetworkPlanner:

> "This was basically the knock-on financing by research that eventually persuaded us to endorse the undertaking. And it was well-invested capacity by research". (Michael, strategic planner, cars division, interview, 15 July 2011)

The satisfactory collaboration between Michael and Oliver eventually resulted in the intern taking up a position in the strategic planning department of the cars division. He was recruited as a doctoral student to continue with NetworkPlanner-related research within the cars division in the beginning of 2011.

7.2.4 Training seminars

Within a couple of months the redesign project grew rapidly in terms of people involved in the development as well as use of the artefact. One the one hand the growth was a measure of success. New actors at PMT and at the trucks division helped to increase the capacity to work with the new artefact and to develop it further. New users indicated a growing interest and increasing value of the artefact. On the other hand, many new customers increased the overhead costs in terms of higher organisation and coordination efforts. New users had to be introduced to the artefact. Training them the use of the artefact was a time consuming activity.

Initially, doctoral students visited workplaces of new users to demonstrate the artefact and how to use it. However, this individual approach was found impractical for the higher numbers of people that started to indicate their interest in the NetworkPlanner. Thus, the training strategy was adapted to accommodate for the new quantity of users.

This is the episode when we contributed to the redesign project during the data collection stage. Our task was to elaborate a structured training programme including the development of materials. Together with other doctoral students, an outline was elaborated for a multi-stage training programme that distinguished users according to their existing knowledge about the artefact. In total, three different courses each consisting of several modules were developed for beginners as well as for advanced users. Developing the contents of the course materials was mostly commissioned to the external OR consultant. We supported the consultant in this assignment.

All but one course were held at the research facility to allow attendants to leave their workplaces and to visit the research facility. The session that was organised outside of the research facility, was held on premises of the strategic planning department of the cars division. It was to show good will to the new users of the cars division's strategic planning department and to make it as easy as possible for that department's staff members to attend the training session as for some it was the first exposure to the artefact.

There was no documentary about the first two training seminars as they were held by two of PMT's doctoral students. But the other seven seminars were organised by us so it was possible to keep track of attendees. Attendees represented 15 different departments from all four operational divisions. Many of the attendees included users who had been working with the NetworkPlanner before but with a researcher supporting them in their activities. Other user had little or no exposure to the tool at all. For them it was a crash course to understand what this tool was about and what potentials it had for their own work. For example, CarCo's internal engineering consultancy dispatched five staff members to learn about the NetworkPlanner. They were interested in exploring the opportunity to add the NetworkPlanner to their repertoire of services.

The training programme was shaped to appeal to and to attract a broad range of people with the intent to promote the NetworkPlanner as widely as possible. Many events were attended by users who knew about the practical value of the artefact but wanted to learn more about it. Although it was attempted to present the artefact as a mature product, attendees were not mislead to believe that it was flawless. It was emphasised that it was an artefact yet in development and that there were still functionalities that needed polishing. However, the core functions were working and ready for practical application as demonstrated by pointing to successfully accomplished network projects in the cars division and trucks division.

7.3 Strategy change in the research organisation

Organisational changes occurred rather often in the research division as several interviewees confirmed. Often such changes were preceded by rotations in the management level. When a new research manager took up her position, strategic deliberations were initiated to elaborate ideas about future directions and activities of the corporate research division as envisioned by the new manager. These activities happened behind closed doors. When results of these deliberations were announced to employees in the research division they usually were in their final state. There was no option for individual researchers to influence the outcome. This approach appears to be opposite to earlier times when the research division had been created. Back then researchers were encouraged to set their own research agenda. Nowadays, after numerous organisational and strategic changes, agenda setting was a rigid top-down process.

7.3.1 Strategic changes and the need for protection

Consequences of a change of the strategic direction had direct effects on an individual's project activities, at times even disrupting the line of work. The OR consultant, who worked with PMT from 2006 to 2009, recalled three such significant changes that rippled through to his research team. The first one he faced was in 2006 which not surprisingly coincides with a new manager being appointed to lead those parts of the research division in which PMT was located. A consequence of the subsequent shift in strategy for the doctoral student was that his research subject was no more on the agenda. He explained the effect this had on his work:

> "Well, you don't stop thinking, but de facto you wouldn't get any new cooperation working because you need the support of the hierarchs for that. You cannot begin any new project. You call your customer and you tell them: 'What we planned for the next year will not be happening. You can complain or leave it, but we just don't have the support any longer to do that'" (Heiko, OR consultant, interview, 11 January 2012)

A full-time employee would most probably be annoyed by this disruptive change, but eventually settle with it. However, for a doctoral student, one year into his research, this was more than just an annoyance but rather a substantial threat to his thesis. A second incident occurred during the development of the early prototype of the artefact. During a trial of strength incident with a team from the Berlin research facility, PMT was outmaneuvered and ordered to abandon its activities into exploring a particular branch of research because the other team successfully claimed its jurisdiction over that research area. The solution was to comply with the decision as a team but to give doctoral students the freedom to continue with their research. It was the strong support of PMT's department manager that allowed for this compromise to come about and to save a student's research activities from the effects of such political decisions. In the case of the OR consultant, it was the department manager who stood up for him and enabled him to continue his work somewhat covertly. A year later the situation loosened up to that extent that his subject was generally accepted again so that he go about his work as before, e.g. engaging with other internal customers again.

The department manager was described as being personally interested in strategic topics and thus granted PMT relatively much freedom to explore related subjects. When it came to organisational changes, he acted as a wall to avert negative implications on his department if possible as depicted Kate, the redesign project manager:

> "[The department manager] assumed the responsibility to be the protective layer between hierarchy and the people who work down here, and to deflect change efforts so that it did not impact on us. And he always made sure that we had adequate budget." (Kate, redesign project manager, interview, 16 September 2011)

As PMT's department manager, he had directly overseen the creation of the team, its initial exploration of the research topics and subsequent development of multiple attempts to transform research findings into practical applications. His role in supporting these activities on multiple levels was pivotal for the NetworkPlanner to reach a relatively mature state. Correspondingly, his retirement at the end of 2009 had a significant effect on PMT and the researchers working on the NetworkPlanner in particular.

7.3.2 Research team relocated to other department

After the department manager retired and was succeeded by another manager, a few months later another reorganisation initiative occurred that affected PMT directly. This time there was no protective hand keeping things together as the manager did in the past. PMT was restructured and all members that worked on the NetworkPlanner were allocated to another department in mid-2010. This change did not result in a friendlier work environment for the NetworkPlanner team. In general, the researchers around the NetworkPlanner had most of the time been in a troublesome political situation. The research undertaking originated to large extent from initiatives that footed outside of CarCo. The top-down-oriented hierarchy struggled with PMT's strong and practice-backed bottom-up approach. Acceptance, or rather tolerance, by top research management was achieved through successful collaborations with operational departments at times, when external funding was an important stream of income, and when the research division could make use of showcasing collaborative engagements between research and practice. However, these expectations have changed since PMT had been created about a decade ago. The redesign project manager briefly summarised her project's situation in relation to the overall research strategy at that time:

> "What is not popular at the research group, neither now nor in the past three years, is the topic production and the topic of [the trucks division]. Actually, we were supposed to work on [the cars division] development." (Kate, redesign project manager, interview, 16 September 2011)

The former department manager shed more light on this conflict by highlighting the organisational interdependence of the research division to the cars division, the largest division at CarCo:

> "I think it is to do with the fact that it depends on the structures in the top. The topic we do is rather production-oriented. And as long as the head of research is also head of [The cars division] development, it will remain difficult." (Patrick, research department manager, focus group interview, 12 November 2011)

Traditionally, the cars division has been the largest and thus the more important division within CarCo. Due to this historically contingent circumstance, the research division was most dependent politically on the cars division. As reminded by the former department manager, the head of the research division was also the head of development for the cars division. This dual responsibility explains a bias towards research topics that are more relevant to the cars division rather than any other division. In particular, the fact that this person is in charge of development, a function that is concerned with new product design and development, is explanatory for the discrimination of production-oriented subjects within the research division. To conclude, it can be stated that, to some extent, the top management of CarCo's research division was hostile to research activities involving the NetworkPlanner. It was only the support of the middle management, i.e. the department manager, and PMT's frequent successes in acquiring both funding from outside the research division and strong support from managers in production-oriented areas of the company, that convinced the top management not to dismiss but to tolerate PMT's nonpartisan activities over a long period of time.

After PMT's restructuration the project manager found herself removed from her previous environment and assigned to a new department and new team leader. The relative lack of support from the new department manager for the development of the NetworkPlanner was apparent. Taking into account the low level of interest of her new superior in her work and considering the new overall situation critically, the project manager decided to bring the project to an end, at least from the research point of view:

> "I drew the conclusion that we reached a certain state and now we transfer. Because for me personally this was unsatisfactory and also for my colleagues, my doctoral students who always had to stand in the shadows. In the new department were we arrived at up last summer, we were not allowed to communicate these topics upwards: 'Stay away with your production topics. I cannot show these to [a top research manager] .'" (Kate, redesign project manager, interview, 16 September 2011)

Discouraged to continue work under such adverse circumstances, she decided to focus on finding a sustainable solution to transfer the NetworkPlanner artefact out of the research division and into the operational area of CarCo.

7.4 Transfer into user departments

By the end of 2010 the artefact had reached a relatively stable version that was regularly applied by the trucks division. By this time, the researchers also had their foot in the door at the cars division. Thanks to several training seminars a wide range of people in various departments had been exposed to the artefact.[29] The project was popularity-wise at a long-time high. Existing users and attendees of the training seminars reported their positive experience to their superiors who reported this further to their superiors. Thus, the NetworkPlanner had a strong visibility in upper management levels at the end of 2010. For the project manager this was an ideal moment to seek closure for the project. She decided to organise a single large event to declare the redesign project as accomplished.

7.4.1 The Launch Event, an agenda-building exercise in disguise

The event was titled 'Launch Event' to show that the artefact development had been finished and that a roll out could begin. Of course, this title was only symbolic as the launch had happened gradually in various different episodes throughout the previous years. But the event's title can be interpreted as an important message aiming at decision makers whose turn it was to agree on what ought to happen next with the artefact, and thus, with the doctoral students whose fate was partly connected with it.

The launch event was held at CarCo's headquarter, home of most of the strategic planning departments, in December 2010 and attracted a large group of people from different levels and departments. About 60 people attended the first hour that comprised several ten-minutes long talks of high-ranking managers from different divisions. The main objectives of the event were, firstly, to officially announce the accomplishment of the redesign project, and secondly, to proclaim the establishment of a community of practice. As described above, announcing the accomplishment of the project was mostly a symbolic act directed at the management including the research division which wanted the project to be finished. The proclamation of a community of practice served the purpose to emphasise the existing social bonds between the different planning departments and to encourage new users to join the open community. It was a concerted show of force to players outside that this was a successful undertaking supported by strong inter-organisational bonds (see Figure 18 for an illustration of the kernel configuration at the time of the launch event with new players highlighted in bold).

29 In total nine training courses were held in the second half of 2010 including five courses that covered the basics and four courses that covered advanced functionalities.

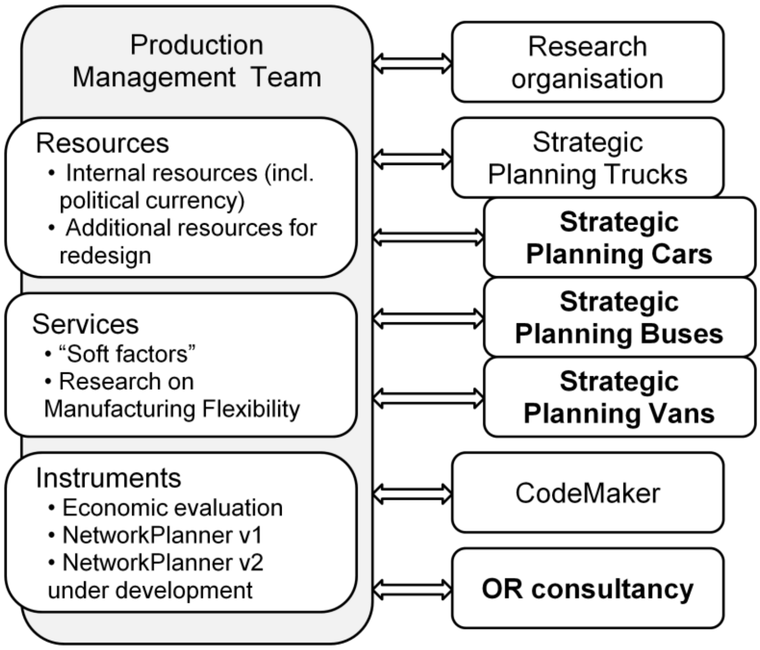

Figure 18 Extended ecology of PMT's kernel at the time of the launch event

The event was successful in making visible the rich research infrastructure constructed over many years. A wide range of people was informed firsthand about the current state of the NetworkPlanner and the value added by the artefact to the overall company. Those attendants who had not had any exposure to the artefact yet must have gotten the impression that this was the final stage of a project that successfully transitioned linearly from research and development to practice. At least this is how the launch event was conceptualised to be perceived. In fact, the launch event disguised the case that yet there was no sustainable solution in place. It was unclear who would take over the responsibility of the maintaining the artefact and how the final arrangements would look like. In this respect, the launch event could also be interpreted as an agenda-building exercise coordinating multiple actors to bring to light shared beliefs and expectations (van Lente & Rip, 1998a). Identifying shared beliefs and expectations allows actors to accommodate their interests in respect with the interests of other actors. This exercise of mutual positioning creates a demand for action that results in agenda-building eventually. To conclude this interpretation of the launch event, it aimed at preparing the agenda for the final negotiation talks between research and the operational departments.

7.4.2 The cars division positioning itself prior to the transfer

For the project manager the launch event was a welcome moment to demonstrate the value added by the NetworkPlanner and the team of people behind the artefact. It was a chance to raise the profile of the artefact and the individuals in the negotiation talks that followed the event. The first action after the launch event was a transfer of expertise, embodied by individual researchers, from research to operational departments.

The trucks division was already well positioned at that time as it had two members of staff who had previously been involved in the artefact's development at PMT. Tom had been a doctoral student at PMT who was primarily responsible for the development of technical and OR-related aspects of the artefact. Anna was a doctoral student developing a trucks-specific network model for the artefact. Previously she has been a student working at PMT. This leaves the trucks division in a good situation to operate the artefact in the long run and to deal with future challenges. In contrast, the cars division had no such arrangements. All it had at that moment was Michael who was familiar with the NetworkPlanner. However, this was by far not enough experience to use the artefact without further support by experts. In short, it was the cars division's strategic planning department who had to catch up if it wanted to secure its stake in the artefact.

There is no clear evidence of any rivalry between the cars division and the trucks division's strategic departments. Indeed, both divisions had been collaborating and sharing information frequently and on different levels including monthly meetings of the departments' heads and irregular meetings between strategic planners. Despite the harmony between the two departments, the socioeconomic discrepancy between the two divisions cannot be ignored. The cars division is by and large the bigger division producing about twice as much revenue as the trucks division. This difference in volume is indicative for the cars division's dominance in CarCo which is also reflected by CarCo's organisational structure. For example, the head of the cars division's development is also head of CarCo's research division. This historically-contingent imbalance resulted somewhat in an understanding that the cars division was regarded as the leading division in CarCo. In this light, it was comprehensible that, at times, the trucks division sampled the pleasures of being the competence leader in complex strategic network planning. For example, during a training seminar, when strategic planners from both divisions attended as trainees, it was a strategic planner from the trucks division who took the chance to lecture his colleague from the cars division when it came to a discussion about financial evaluation of options in network configurations.

With the power dynamics in mind, it is not surprising then that the cars division increased its effort to gain control over the artefact to not depend on any other organisational entity. The first decision by the cars division's strategic planners was to take onboard Oliver, the intern who had been collaborating with Michael in course of the network project at the cars division. Oliver was recruited as a doctoral student to work with the strategic planning department in February 2011. With this move the cars division positioned itself to gain some agency so not to be reliant on any other player, in particular not from the trucks division who de facto was the intellectual property owner of the NetworkPlanner.

Employing one of PMT's interns was a first step. However, it was yet insufficient as intern had had only limited exposure to the artefact and its development. To mirror the situation as it was in the trucks division, where there were two previous PMT members at work, the cars division was yet one person short. This gap was filled by the employment of Alexander, the doctoral student who had previously been supervising Oliver at PMT. He was offered a full-time position as strategic planner at the cars division later in April 2011.

7.4.3 Community of Practice to coordinate further actions

After the establishment of the community of practice was announced at the launch event in December 2010 a first community meeting was organised five months later in April 2011. This event was titled 'initial meeting' to mark the first event of its kind. It was organised by the research team and held on the premises of the research facility. A total of twenty individuals attended the meeting of which half the people were users. With six attendees the majority of the users were the trucks division's strategic planners. Three attendees represented strategic planning of the buses division and the cars division while the remaining two individuals were potential users from other departments. A small group of three individuals were externals: the OR consultant, a visiting professor and myself. The last six attendees represented what remained of the former PMT including Kate, the redesign project manager, Alexander and two other doctoral students.

The agenda of that meeting was to present what had happened in the months since the launch event in regards of the development by the researchers and the application of the artefact in the user departments. Further topics were the future of the community, the transfer of the artefact and a concept for maintenance and support services for the artefact. Particularly the latter two items on the agenda were still unresolved matters as no final decision has been made by relevant decision makers. The meeting was used to discuss different options presented by the redesign project manager. She reiterated the research strategy that did not include the NetworkPlanner development among the remits of the research group. The two options she proposed differed in the level of coordination among the different users. One option was that every user department would deal with the development, application and maintenance of the artefact individually. The other option accommodated a collective approach with the community of practice being the instance that would coordinate all activities related to further development, maintenance and support. This option also stipulated a financial commitment by each participating department.

Independent from the final solution, a solution had to be found for the problem of who would be providing the services for maintenance and support for the artefact. These activities had previously been catered for by the researchers. However, the end of this arrangement was a settled matter. An alternative had to be put I place. CodeMaker, the software company that initially developed the new version of the NetworkPlanner and which was intended to take this role, was not available any more. Instead, the OR consultancy offered to extend its services to cover maintenance and support activities. For this purpose the consultant outlined the range of services his company could cater for and how much these different levels of support would costs. A forth option comprised a cooperation with CarCo's internal engineering consultancy. The engineering consultancy had previously sent five consultants to the training seminars to learn about the NetworkPlanner and to evaluate its value for the consultancy. After his presentation, the attendees were asked to discuss the pros and cons of each solution.

After the final presentation on future challenges of the planning and coordination of global production and supply networks by the visiting professor, the redesign project manager concluded the event by wrapping up the event. In her final address she outlined the next steps to be taken by each represented department. She stressed the need to discuss the potential solutions presented at this event with other members of the respective department and to report to her what solution was preferred. She would collate the results and forward a recommendation to a group of managers who had scheduled a meeting in June 2011 to decide on further actions.

The community gathered again in December 2011. In the eight months that had passed in between, the transfer of the artefact from research to the members of the community had been accomplished. During this transitional time, the internal engineering consultancy withdrew its interest because it found that the artefact did not match the organisation's requirements. The artefact was too specific and complex to be used in projects dealt with by the consultancy. Due to the steep learning curve and the specificity of use cases in which the NetworkPlanner was applicable, it did not fit the into the methodological tool kit of the consultancy. The only remaining option was the OR consultancy, which readily stepped into the gap. Consequently, the OR consultancy became the only service provider covering activities including, among others, provision of support and further development of the technical artefact.

The second community of practice meeting was organised by the trucks division's strategic planning department[2]. The meeting attracted 22 people from four departments. Half the attendees were strategic planners from the cars division because the meeting was held in the building of that department. Seven planners from the trucks division came over from their offices on the same site. Two attendees represented a department that dealt with challenges in transport rather than production. One of them was Oskar, the intern who had been working with the research team parallel to his studies for about two years. Making use of his expertise in developing and applying the NetworkPlanner he left the research team to do his Masters thesis on a research problem within that transport department. The transport department was interested in learning about the possibilities afforded by the artefact during this engagement. Another attendee was from the controlling department. Finally, one attendee represented the strategic planning

2 To coordinate the event with the other participating departments and to assist the lead planner at the trucks division in the agenda setting process, we were commissioned to support the organisation of this event. Similar to the initial meeting the agenda comprised updates on technical changes of the artefact and methodological advances on the different network models under development by different students. Planners presented current and new projects where the NetworkPlanner was put in action. Oskar reported on his approach to adapt the standard descriptive model to accommodate the requirements of the project in his department. After these presentations, attendees were asked to participate in focus group discussions.

department of the buses division. The constituency of the event reflected the purpose of the community of practice concept in respect of the NetworkPlanner. A core group consisting of planners from the cars division and the trucks division dominated the community but other departments interested in the artefact and the practice of strategic planning were encouraged to participate and to contribute.

Both community meetings successfully brought together people interested in the practice of network planning and provided space for the exchange information and to share knowledge. The heads of the strategic planning departments of both the cars division and the trucks division attended the events and acknowledged the potential contribution of these meetings to increase quality of the network planning practice in CarCo. Despite the positive feedback, there was no further community of practice meetings in big scales thereafter. What followed were occasional informal meetings off-work which were mostly organised by the generation of planners who previously were actively involved in the development of the artefact. Thus, a space for interaction and knowledge exchange was retained, albeit on a smaller scale.

7.5 Conclusion

Although the redesign project was intended to 'close' the NetworkPlanner development, a well-minded and broadly supported approach to improve the flexibility of the artefact yielded unintended and severe consequences. The new turn in design weakened and partly uncoupled the socio-technical configuration between the artefact, organisational settings and practices, and the individuals involved which had been carefully co-configured in numerous episodes over several years. What followed was a new season of episodes where parts of the artefact had to be reconceptualised and redeveloped, and users had to re-adapt to the use of the altered NetworkPlanner anew. However, despite a serious strain of resources and organisational tensions caused, the technical change opened up new avenues to promote the artefact to a new array of players. The newly acquired generic capability, whose implementation was the cause for significant technical and managerial struggles, enabled the proponents of the technological project to create bespoke couplings between artefact and users relatively easier than it would have been possible with the old architecture. The generic feature enabled different researchers to pursue new strategies to engage with users in more effective ways. In other words, it was a feature that was particularly effective in enabling social learning processes between actors and across multiple locales.

This chapter closes the investigation into the empirical case study. We started with a historical examination of the corporate history to learn about the organisational landscape and to understand why historical and contextual dynamics created opportunities for specific actors in a certain locale to pursue particular strategies and actions. Without the knowledge and the understanding about these historio-contextual details it would have not been possible to explain the reasons why some strategies where more effective than others. It was our purpose to highlight the close alignment of historically-contingent, contextual dynamics with local actions of individual actors. The historical examination put the technological project into perspective to the many dynamics and contingencies that shape the course of actions of organisations. These dynamics and contingencies are chaotic due to the numerous linked ecologies that characterise an organisation. Local events play out in the context of such linked ecologies. Therefore, we argue, it is an important requisite for a social study to know about these ecological dynamics to make sense of events within individual ecologies.

This and the previous chapters detailed the events and processes that played out within a set of linked ecologies over a longer period. Reporting about the social shaping of the NetworkPlanner, we continued to relate local practices to dynamics in the wider ecological fabric. The global context and local processes are mutually intertwined to the extent that any incident on each side ripples through to the other side. A change event in the context allowed for actors to take advantage on a local level. For example, after losing its interest in the NetworkPlanner, a change of direction by the corporation's Board of Management enabled the industrial researchers to direct its attention towards the engagement with strategic planners that division. Equally, advances on local level can have an effect on contextual properties. For example, after implementing a generic framework, the industrial researchers were able to pursue new strategies to address new audiences. Technological advances on the local level thus allowed new possibilities to interact with other ecologies and contexts.

In conclusion, the empirical chapters attempted to jump back and forth between content and context to make visible these linkages between multiple locales in different ecologies. Since we investigated how the technological project evolved over an extended period of time, we traced qualitative changes in these relationships. Over time, new actors entered the scene while others departed. At times, actors reappeared to form previous alliances anew. However, the relationships changed in shape and contents as compared to previous relationships. In general, change was a prominent feature throughout the case study. Almost every element, if not any, was somehow affected by change: the technological properties of the artefact, the configuration of individual actors and organisational players, relationships between players, etc. The innovation process itself changed qualitatively over time. While uncertainty and ambiguity dominated early activities, the innovation processes gained in pace and clarity over time. What was a distributed research undertaking in the beginning evolved to a technological project with a project management structure. As the innovation process unfolded, a technological artefact crystallised in context of an ecology of actions distributed across multiple locales. The technological artefact is a reflection of these historically-contingent and context-dependent actions. In the following discussion chapter we will elaborate how the empirical data relate to our ecological framework. There, we discuss in more detail the relationship between the context and content of technological change.

8 Discussion

The social shaping of technology is a long process of negotiations where progress plays an important role. Privileged actors make choices that decide about shape and content of an artefact. Technological development is thus a 'garden of forking paths' (Williams & Edge, 1996, p866) where when a choice was made, new choices open up while others close down. Consequently, actors construct their own histories by making decisions among a variety of choice options. However, the conditions under which these choices are made and the contents of these choices can be beyond the immediate control of said actors. The availability and contents of choice are shaped by pre-existing social structures, i.e. the context of action. Therefore, to understand the social shaping of a technology, i.e. the availability and contents of past technological choices, one needs to understand the context under which a technology was shaped.

In this chapter, we attempt to condense and to summarise the previous empirical chapters by applying the ecological framework. In order to simplify the analytical narrative and to strengthen the readability of the complex case analysis, emphasis will be given to a comprehensible reflection of the empirical data. The chapter is structured in two sections. The first section will be reflecting primarily on the context of the technological development. In particular, it will report on how the initial organisational topography, in which the technological development was embedded and which patterned subsequent developments, came about in the first place. This first section will stress transformations of larger social and corporate structures in CarCo as they occurred from the 1980s up to 2000. The second section addresses primarily the dynamics of technological developments as they occurred in the period between 2000 and 2012. There it will be reported on how the group of industrial researchers accumulated and transformed resources to sustain their research activities and, consequently, the development and implementation of the technology concerned. All concepts of the ecological framework apply to the whole period. However, we will pull out and detail those episodes of the innovation process that illustrate the concepts well.

The two sections in this chapter address macro-level dynamics and micro-level observations, respectively. Nonetheless, the analytical narrative attempts to maintain the same flight level by taking a meso-level perspective. This perspective is an intermediate view that compromises between individualism and emergism (Abbott, 2005). The former is an account where social systems are the sum of all individual actions while the latter is an account where social systems have an inherent logic that determines the actions of an individual. In other words, the meso-level perspective acknowledges the actions of individuals but equally takes into consideration how structural properties are involved in shaping social dynamics. For this reason, the analysis adopts the ecological metaphor and the concept of linked ecologies as the underlying conceptual foundation in order to maintain a meso-level perspective. In this intermediate view, individuals can freely interact but within a corset of structural conditions negotiated collectively through past interactions. Past events of negotiations, history in general, therefore are crucial pieces in the understanding of why and how a technology was shaped in a particular way and why one choice was made over another in contextually patterned situations. With the localist turn, studies of technology either neglected or took for granted such knowledge about historical facts and identities of actors and organisations (Pollock & Williams, 2010). This discussion chapter aims to foreground the role and influence of history and context, and the identities and relationships of individual actors and organisational players in the social shaping of technology. This combination of context and content is at the heart of the Ecological Shaping of Technology framework.

8.1 The context of social shaping of technology

The first section addresses contextual and historical matters of the case studied. It will summarise and discuss how historical transformations within CarCo patterned the conditions under which the development of the NetworkPlanner was made possible in the first place. Visionary and strategic efforts of transforming the firm's organisational landscape triggered long-term developments which patterned the context of both the research group in general and the research team studied in particular. Elaborating the coming about of this peculiar organisational context will explain why it was a certain set of actors, the members of PMT in this case, who found themselves eventually in the spotlight of inter-divisional tensions and why contextual conditions limited the range of choices made that eventually led to the take-up of the development of the NetworkPlanner.

8.1.1 Historical transformations shaping the context of the research group

The development of the artefact examined in this study was not the intentional outcome of a deliberate research strategy. It was not an accidental event either. It resulted from situated actions (Suchman, 1987) by a small set of actors whose choices were limited and governed by the particular topography of a socio-politically constructed organisational landscape. The configuration of CarCo's organisational topography was also neither fully planned nor a random occurrence but resulted from the unfolding of consequences of organisational transformations within the firm. We have to go as far back as to the mid-1980s to learn about the initiatives of organisational transformations that patterned the socio-political configuration in which the emerging research team was embedded in 2000.

In scope of the grand vision in the 1980s the research group was established to symbolise CarCo's excellence in technology and research, and to be the link between various organisational units that characterised the diversified but integrated technology firm. In the early 1990s the research group witnessed the peak of its reputation within CarCo. Indeed, when the organisation was new and effective ways to coordinate central research directions were yet to be implemented, the researchers were granted much intellectual freedom in deciding about the contents of their work. However, subsequently their privileged standing and autonomy was gradually reduced by the implementation of more and more quality and performance measures to ensure their alignment with business strategies.

An important organisational circumstance of the research group was that it was not set up as an independent division. Reflecting existing internal power structures, it was attached to the car division, which was the largest division among CarCo's operational divisions. In particular, the head of development in the car division became also the head of the research group. Attaching the corporate research unit to the car division gave the car division privileged managerial control over the unit. From a linked ecology perspective, the centralisation of corporate-wide research activities into the research group can be interpreted as the formation of a new location, in an Abbottian sense, which the car division successfully gained control over due to its privileged position in the company. This political bias within the research group did not play an immediate role in the biography of the artefact because the grand vision embraced an inclusive approach encouraging and empowering researchers to engage with research topics beneficial for all divisions. It was not until ten years later that the vision of an integrated technology firm was replaced by an emphasis on the shareholder value. This shift in the corporate vision was accompanied by major transformations of CarCo's organisational and political topology. It was then that the hierarchical location of the research group inside the political structures of an operational division started to show an effect.

As the vision of the integrated technology firm failed to deliver its promises it was increasingly regarded as a failing overall strategy. The new CEO appointed in the mid-1990s re-prioritised the corporate strategy to focus again on the core competencies of manufacturing land-based vehicles and de-facto abandoned the grand vision of his predecessor. The previous corporate vision promoted technological excellence as the dominant evaluation criteria. A shift to a shareholder-oriented vision, however, also shifted the dominant evaluation criteria away from technological quality towards the economic qualities of productivity and profitability. As a result, CarCo experienced a considerable change in its corporate culture due to a change in the dynamics of collective expectations (Konrad, 2006). The wide-spread disappointment, also reflected by critics outside the firm, about the moderately successful strategy of technology integration paved the way for rhetorics about productivity and profitability to gain traction. Proponents of technological excellence, of which the research staff in the research group was among the strongest supporters, began to lose out against the supposedly rational arguments from proponents of the new corporate strategy already in the years leading up the swap in the board room.

In the arena of expectations concepts, enactors engage with selectors to gain their trust and mandate to pursue a direction of actions. The vision of the integrated technology firm can be interpreted as an arena which CarCo entered under the leadership of the CEO appointed in 1985. The dominating cultural matrix of expectations was characterised by the widely shared belief that high investments into technology and science hold the key for riches and high profitability. These generic expectations surrounding the idea that research and technology excellence were sufficient for the CEO to get a mandate from the board to pursue this strategy. Putting the vision into practice and delivering the promises in terms of specific outcomes, however, failed in the long run. Eventually, the strategy was deemed a failure as the promise was found to be undeliverable. The board did not renew its mandate to the CEO and appointed a new one who departed from a strategy pursuing excellence in research and technology in favour of a strategy that favoured economic factors.

With a new CEO and a new cultural focus in which economic considerations prevailed, all assets of the firm were re-evaluated in terms of their shareholder value and their contribution to CarCo's core competencies. Organisational units were singled out and either put up for sale or liquidated. In other words, CarCo was un-diversified and re-homogenised. This had a negative consequence on the research group. At the time of its founding, the research group was envisaged to be the binding element for the diverse technological landscape united under CarCo. However, with an increasingly homogeneous corporate landscape and a new cultural matrix of expectations in place, this broadly defined objective did not match the corporate strategy any longer. Many research projects, although technologically top of their class, saw their perceived value decreasing because they were not exclusively tailored towards CarCo's redefined core competence which was the manufacturing of land-based vehicles. Thus, the research group found itself in a situation where some of its outcomes risked not meeting the requirements in terms of both the specific technological needs of operational business units and the dominating performance measurement criteria. Applying the linked ecology concept again, this episode of organisational transformations resulted in a major modification of relationships between the research group and other linked ecologies. While the research group enjoyed a dominant role in the previous corporate vision, this status was largely reduced in the succeeding corporate vision. This change in status was mostly represented by a reduction of linkages to other organisational units of which some disappeared entirely. Besides this qualitative change in relationships, the corporate arena of expectations to which the research group catered for became a space populated by fewer but a more homogeneous group of selectors. The narrower range of selectors resulted in a narrower range of promises acceptable within the arena of expectations. Research undertakings previously accepted by a heterogeneous group of selectors failed to meet functionally more specific expectations of homogeneous selectors. The fabric of linked ecologies, the topography surrounding the research group, therefore is linked intimately with the contents of promissory activities. A change in the fabric of linked ecologies inevitably affects the arena of expectations and its inherent cultural matrix.

This subsection has reflected on events that happened over a period of twenty-five years in which the larger context of this case study had developed. The developments reported unfolded slowly over a long period of time. The meso-level perspective, which emphasises how dynamics shape individual ecologies in contrast to an actor-oriented micro-level perspective, maintained the analytical gaze on single organisational units but took into account large-scale dynamics affecting the entire firm. The following subsection will turn the other way and examine actions of a collective of individual actors. However, we maintain the meso-level perspective to foreground how dynamics play out within an ecology of interconnected organisational players.

8.1.2 Context shaping conditions of the organisation of the research team

Due to investments in highly-educated scientists specialised in narrow subject fields and expensive instruments and materials, strategic redirections were more difficult to impose on the research group than on other parts of the firm. After all, R&D was an important prestige object for the public perception of the firm. CarCo's new corporate landscape therefore posed a long-term structural problem for the research group. Typical for hierarchical and mechanistic organisations (Burns & Stalker, 1961), the senior management of the research group decided to delegate elements of the problem to a new organisational unit and thus created a new team, the Production Management Team (PMT), to address the problem of the low spillover of research outcomes into operations. The general understanding was that one major problem of the low spillover was due to the late consideration of social and economic factors in the research and development of new technologies. It was a lack of "soft skills", as one member of PMT put it, that rendered final research outcomes unfit to the operational requirements on the shop floor. The supposedly missing soft skills thus were a cause for the apparent mismatch between research activities and operational requirements. Obviously, even five years after the coerced introduction of a new corporate culture, the research group was still struggling to conform to the new culture. The new team ought to build a bridge and to be the missing link between the two cultures. The remit of the new team, mainly to provide technology assessment services to other research groups in order to facilitate a successful transition of research outcomes into operations, indicates that a linear model of innovation prevailed when the idea for the team was conceptualised. On a basic level a linear model implies that the innovation process follows an inherent logic where a technology goes through the process of design and development before it transitions to the market (Williams & Edge, 1996) or into the operational environment in case of production technologies. Broadly speaking, technology assessment, among PMT's chief responsibilities, has three functions: forecasting, monitoring and control (Kranakis, 1988). Because PMT was instructed to engage with existing projects, where technologies have already been designed and developed to large extent, the control aspect of technology assessment was the only function that was available for PMT's members to engage with. This later-stage control function aims at "[shaping] the ways and contexts in which technologies are used" (Kranakis, 1988, p. 291). Thus, PMT's members engaged with their research colleagues' technologies-in-development and potential users of their technologies.

A budgetary detail ensured that PMT had a strong interest in collaborating with its internal colleagues. Half of PMT's budget was guaranteed. The other half was to be acquired through their collaborations with other research projects. This financial design feature rendered the internal research group a selection environment with one side offering services and the other side selecting to accept the offer, or not. PMT's members became market players who had to promote their services like vendors on an internal quasi-market. Thus, the lack of funding required PMT's members to act like vendors. This included an increased degree of autonomy in the team. To offer and sell their services on the quasi-market, PMT's members were required to adopt a different mindset towards their work than their colleagues working on their own projects. The dynamics of expectations became a highly important aspect of PMT's work. Because they had to promote their work to other players, PMT's members adopted a strong routine of raising expectations by promoting their services and promising increased gains to other market players. Similar quasi-market dynamics had been observed in the research unit of a big bank. A group of internal researchers combined deliberate strategic decision-making with opportunism to offer their services to internal departments in order to develop and implement multimedia technology (Gallacher, 2004). To conclude and to emphasise the significance of PMT's contextual circumstance, the research group, unintentionally as we argue, created a team that had no choice but to develop an idiosyncratic style of work, which was dominated by promissory activities, that diverged from what was perceived as the norm within the research group. The socio-political configuration of ecologies in which PMT was embedded gave rise to a liberal culture that encouraged the researchers in PMT to seek out relatively autonomously for ways to find new locations in order to fund their own activities.

The innovative idea to introduce some degree of market liberalism, however, failed to anticipate the behaviour of other market actors. In particular other internal researchers in the research group, who controlled the budgets of their research projects at which PMT was aiming at, showed unanticipated reactions. These colleagues were found to be reluctant to comply with the liberal idea that expected them to share their budgets for services they did not necessarily regard as necessary. Different to what the senior management anticipated, the researchers did not see the value in PMT's offerings. Far from it, they did not like sharing sensitive details of their work with external actors who then evaluated their work. To them PMT appeared to be yet another controlling instance that tried to gain control over their research activities. Understandably, they were reluctant to collaborate with PMT. As a consequence of their colleagues' resistance and the viscous flow of income from internal collaborations, PMT looked out for other sources of funding.

The tension in the supply of resources required PMT to adopt novel strategies to sustain their activities. The unintended consequence here was the emergence of a style of work that was characterised by an enhanced relevance of promissory work in the routines of PMT. Since the internal contest for resources and status turned out to be problematic, members of PMT drew their attention to opportunities outside the firm. An opportunity where PMT could apply their skills in promissory work was the participation in publicly funded projects. Looking into the potential of new and promising technological arenas was another reason why PMT was created and falls into the remit of another function of technology assessment. The public projects provided PMT with additional resources and the mandate to freely engage in research activities as in contrast to the primary objective where the dependence on other researchers restricted PMT actions. Thus, working on the research projects was a more pleasing and rewarding activity for it allowed PMT to explore a new technological arena and to develop unique expertise in a subject with potentially high value for CarCo. External funding also enabled the team to access relatively cheap but competent workers by recruiting PhD students. The focus of PMT's activities switched over time to deal with research objectives of publicly funded projects rather than the collaborative work with other internal research projects.

8.1.3 Conclusions: Brown field of history and context

The two subsections above looked at different developments on different time scales. All these developments are interconnected and played a role in patterning the conditions and the context in which the development of the NetworkPlanner commenced. The first subsection reflected on historical transformations which reconfigured CarCo's organisational landscape significantly. Unfolding consequences of subsequent transformation initiatives eventually shaped and configured the socio-political topography of the firm. The context of the research group shaped the cultural matrix of expectations and the set of assessment criteria that was applied to determine the value of research activities. To sum up, the historical transformations beginning in the mid-1980s were in favour of the research group which was established as the organisational unit that was supposed to unite corporate-wide research efforts. The following round of historical transformations beginning in the mid-1990s reversed some of the previous transformations and left the research group vulnerable and in need to deal with an organisational landscape that was adverse to its initial purpose. In the second subsection it was discussed how the research group attempted to deal with this tense political situation by creating a team of specialist to support other researchers in aligning their work with the specific requirements of the operational divisions.

These two narratives highlighted past events and dynamics that happened in different moments in time and on different scales. The historical transformations affected the entire organisation over a period of two decades while the creation of PMT happened in a specific locale and moment in time. All these occurrences shaped the initial context and conditions of PMT's engagement with its research activities on the public projects and consequently with the development of the artefact. The historical context and its examination in this study serve more than just to be an informative backdrop. It is the most immediate explanatory source to understand why the development of the technological artefact was undertaken in the first place and why it was taking a particular direction in the beginning.

This section summarised data that highlighted the role of historical events and dynamics in patterning the socio-political configuration, or context in other words, in which PMT was automatically embedded in the moment of its creation. Rather than being a vacuum or green field where everything is possible and 'Sartrean Engineers' (Latour, 1988) experience no restrictions besides material or non-human barriers, technological development occurs on a brown field (Sørensen & Levold, 1992, p.32):

> "The problem is that the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions" (Sørensen & Levold, 1992, p.32)

Past events and actions, even remote to the locale of technological development, have mudded the political playing ground and created a space in which actions of individuals are limited due to pre-existing conditions and patterns of shared beliefs and expectations inherent in a historically shaped context.

The next section will reframe the development and diffusion of the NetworkPlanner in a way that appreciates historical events and contextual contingencies. It will continue exemplifying how an ecological view, following the biography of an artefact approach, supports tracing related innovation processes across a diverse organisational landscape and multiple locales while taking into account relevant dynamics in contiguous ecologies.

8.2 The content of social shaping of technology

The first part of the discussion chapter has examined how historical transformations shaped the context and the conditions of the social space in which the Production Management Team (PMT) had been embedded. Knowing of these historical dynamics is important to understand how the organisational context affected the shaping of the technological artefact. The following sections will report how this technological development unfolded and how this development related to events in contiguous ecologies. We will begin with examining the conditions under which PMT was supposed to be operating and how these conditions required PMT to adjust its objectives. The repurposing of its objectives led PMT to engage with multiple user organisations. Thanks to these engagements, the technological artefact evolved and gained in capabilities which, in turn, allowed PMT to expand its activities further. Eventually, we will summarise how the research infrastructure behind the artefact was unwound.

8.2.1 Repurposing the team to investigate a new research subject

PMT was initially created to pursue the goal of supporting other research teams within the research group by offering technology assessment services. The provision of such services was motivated by historical contingencies that left CarCo's entire research organisation in an organisationally tense situation since grand-scale corporate transformations resulted in a relative mismatch of prior research strategies with new business strategies. However, PMT was required to remap its initial strategies and to put more emphasis on the team's secondary objective after the primary objective, and with this the basic funding arrangements, did not work out as expected. In order to survive and to generate other income, PMT was required to look into new promising arenas and for other profitable opportunities to engage with. Originally established to support other research teams, PMT's objective was partially repurposed to engage with the research subject of flexible manufacturing – an entirely new location in the Abbottian sense. This concrete opportunity for PMT to enter the promising arena of manufacturing flexibility was due to external events originating from another locale.

The German Federal Ministry for Education and Research (FMER) made available funding for research undertakings that aimed to improve the competitiveness of SMEs in the manufacturing industry. This created an incentive for eligible firms to enter the flexible manufacturing arena. By limiting eligibility criteria, however, the Federal Ministry encouraged primarily SMEs to enter this specific arena. It was only due to another player, an engineering consultancy, that CarCo was able to participate despite not being a SME. This player invited PMT to join its undertaking in creating an alliance of ecologies to form a research consortium and to draft a joint research proposal for the bid. Eventually, the joint research proposal was awarded a research grant to run the SATFAB project. Existing resources – mainly manpower as the team yet had not developed unique instrumentalities else than conducting generic technology assessment tasks – which were not optimally utilised before were allocated to the SATFAB project. The incoming research fund was an important political currency to justify the transformation of PMT's objectives. The acquisition of external research funds was generally well perceived by the management of the research group. Following the terminology of the kernel of research infrastructure concept (Ribes & Polk, 2015) the kernel, which is the totality of resources and services under control of PMT and its members, was both repurposed and extended in order to engage with a new arena. With the establishment of the research consortium and new linkages between players, especially with FMER, PMT successfully entered the new arena of flexible manufacturing. Its purpose from working with other research teams was recalibrated to also engage with a new research object. Consequently, the grant created an opportunity to take up work on instrumentalities that later led to the development of technological artefacts.

Another public research grant was acquired soon after. Similar to the Federal Ministry, the European Commission (EC) aimed to improve the competitiveness of manufacturing industries in its constituent nations. Flexible manufacturing, therefore, was equally a relevant arena which the EC wanted to see being populated by European players. Taking the lead, PMT put together another alliance of players and succeeded in tapping the research fund provided by the EC which gave rise to the LICOPRO project. The additional funding yet again extended the kernel's resources. This enabled PMT to recruit new student members which were tasked to intensify work on promising instrumentalities, i.e. elaborating theories, methods and technologies relevant for the subject of flexible manufacturing from the point of view of a car manufacturer.

8.2.2 Linking up with internal user departments

The resources provided by SATFAB and LICOPRO enabled the research team at CarCo to enter a new arena and to explore the subject area of flexible manufacturing. The goals in these projects were to formalise functional requirements of methods and techniques that were potentially helpful in solving the abstract problems of the technological field of flexible manufacturing. Besides the two projects, PMT simultaneously advanced another strategy to sustain PMT's research infrastructure over time since there was a due date attached to the public project.

PMT's growing kernel, including the increase in methodological and technological capabilities, opened up opportunities to engage with potential users within CarCo. To attract new sources of funding and to raise expectations with new players, members of PMT approached internal practitioners and demonstrated both their artefact and their competences in mastering complex strategic planning problems. Actually, such interactions started to take place soon after the projects were taken up in the first place because PMT developed a strong routine of seeking new sources of funding early on its existence. During these interactions, promises where voiced that the artefact was capable of solving the complex problems strategic planners were struggling with in their projects. What distinguished these promises from SATFAB's and LICOPRO's functional promises was that PMT's members were challenged to take into account the contingent dynamics and developments they stumbled upon locally when interacting with strategic planners. Thus, PMT's promises were not only specific but also localised since every planning department was dealing with different sets of challenges, technically and politically.

Each strategic planning department operated within its own arena of expectation. Since PMT required only little adjustments to its rhetoric to voice similar promises to different planning departments, these arenas possessed similar features. This hints at the co-existence of contiguous arenas which are distinguished only by a different set of beliefs and expectations, i.e. the cultural matrix of expectations, dominant within the respective division. Differences between these matrices become visible when operational premises, in other words beliefs and expectations, change. For example, the bus division, PMT's first internal client, withdrew from the alliance with PMT because planning premises changed. Similarly, the car division's cultural matrix of expectations changed in a later stage of the project in favour of the NetworkPlanner after the senior management decided on a different production strategy. Attracting the interest of selectors in charge within the confines of these various arenas required PMT to adjust the contents of their promises according to the requirements of the cultural matrix of strategic planners of the targeted department. The generic functionality of the final version of the NetworkPlanner was an attempt to do justice to the variations in the cultural matrices of expectations dominating these arenas.

Even when PMT's researchers succeeded in attracting the interest of practitioners, the planners proceeded carefully in evaluating PMT's promising claims about benefits and demanded proof. However, in order to provide such proof, the researchers required access to live data and, thus, to real life projects. In effect, the demand for proof was the first mandate handed over to PMT to engage in a collaborative exchange. The presentation of results in follow-up meetings presented further opportunities to raise new expectation by making even bolder claims about technological and methodological capabilities. The completion of one promise-requirement cycle enabled the initiation of another. Every successful completion of a cycle contributed to building the trust relationship between enactors and selectors and to gaining a mandate with more privileges attached. As the community of strategic planners at CarCo was manageable in size, reputation turned out to be a valuable currency when it came to approaching planning departments in other divisions. References to collaborations and successfully accomplished network projects, i.e. previous promise-requirement cycles in other locales, made it easier to engage in new but thematically related promise-requirement cycles.

Over time, PMT's researchers succeeded in linking up with multiple organisational players within CarCo. What started with a collaboration with the bus division led to the application of the prototype in a network project in the car division. Eventually, the truck division was found to be the most interesting player as its production network and its strategic planning organisation showed qualities that favoured the application of the NetworkPlanner. For historical reasons, the Truck division had two strategic planning departments within the overall planning department. Although their responsibilities did not overlap as they were separated geographically there was in a sense a competition going on between the two. Besides different responsibilities, there were also some cultural and methodological differences in the way how each department was going about the strategic planning process in general. One department, referred to as Team B in the empirical chapter, was collaborating with an external company to develop their own technological artefact in order to support their work. Team A, on the other hand, was without a bespoke tool and relied entirely on methods based on conventional spreadsheet approaches. For this reason, Team B was not interested any other artefact whereas Team A obviously was curious to learn about any artefact that could support their work and that potentially could compete against Team B's artefact. This constellation of existing linkages between ecologies, therefore, was an influential factor in predetermining the chances of success for PMT to implement their artefact. After successfully adopting the NetworkPlanner, Team A took turn to convince Team B, who was still working on its own artefact, of apparent benefits of the NetworkPlanner. It was only after a political move by an individual actor, who switched from PMT to an influential position within the overall planning department and close to the head of that department, that Team B abandoned the development of its artefact in favour of the NetworkPlanner after a benchmark of the two artefacts was undertaken. To summarise, the capabilities of the technological artefact were an important factor in attracting the interest of Team A in the first place, but it was the combination of skilful strategising and navigation within a historically shaped and politically-laden ecological terrain by multiple actors involved that eventually led to the NetworkPlanner being embedded in that social environment.

So far we have focused on how the kernel of PMT's research infrastructure, the totality of resources and services available to PMT's members to investigate the subject of flexible manufacturing, has been established and linked with other organisational players. Next, the discussion will examine how the NetworkPlanner itself had been developed. A technology does not emerge independently from social processes but is a co-developed product of social interactions. In other words, the artefact has been worked on at the same time as the events occurred that have been discussed above. However, to maintain narrative simplicity, the development of the artefact is narrated separately in the following section. This is also to highlight links to other social dynamics in remote locales which are independent from these events discussed previously but which influenced the social shaping of the technology nonetheless.

8.2.3 From generic theory to functional prototype to specific artefact

The special episode in the truck division exemplifies that the NetworkPlanner is shaped contextually and historically depending on the fabric of linked ecologies. However, the emerging technical capabilities of the NetworkPlanner also contributed in shaping social dynamics and the context of its development. This subsection will emphasise on the technical qualities of the NetworkPlanner and how they relate to remote developments in other locales. Especially, we examine why the development took the turn to incorporate methods of operations research (OR). Indeed, the adoption of OR methods represents the linkage to developments beyond the immediate set of actors involved in the technological project.

In Fujimura's (1995) study the articulation of oncogene theory kicked off a complex and ramified social process within the domain of cancer research that over time fundamentally transformed how cancer research was interpreted and how the field operated. In this case study, a similarly game-changing event can be identified with the exploration and utilisation of a theory based on operations research (OR) methodologies in the domain of strategic network planning. Jordan and Graves' (1995) theoretical study on the "Principles on the Process Benefits of Manufacturing Flexibility" became a seminal work for researchers interested in supply chain configurations in light of uncertainty and complexity (Volling et al., 2013). This paper also attracted the interest of

PMT's researchers. The publicly funded research projects SATFAB and LICOPRO enabled PMT to explore these and related theories and methods relevant for the domain of flexible manufacturing in two ways. Firstly, it justified and legitimised the repurposing of PMT's kernel towards the study of a new research subject. Secondly, both projects extended the kernel by providing new research funds which allowed the recruitment of three doctoral students, each dedicated to a different aspect of flexible manufacturing. Drawing on students doing their undergraduate and postgraduate dissertations, PMT's doctoral students began experimenting with operations research (OR) methodologies by developing functional prototypes. Further, the LICOPRO project linked PMT with academic partners who provided valuable theoretical expertise in exchange for insights into real life cases and data from CarCo. In collaboration with academic partners, PMT's researchers were able to advance their knowledge on the subject, methods, and, consequently, their prototypes. One of the first prototypes, therefore, was a repository of Microsoft PowerPoint slideshows that documented relevant concepts and information.

The OR grounded approach gave PMT's researcher strong advantages in pursuing their research objectives. First of all, it directed PMT's researcher towards an approach promising a possible set of methods to solve complex problems as experienced in the management and planning of production and supply networks that could not be addressed with conventional approaches. Researching methods with potential practical benefit for CarCo further legitimised PMT's exploration of the new arena and location of flexible manufacturing. Second, OR and its different facets were being researched by a global community allowing PMT to establish links and collaborations with numerous well-known research groups and institutes, and to draw on a wider pool of theoretical findings and resources. The extended network led, thirdly, to an increase in reputation and recognition by other organisational units within CarCo. The research division appreciated international collaborations as they increased the division's visibility within the corporation. Equally, the reputational gain was valuable as a currency to improve PMT's position when engaging in promissory activities with user departments. The opportunity to point to a large network of academics and practitioners that supposedly believes in and utilises the same theoretical foundation is more convincing a fact (Latour, 1987) than in the case of a technological development that only draws on the expertise of a limited grouping as did the competing technological artefact that was developed by Team B in the Truck division, for example.

The approach elaborated by Jordan and Graves (1995) was a generic theory addressing a general and abstract production problem faced by manufacturing companies all over the world. PMT's researchers adopted the theory as for them it appeared to be the most promising approach in finding a workable solution to the type of problems addressed in their research activities. The researchers concretised the theory by adapting it to the requirements of CarCo's global production and supply networks. Although CarCo's network spans the globe, it nonetheless introduced restrictions and specific requirements of a single organisation. Thus, the generic theory was reduced and concretised to functional methods applicable to the needs of a certain corporate environment. The functional methods were embedded in and embodied by the NetworkPlanner, a functional and prototypical artefact. Technically, the artefact evolved from a repository of slideshows to, at first, a generic set of Microsoft Excel spreadsheets with complex formula that processed data. With the implementation of OR-based functional methods these formulas became mathematically more complex. The next stage was to adapt the functional prototypes into technological solutions fit for operations in specific locales.

The prototype was instrumental in demonstrating the capabilities of the functional and OR-based methods to an interested audience of strategic planners. The exposure to practitioners taught PMT to consider elements such as graphical user interfaces. Their artefact became 'sexier' as more components were implemented that catered for the needs of non-scientists and that increased the perceived ease of use. Different currencies were used to appeal to the varying tastes and requirements of different researcher-user nexuses. Engaging with potential users allowed the researchers to gather more detailed requirements about the specifics of user locales and to adapt the functionalities of the prototype accordingly. Identifying, implementing and refining the best information technological components was an arduous exercise shared with and delegated to both the doctoral students as well as the undergraduate and postgraduate students working with PMT. The prototype gained in sophistication the more it was exposed to and utilised in real-world projects. Also, the artefact gained in technical sophistication as not only components were replaced with better ones but that the artefact was completely overhauled changing its underlying technical architecture. The prototype transformed from an improvised set of interconnected spreadsheets to a professional software with a graphical user interface and powered by a database management system.

While generic theories were the boundary objects between PMT and its academic partners, the prototypes became boundary objects between PMT and an increasing number of internal strategic planning departments. For the user departments, it was a promising artefact potentially capable of solving important but complex practical problems. For PMT, on the other hand, collaborations with internal users was the necessary currency to persuade the senior management of the research division to continue allocating research funds for their research activities. The more PMT's researchers engaged with users, the more promises were made and requirements mandated, the more local constraints were implemented in the prototype, the further the crystallisation of abstract theories into specific problem-solution techniques proceeded. The diversity of user engagements provided a diverse set of requirements, allowing PMT to get a rich body of knowledge on various facets of strategic planning. This is why the final version of the NetworkPlanner was a highly flexible instrument trying to live up to a wide range of expectations held by various individuals in different locales. Eventually, this wide range of expectations encouraged the redesign of the system which led to the problematic development of the NetworkPlanner with a generic framework.

The adoption and declaration of the NetworkPlanner as standard planning instrument in parts of the company effectively transformed the practices of strategic planning within CarCo. Furthermore, it transformed the way how problems of strategic planning were interpreted. This was most obvious in the fact that the user departments began articulating problems from the point of view of the NetworkPlanner. The doctoral students recruited by the strategic planning departments continued to develop the artefact and to adapt it to the specifics of their divisions. They engaged with new sets of research questions whose articulation was tied to the capabilities of the artefact to engage in ways with existing problems. Thus, the flexibility of the artefact gave rise to the articulation of problems which previously could not have been addressed drawing on conventional methods. The technological artefact was utilised to explore new ideas and methods by creating functional and experimental prototypes. In other words, the process of concretisation began to reverse and to turn into a process of abstraction where local experience informed the formulation of new functional methods based other generic theories. The final episodes in the case study, therefore, hinted empirically at what the notion of instrumentality conceptually addressed as the reciprocal advancement of science and technology.

This section shed light on the development of the technological artefact, the NetworkPlanner. Following the intention of articulating an ecological perspective on the social shaping of the technology, we highlighted how the artefact relates to dynamics in other locales. In this case, it was elaborated, that the methods and techniques utilised by the NetworkPlanner have not been invented by PMT's researchers. Rather, the intellectual origins of the artefact are identified to stem from outside of CarCo. It was the development of a generic theoretical approach by researchers elsewhere that inspired PMT's researchers to pursue a particular methodological direction. However, it was PMT's researchers' achievement to concretise and localise the generic and abstract theory according to the specific requirements extracted from CarCo's strategic planning departments. In line with notion of the instrumentality package of our framework, we have elaborated the links between theory, method, technique and artefact and thus indicated that the contents of a technological artefact are contextually shaped. The ability of the artefact to shape its context is indicated by the observation that the more feature were integrated into the artefact, the wider applicable it became. Thus, the evolving artefact allowed PMT's members to engage with a wider range of users interested in the qualities of the artefact. Also, the innovative capabilities of the artefact allowed users to tackle new problems. Thus, the NetworkPlanner enabled to some extent the redefinition of the strategic planning process and the kinds of problems addressed in this process.

8.2.4 Unwinding the research infrastructure

PMT's members succeeded in initiating sustainable collaborations with other players in CarCo who benefited from the application of the NetworkPlanner in their work activities. These engagements with users or, in other words, episodes of social learning contributed largely to the refinement of the artefact. User feedback and feature requests provided PMT's researchers with opportunities to engage in promise-requirement cycles and to elaborate the NetworkPlanner's capabilities. Another important result of longer-lasting engagements with users was the migration of researchers. Individual researchers switched sides leaving the research team and joining user departments. In particular, both the truck and the car division recruited each a doctoral student and a dissertation student working with PMT. Doing this, these individuals carried with them the knowledge about instrumentalities, i.e. knowledge about the artefact as well as the theories and methods utilised by the artefact. Since the artefact was an in-house development, it was unproblematic for these individuals to carry on contributing to further developments from a user perspective and across organisational boundaries. Therefore, it was not simply a process of implementation or diffusion but episodes of a process which resembles what Ribes and Polk (2015) described as the forking of a kernel. These authors introduced the notion of forking to describe how a newly established kernel makes use of resources and services of an existing kernel to serve a distinct but remotely related purpose. In open source software development, where the term is commonly applied, this is a process splitting a technological development, its respective community of developers and, to some extent, the available set of resources apart. It is a method to encourage alternative technological innovations and also to resolve conflicts about visions of future technological development. In our case study, the actors switched departments but continued to interact with their former colleagues at PMT and informed the ongoing development of the NetworkPlanner after their transfer. At the same time, they engaged with the investigation of problems specific to the local requirements of their new employers.

PMT's kernel was forked twice. First it was forked to the truck division then, about two years later, to the car division. This second process took place in light of the plan by senior management of the research group to withdraw from the technological project. In hindsight, the second forking of the kernel can be interpreted as part of a process to unwind the research infrastructure in charge of the development of the NetworkPlanner. In this process of dispersal, valuable resources, including human actors, in the research team were redistributed and relocated into other institutional arrangements and sociotechnical configurations within other locales and ecologies.

In case of the NetworkPlanner, the dispersal was the result of reaching a certain degree of maturity in the instrumentalities elaborated within the kernel. After more than a decade, theoretical research activities had been largely succeeded by the practical activities of the development and implementation of a technological artefact. The existence of PMT's research infrastructure, at least the part that was dedicated to the NetworkPlanner enterprise, reached a point at which resistance from the senior management to support this type of practical research any further was too strong. Thus, it was decided to unwind the research team working on the technological artefact to free up resources and capacities for other and more promising research activities.

Dispersal is not an ending but a major transformation of funding, management and coordination arrangements of the kernel's resources. Ever since the start of the research activities PMT has been the central player in the development of the kernel. With the retreat of this central player, the kernel entered a different mode of operation where its future development became an activity largely distributed among the two forks. A notional community of practice has been created to fill parts of the void and to serve as a common platform for representation and exchange. The NetworkPlanner's generic capabilities provided much common grounds on which collaborative but distributed development was regarded as useful. In the first months after the dispersal was accomplished, interaction between the two forks was still observed. However, further close-up observations of how the dispersed state of the kernel unfolded further was beyond the temporal scope of this thesis.

8.3 The relationship of context and content in technological change

In the first part we highlighted that PMT was embedded into a brown field patterned by previous actions and established sets of linked ecologies. This brown field patterned the starting conditions and the range of options available to members of PMT and other relevant actors. In the second part, we have revisited how the research infrastructure responsible for the development and implementation of the NetworkPlanner unfolded under the leadership of PMT and in light of the contextual constraints of the given brown field. To avert a financial bottleneck the research team made an unanticipated turn by focusing its activities on researching a new technological field. By navigating around a serious problem it entered a promising new arena which allowed the team to expand its capacities to engage with the development of a technological artefact which utilised generic theories to solve complex problems practitioners were struggling with. Multiple episodes of innofusion led to the implementation of the NetworkPlanner as a standard instrument in the strategic planning process in adopting divisions. With the gradual transfer of the artefact into operations, the research infrastructure was unwound as institutional support for further development ceased.

These local events occurred over a period of twelve years, in contrast to the 25-year period in which historical dynamics shaped what was found to be the relevant context of the NetworkPlanner enterprise. Comparing these two figures, we can deduce that, at least in this case study, that the shaping of influential contextual factors takes about double the time than the shaping of the actual contents. In other words and in more general terms, context and content evolve in different speeds. Despite this difference on a temporal dimension, both dynamics are intrinsically connected. As time moved on, contextual dynamics, i.e. changes in contiguous ecologies, kept interfering with ecologies and actors directly involved in the development of the technological artefact. For example, the eventually successful implementation of the NetworkPlanner in the car division was mostly due to the change in the division's strategic planning premises. This was triggered by a change of strategy decided by the management board in order to react to changing market conditions. Without this decisive strategic change, which was outside the reach of any actor involved in the project, the outcome of the technological development would have been different since the car division was a powerful ally for PMT. After all, the research group was embedded in the hierarchical structure of the car division and thus sensitive to dynamics in that division. Equally, the innofusion of the NetworkPlanner influenced its context by affecting practices in linked ecologies. Especially the application of the generic version of the artefact enabled strategic planners to engage with problems that previously had been unattainable with conventional methods. Thus, in the long run, the innovative technical capabilities inherent in the NetworkPlanner redefined the contents and the meaning of the strategic network planning practice in CarCo. What previously was performed by drawing on standard applications, such as software available in the Microsoft Office package, evolved to the utilisation of professionally designed software that required understanding of operations research methods. The adoption of the NetworkPlanner strengthened the position of strategic planners in relation to its linkages to other functional areas such as controlling and its representing ecologies.

Since the research purpose of this thesis was to explore how best to study long and complex technological developments, we have applied concepts of our ecological framework to bring some order to the many events and dynamics observed in this case study. The analysis benefited in the sense that events and developments were interpreted according to the conceptualisations put forward by the framework. As the structure of the discussion demonstrates, we were encouraged to split the analysis of context and content into separate sections. This discussion, we argue, makes a strong point in showing that technological change does not occur on a green field where technologists and engineers are free to unfold their ideas and actions but are strongly restricted by the brown field of interests and expectations inherent in existing and surrounding social structures. Understanding technological change essentially rests on the equal understanding of the context and the content of technological change.

Overall, our framework contributes to the development of a methodological approach that aims to balance analytical attention equally between matters of context and content. This lines up with arguments put forward by the Biography or Artefacts and Practices perspective which calls for sensitising spatial and temporal concerns of technological change. Based on the ecological orientation of our analysis we gained a different perspective on the interactive relationship between multiple ecologies over longer periods of time. The next section will elaborate findings that have been made possible by this ecological perspective.

8.4 An ecological approach to expectation dynamics

A prevailing feature of our case study has been found to be the flexibility and mobility of both actors involved in the innofusion process and the technical artefact. PMT's members navigated from one division to another in their endeavour to implement the artefact in a strategic planning department. These recurring engagements with users and their respective requirements shaped the content of the artefact, PMT's kernel of research infrastructure and, eventually, practices of users. Our ecological framework described these engagements as processes where predominantly PMT's members attempted to construct relations to other ecologies – a process Abbott (2005) termed ligation. In section 3.2, where we set out to construct the part of the Ecological Shaping of Technology framework that focuses on mapping the ecological terrain of a technology project, we noted that the combination of ideas from the sociologies of professions (Abbott, 2005) and expectations (Bakker et al., 2011) appeared promising in providing a more nuanced description of change in relationships between ecologies. This conceptual combination produced an insightful perspective on how actors engaged in promissory work to construct and sustain relations with actors from other ecologies over time. In this section we will focus on this specific element of our theoretical framework because it highlights a frequently observed phenomenon in our case study that allows for a special contribution to the literature on the innofusion process.

In our empirical chapters we have described how the NetworkPlanner gained in shape due to continuous efforts of actors who sought out to find a location to which the artefact could be transferred to at the end of the development. Over the course of a decade the emerging artefact had been introduced to multiple users in various departments and divisions. Developing a technical artefact from scratch, PMT played the role of an enactor that promised benefits to potential users, i.e. selectors, in order to get financial resources to fund the development, and political currency to strengthen the legitimacy of the project in the research group whose senior managers held a sceptical view on the undertaking. The first promise-requirement cycles highlighted in our analysis were PMT's participation in SATFAB and LICOPRO, the two publicly-funded projects. Participating in these projects enabled PMT to extend its activities to another technological field. Previously, PMT's primary objective was to collaborate with other research projects and to provide additional services including economic evaluations of technology implementation and others. The public projects expanded the range of objectives to include research on flexibility in production and supply networks. Drawing on terminology from the sociology of professions, the new subject area can be interpreted as both a 'location' that is worked on by PMT's researchers and a 'proto-boundary' that demarcates sites of difference. The difference here is similar to what Hughes (1983) described as a reverse salient. A reverse salient is a technical component that is holding back the advancement of a larger system. Thus, the proto-boundary in our case indicates practices that would significantly benefit from new technological solutions. We argue that by the time institutional bodies provide funding to research a certain subject, the subject in question is past the stage of being a mere 'difference'. By this time it has been identified and classified as a worthwhile research topic by a range of players including practitioners, policy makers and researchers. In a drive to foster innovation, the efforts of the institutional players, in this instance a federal ministry and a transnational funding body, therefore reflected the broadly-shared intention to explore whether the proto-boundary of 'manufacturing flexibility' allowed for the creation of novel social entities such as novel technological development initiatives, technology spin-offs, etc.. The effort of doing the actual exploratory work had been delegated to respective research consortia of which PMT was part of.

The first two promise-requirement cycle, with PMT taking the role of an enactor and the funding bodies that of selectors, aimed at testing the potential of a new technological field – the proto-boundary labelled 'manufacturing flexibility'. We briefly remind that this particular proto-boundary emerged from the convergence of multiple domains including, at least, industrial and academic research on production and supply networks, as well as advances in both technological capacities of information technologies and methods in operations research. The exploration and testing of the potential of creating a new social entity along this proto-boundary commenced on a generic level where technical specifications and local requirements were yet abstract. Participants of the publicly-funded projects engaged with researching issues surrounding the subject of manufacturing flexibility in order to improve understanding and develop concepts and methods to cope with related problems. As time moved on, participants, and PMT in particular, gained experience on the subject, its potentials and specifics. However, since the public funds would run out at some point, PMT's research activities would simply be redirected to other subjects at the end. To avoid this, PMT's members began to seek new selectors within the confines of CarCo for two reasons. First, they needed to secure external mandates and resources to sustain the level of technological development. And second, the development reached a point where researchers required more specific and practical input rather than more generic research. This is when attention was widened to potential users.

Strategic planning departments were found as relevant arenas that showed interest in the artefact. Thus, on approach, new promises were uttered to new selectors which granted mandates and provided further resources including both financial and political currencies. These engagements with users were new instances of promise-requirement cycles. PMT kept the role of the enactor whereas user departments and respective decision-makers therein took the role of selectors. As in the first promise-requirement cycle PMT's members engaged in maximising expectations of selectors in order to secure new resources and mandates. What was different with these cycles was that the mandate did not guarantee a durable state of stability. Contrary to long-lasting resourceful packages provided by public funding bodies, PMT faced a different situation dealing with potential user departments. Instead, engagements with strategic departments resulted in a series of promise-requirement cycles in which claims made by PMT's researchers were continuously scrutinised. While the Federal Ministry and the European funding body were satisfied with abstract formulations of promises and gains articulated in a research proposal, user departments were more demanding. Orally presented claims made by PMT's members in formal meetings were more frequently tested against specifications and requirements rendered by respective users and their social settings. PMT's members visited user departments repeatedly to demonstrate the artefact's abilities. These engagements were arenas for PMT to meet selectors with whom they negotiated about both present and future capabilities.

The artefact was still under development at the time of the first interactions with potential users. It was not fully functional and not even stable enough to be used by a non-expert. Basically, it was useless in the hands of a user unless the user was carefully navigated by an expert from PMT. Despite a technical state that leaves a lot to be desired, PMT's members succeeded in persuading user departments to test PMT's artefact and practical competence by granting temporary mandates to support them in their projects. In order to secure these and future mandates PMT's members promised users that their artefact could be relatively easily adapted and expanded to fulfil the requirements posed by the strategic planning projects dealt with by user departments. The initial mandates granted by user departments were volatile as their level of commitment was low. Initial engagements aimed at building trust between PMT's members and user departments. Also, initial promise-requirement cycles with a user department yielded political currency for PMT rather than financial resources. To safeguard PMT's transition from being partially dependent on external public funds to fully dependent on internal funds again, political currency was more important for PMT as it helped justifying the continuation of its research activities to the management of the research organisation.

Frequent promise-requirement cycles with users involved became more specific and tailored to their needs. Selecting users were able to test if new technical fixes met requirements while enacting developers got further feedback and opportunities to make new promises about prospective features. PMT's members continuously succeeded in meeting expectations and returning to the arena to reengage with users despite the artefact being still under development and reliant on some sort of student-led 'concierge service'. As a result, the artefact strongly benefited from these shorter intervals in which feedback was received and timely incorporated into the shaping process. The artefact changed its shape according to the engagements prevailing at the time – a context-contingent process we described as ecological shaping. To sum up, capabilities present at the time of a prototypical demonstration were important to initiate engagement with potential users but it was the potential of future capabilities that allowed enactors to return.

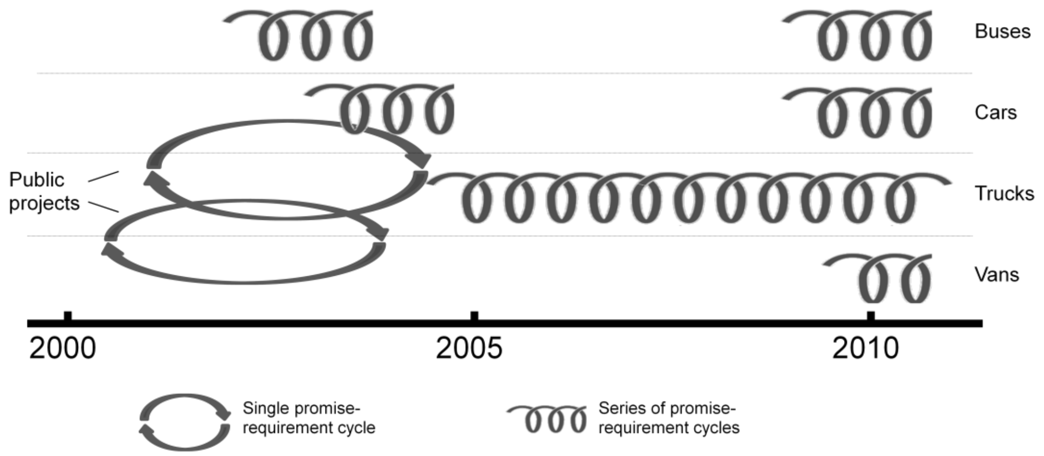

Figure 19 Yoking process of the NetworkPlanner

Another interesting observation that emerges from analysing these promissory engagements with users is the view of yoking together the technological development with another ecology and to 'anchor' the artefact temporarily to that ecology to sustain its further development. Promise-requirement cycles do not guarantee adoption but are sequential episodes in a process of convergence. Setting up relationships with multiple user departments at various moments in the innovation process contributed to sustaining the availability of both financial and political currencies. The survival of the development was dependent on PMT's members' opportunistic navigation along the changing textures of CarCo's ecological terrain. Anchoring the artefact temporarily in a particular spot of that terrain, i.e. yoking it to another ecology, enabled the undertaking to survive for another moment and to move to a new position from where PMT could access and yoke it to other ecologies that were previously out of reach. For instance, the initial engagement with planners from the Buses division, an opportunity contingent to spatial proximity, gave PMT's members the opportunity to learn about the specifics of internal planning practices including the requirement to comply with financial regulatory standards (see Figure 19 for an overview of the yoking process of the NetworkPlanner). Expertise in formal planning practices was an important factor enabling PMT's members to approach the Cars division and to continue user engagements with a new partner. When practitioners from the Buses division withdrew, the Cars strategic planning department was a temporary saviour providing legitimacy for the artefact's further development until the interaction was interrupted by yet another withdrawal. However, the development of the NetworkPlanner survived long enough for the tool to be applied in the Trucks division where the yoking process was most successful. Temporarily anchoring the technological development and PMT's respective ecology to others was a strategy to sustain the undertaking over time. In the course of yoking the artefact to other ecologies, PMT's kernel gained relevant resources and capabilities which increased the likelihood of the survival of the artefact and the organisation surrounding it.

To come to a conclusion, we will wrap up this section by elaborating the key contribution of our framework in more abstract terms. The process of ecological shaping of technology is characterised by enactors bringing together selectors to work together on a technological undertaking. Technological development becomes a social space, an arena or location in between one or more social entities, in which actors come together to engage in promise-requirement cycles. The intersection between this yet virtual social space and existing entities occurs along proto-boundaries that mark sites of difference and potential spots along which new entities could emerge. Enactors work on bringing in selectors into this social space by identifying or demarcating proto-boundaries. This process of bringing together or linking up of ecologies has been described as yoking (Abbott, 1995). In the Abbottian sense, yoking is a dynamic but slow process that can produce strong institutional links but which can endure over multiple decades. We propose a more granulated interpretation of yoking by enriching it with concepts of expectation dynamics. This allows the notion of yoking to be applied to more fast-paced developments that occur over shorter periods of time such as the development, implementation and adoption of a technological artefact. The concept of arenas of expectation and the corresponding notion of the promise-requirement cycle allow theorising the yoking process on the level of both individual actors and institutional collectives. Here, yoking describes an innovation process in which actors anchor a technological artefact and its shaping process to one or more ecologies over time. Doing this they take advantage of beneficial circumstances that prevail in ecologies in social proximity to the technological development. The yoking process proceeds through a series of promise-requirement cycles which bring both enacting and selecting ecologies together the closer the artefact comes to meeting expectations of users and requirements of their social settings. Our interpretation of the yoking process brings in an ecological perspective that takes into account change as it unfolds over different moments in time and across multiple spatial locations.

9 Conclusion

This study set out to document the long and complex story of the development, implementation and adoption of a technological artefact and to identify effective ways to analyse such a complex and extensive social phenomenon. A review of the evolving literature on the social analysis of technology and innovation highlighted that some of the most prevalent theories on technology fail to give proper attention to contextual and historical influences. Indeed, common action-focused approaches such as Actor-Network Theory and Social Construction of Technology have been found to be profoundly acontextual and ahistorical. Although such theories have made an enormous contribution to the growing body of research that focuses upon the social dynamics of the shaping of technology, they neglect structural influences and, hence, omit important aspects in the explanation of technological change.

At the same time we note a recent resurgence of approaches which encourage analysts to transcend methodologically and conceptually limited framings in terms of space and time of their objects of study. Exploiting these revised articulations of the technology/society relationship, this study adopted an ecological and biographical perspective to highlight how the development and implementation of technological artefacts is strongly shaped by historical and contextual contingencies. To this end we developed a conceptual framework, tentatively termed Ecological Shaping of Technology, which combines methodological principles of the Biography of Artefact perspective with cognate concepts that articulate nuances of spatial and temporal aspects of technological change. The framework has been applied to analyse the case study of the development, implementation and adoption of a strategic information system.

This chapter will review how the findings arising from the analysis relate and contribute to wider academic debates in technology studies. We identify three major contributions to knowledge in our study. To begin with, first, our case study offers an extensive narrative and analysis of the long and complex biography of a technological artefact. Studies of this sort remain a rare and thus important empirical contribution to researchers and practitioners alike. It provides valuable insights to learn about the extent and contingencies that govern the lifecycle of complex decision support systems embedded in larger organisations. Second, we reflect upon our reasoning to develop the

Ecological Shaping of Technology framework to address conceptual limitations of prevalent theories of technology. This is accompanied by the foregrounding of an ecological metaphor to underline the basic tenets of our approach and a summary of the conceptualisations and empirical findings emerging from the framework. This part wraps up with elaborating our contribution to research on innofusion. Third, by applying the still emergent 'Biography of Artefact and Practice' perspective to study the innovation process of a single technological artefact we both test and develop the perspective in a new cultural and organisational context, an innovation project in a large and historically complex industrial corporation, and contribute to addressing methodological concerns. In particular, this case-study can be a helpful starting point for the design of doctoral research undertakings that aim to study biographies of technology in similar organisational arrangements. Then we reflect upon how the unfolding of this research journey and the design of this study was intertwined with events taking place outside the control of the author. Unexpected events required adjustments and improvisations which contributed to the shaping of the final outcome of the study. The chapter will conclude with a discussion on research limitations and opportunities for future studies.

9.1 An ecological analysis of a technological artefact

A major intellectual challenge of this thesis was to find a way to report the long and complex innovation journey taken by the NetworkPlanner, the technology concerned in this study. This challenge increased with the intention to explore an extended temporal and spatial horizon to pursue 'why' questions rather than just questions of 'what' and 'how'. However, prevalent approaches and frameworks were found to be restrictive in regards of addressing 'why' questions. Limitations in theories on technology such as Actor-Network Theory (ANT) and Social Construction of Technology (SCOT) were identified regarding the acknowledgment of issues of history and context. Indeed, students of technology are explicitly discouraged from paying too much attention to historical and contextual aspects (see Callon & Law, 1982, and Pinch & Bijker, 1986).

Proponents of the actor-network theory (ANT) framework suggest focussing exclusively on the manipulation and transformation of interests of individuals (Callon & Law, 1982). Their subjects of inquiry are powerful and privileged individuals, i.e. scientists and engineers, whose presence in the spotlight of social inquiry is taken for granted. Social inquiries focus on activities of these actors who engage in translation and alliance building processes constructing intrinsic networks with human and non-human actors. From this perspective, context and social structures do not exist as entities outside the network but are represented as allies tightly interwoven in the actor-network (Latour, 1987; Callon & Law, 1982). What about history, we are prompted to ask. Callon and Law (1982) address that question and express their view that tracing social structures, context and history is not of special relevance anyway:

> “Though it may be that for any particular study this process can only be traced so far before a ‘backcloth’ of prior interests has to be taken for granted, our aim would be to avoid attributing any special status to that backcloth” (Callon & Law, 1982, p. 622)

In short, the necessity for a broader historical and ecological analysis is downplayed. Rather, ANT proponents advance the imperative to ‘follow the actor’ to trace relevant contextual information in the form of associations to other actors in proximity. But which actor do you follow, is the next question (Sørensen & Levold, 1992). Because ANT emerged from laboratory studies, the scientist is regarded as a key figure in actor-network theoretical accounts of technological development (Latour, 1987). Actor-network theoretical accounts of engineering-related projects put their emphasis on engineers, who take the role of the heroic actor, building networks of heterogeneous elements (Law, 1987). The framework is criticised for its atomistic and actor-centric focus which overstates the potentials of individual actors (Sørensen & Levold, 1992) and perhaps in consequence adapts a voluntaristic and even militaristic tone (Fujimura, 1995). Sørensen and Levold (1992) also raise the insufficiently addressed issue of context and history and note that:

> “The problem is that the terrain on which engineers and technological scientists move has been thoroughly shaped by previous actions” (Sørensen & Levold, 1992, p.32)

Merely observing engineers or scientists will not provide the insights necessary to understand historical processes, as they occur beyond the reach of what can be observed locally and temporarily. Instead, they argue that a “heterogeneous mix of historical, ethnographic, economic, and sociological competence seems required” (Sørensen & Levold, 1992, p.32). Hence, rather than occurring in a vacuum or ‘green field’ where everything is possible and where ‘Sartrean Engineers’ (Latour, 1988) experience no restrictions besides material or non-human barriers, technological development typically takes place in a 'brown field'. There, past events and actions, more or less remote to the locale of technological development, have muddied the political playing ground (see Sørensen & Levold, 1992, quote above) and created a space in which actions of individuals are limited due to pre-existing patterns of shared beliefs and expectations inherent in a historically shaped context.

ANT emphasises actions of individuals, and how they align and adapt interests of other actors according to their own interests. SCOT focuses on how social groups negotiate over problems and try to find solutions by reducing interpretative flexibility. This approach is helpful in learning how a technological artefact comes about (Bijker, 2009). However, like ANT, it fundamentally lacks in conceptual capacity to address the question why an artefact is being developed in the first place and how the development is sustained over time. In particular, the simplicity of SCOT's conceptualisation of relevant social groups as the main analytical entity fails to do justice to complexities of relationships between individual actors and organisational players (Rosen, 1993). Our account has highlighted that social groups can be highly dynamic. Their identities and objectives can change significantly over time since they are partly defined by contingent linkages to other ecologies. Further, the notion of closure and stabilisation remain disputed as the interpretative flexibility of technological features can be irresolvable (Rosen, 1993). Moreover, as this case study has indicated, interpretative flexibility of features of the NetworkPlanner was correlated with the necessity of the industrial researchers to gather more resources and to sustain the survival of their technological project. Actors may on occasion seek to reverse stabilisation in order to attract new sources of funding by accommodating interests of new users.

The strong focus on context inherent in an ecological analysis addresses another limitation of the SCOT approach which is to explain why certain problems and relevant social groups come into being and why some are given preference over others (Russell, 1986). A contextualised account that pays attention to historical and ecological developments offers to explain contingencies in the yoking of actors and activities. By now it should be clear that some theories of technology are methodologically restricted in their ability to take into account details of history and context, either by design as in the case of Actor-Network Theory, or by decision as in the case of Social Construction of

Technology (SCOT) where the theorists lean on foundational ideas of ANT (see Pinch & Bijker, 1986). Therefore, these methods are of limited capacity in addressing certain social inquiries. They may be flexible and helpful tools for conducting empirical inquiry into how technological development occurs and proceeds. But issues of context and history, or more generally time and space, crucial aspects to respond to 'why' questions, are inappropriately and unsatisfactorily accounted for.

9.1.1 The ecology metaphor and a suitable framework

One of the reasons for the lack of interest in engaging with these considerations is the use of metaphors that limit the analytical gaze of theoretical frameworks. Network and system metaphors are inherently limited in their capacity to represent matters of history and context, or, time and space adequately. Both metaphors make assumptions about stability in structures in which technological developments are embedded in. For example, ANT disavows stability, but, lacking tools for discriminating between contexts in which change can or cannot be anticipated, it de facto presumes stability amongst those elements that are not included in the nexus of action that it focuses upon. Such assumptions are helpful when examining research objects that have temporally and spatially limited scope where contextual factors remain stable. However, as we argued, for the analysis of technological projects, such limitations are detrimental to the explanatory capacity of a theoretical framework. A problem is that we cannot trace the histories through which stable systems or networks are achieved. It was for this reason that an alternative metaphor was proposed to serve as the foundation for advancing the articulation of new concepts and theories on technology dynamics.

Drawing on studies of natural ecosystems, the metaphor of ecology has been adopted. It differs significantly to system and network metaphors in the appreciation of chaotic and unpredictable dynamics which emanate from interactions between neighbouring ecologies. While systems and networks tend to be conceptualised as central entities with fixed surroundings, ecologies are characterised by decentrality, openness and volatility (Abbott, 2005). Change events within an ecology do not go unnoticed but are met with counter-reactions in other ecologies. Contextual interrelations are inherent features of the ecological metaphor. Tracing changes of relationships between ecologies consequently enables tracing historical developments. In conclusion, the ecological metaphor was found more suitable as a foundation for conceptualisations of technological change when considering extended scales of time and space. Abbott's work, arising from the sociology of professions, was particularly instructive.

Some elements of our approach were anticipated by an early interpretation of the network metaphor which distinguished analytically content from context of technological development while simultaneously highlighting the inseparable nature of the relationship (Law & Callon, 1988). Although this framework articulated the contingent negotiation processes between resource-providing global actors with technology-creating local actors and although the empirical data makes extensive note of fluctuations in the constituency of the context-defining, global network, it lacked the metaphorical depth to account conceptually for these well documented ecological dynamics. The explanation of technological change was limited conceptually to events and developments occurring along a single axis of local and global actors. For this reason, we developed a new framework, which was tentatively titled 'Ecological Shaping of Technology', drawing on conceptualisations deemed in compliance with the ecological metaphor. Recent advances in the Social Learning perspective, an approach that sought to develop the first generation of theorisation in the Social Shaping of Technology tradition (Sørensen, 1996), called for more nuanced theorisations of spatial and temporal aspects of technological change. Inspired by the social learning approach, the Ecological Shaping of Technology framework was developed by combing a set of ecologically-sensitive concepts.

Using this framework to analyse the empirical data allowed getting a handle on the complexity of the case studied while taking into account conceptually historical and contextual contingencies of multiple locales. Informed by an ecological approach, the analysis tackled questions of how the technology was shaped as well as questions that explored the reasons why certain developments occurred. Instead of emphasising heroic actions of individual actors or social groups, as ANT and SCOT respectively tend to do, our framework highlighted details of dynamics in other locales which explained why an actor or group of actors were in the privileged situation of having a choice in the first place. Heroic actors deserve credits in situation where they succeed in creating choices which would not have been there without their doing. Other moments of choice, however, are not the result of their doing but emerge from events over which these actors have no immediate control. Action-oriented approaches lack the capabilities of attributing credits to important but non-agential developments. As a result, those remote developments are either ignored or credits are unproportionally given to local occurrences.

Thus, an ecological perspective that takes equally into account the content and the context of technological change promises to address fundamental conceptual weaknesses of the most prevalent theories on technology. This case study demonstrated the application of an ecological perspective in the social study of a technology. In the next section we will address how our approach and framework help in understanding and telling the long and complex story of the development and implementation of a technological artefact.

9.1.2 Ecological shaping of a strategic network planning tool

The case study of this research project was a technological artefact developed in a research department of a German car company. Its development lasted more than a decade during which it evolved from a prototypical artefact to a professional application in the strategic network planning domain. During its shaping process it was introduced to and tested in different user departments. Thanks to these engagements with users, the artefact gained in meaning as users found ways to accommodate the artefact according to their social and political interests. In these engagements, developers learned about needs and concerns of users and adapted the technology accordingly. Eventually, the resulting strategic network planning tool was successfully transferred into operational departments. This was a sketch of 'how' the social shaping process yielded the strategic network planning tool. Our intention was to go beyond a mere description of what happened. We wanted to explain 'why' the project produced not just any tool but this particular instance of a technology. Prevalent theories of technology offer frameworks and concepts to answer 'how' questions of technological development (Bijker, 2009). However, our research found that addressing context-sensitive 'why'-questions has not been a major concern of technological theorisation until recently. The Biography of Artefacts and Practice perspective is an intellectual endeavour to give further momentum to contextualised theorisation of technological change which has been previously advanced under the umbrella of social shaping and social learning theories. Since this perspective is an emerging field of study, concepts and frameworks are yet under development and few in numbers. For this reason, we developed our own framework, tentatively termed the Ecological Shaping of Technology, to contribute to the emerging field and to provide for a helpful language to describe and explain relevant technological dynamics in this case study.

We have learned that technology is the configurational product of interactions between multiple actors. Our framework adopts a multi-level view and a longitudinal understanding of technological change that traces historically these long chains of interactions. However, as we traced these prolonged innovation processes we found that they continued to be characterised by surprises and discontinuities the longer the time-frames were that we examined. Prior attributions, such as the roles and authorities of relevant players, were relativised when we extended the scope to examine dynamics beyond the immediate vicinity of the development of the artefact. Roles of individual actors that were clear in one time-frame increased in ambiguity in a larger time-frame. Equally, organisational players rose to prominence but disappeared again over the period of a decade. Varying the parameters of time and space elicited the relativity of roles and authorities as the ecological terrain, or topography, around the technological project was instable. Popular conceptualisations of heroic builders of systems or networks failed to account for these longitudinal dynamics. We conceived of the ecological framework to grasp the historically shaped and contingent topography uncovered in the analysis of the evolution of the development project. Further, we aimed to link the surrounding topographic texture to the events that took place in scope of the technological project. In this light, events are to be seen as patterned by historical developments and local circumstances where the constitutions of players, technological artefacts and contexts are subject to significant changes.

We adopted the kernel concept to add an infrastructural perspective to the framework. Through the extended time-scale of this investigation we learned that many elements in the technological project were subject of significant changes as the ecological topography surrounding the project varied over time. The concept of the kernel of a research infrastructure helps us to simultaneously to account for persistence in the instrumentalities, resources and services held together over time, and the need to allow for flexibility in the constituent elements of a research infrastructure (Ribes & Polk, 2015). It attributes to the technological project a notion of 'sameness' that runs like a common thread through space and time. Maintaining the availability of resources in order to react to and to prepare for change was a crucial activity that characterised the innovation process throughout the project. Thus, the kernel conceptualised a structural foundation on which future changes could be built on. The respective mechanisms to build upon the project's kernel was framed in terms of a promise-requirement cycle where actors enter arenas of expectations to win mandates over resources and jurisdiction over problem areas (Bakker et al., 2011). In this case study, public funding bodies sought to strengthen the promising arena of flexible manufacturing by providing research grants. These grants funded research efforts that eventually culminated in the development of the artefact. Recurrent promise-requirement cycles created temporary stabilities, or linkages, between players that allowed for social learning to happen and technological development to continue. These linkages between players are understood in terms of Abbott's (2005) conception of linked ecologies. The framework provides a specialised conceptualisation for interpreting processes in a social, decentralised and interconnected world. Actors seek to advance their agendas by forming temporary alliances in order to compete with alliances of other linked ecologies. The history of a technological development is a history of changing relationships and shifting alliances.

Since the artefact integrated methods of operations research, the developers drew on expert knowledge from academic partners to develop prototypical artefacts adapted according to the specific needs of the car company. An artefact thus crystallised from and extended the reach of an instrumentality package. Instrumentality has been defined as a method to transform nature and the notion also points to the mutual relationship between objects of science and technology (de Solla Price, 1983). An instrumentality package represents a distributed ecology of boundary objects which link multiple players through a lineage of theories, methods and artefactual instruments that are related to each other (Fujimura, 1995). Interpreting technology as a component of a wider instrumentality package helps to link technological development to a wider context, including the scientific realm, and to track its advances beyond organisational and disciplinary boundaries and across time and space. As the source of funding shifted from public grants to internal commissions from user departments the technological artefact was shaped according to increasingly specific user requirements. Internal politics encountered in user departments also influenced the shaping of the technology and strategising processes of the developing researchers. The more resources and capabilities the kernel accumulated the more opportunities for alliances and political configurations opened up. Temporary alliances with different players at different times helped the researchers to sustain their innovation project in the long run.

In the course of time virtually every element in the technological project had been affected by change at some point in time. There was no key engineer directing actions following a grand vision. There was no consistent organisational agenda or a senior manager that voiced top-down directives. There was no user who consistently voiced requests that guided the development from the beginning to the end. The innofusion of the strategic planning tool was the result of an innovation process distributed across a collective of actors who pursued their individual and their organisations' agendas. Our longitudinal analysis suggests that attributions of authority and the role to actors are relative and dependent on time and perspective. It is not recommended to make prior judgments on who the key actors are without exploring the historical and ecological context of an innovation project. The ecological metaphor allows for a broader and fairer attribution of credits for successful achievement of technological change where other theories cut the analysis short and attribute credits unproportionally to a fewer number of people in senior positions. Particularly in regards of current trends of popularising entrepreneurship, where successful entrepreneurs tend to be stylised as role models for young generations, we find it is essential to offer a perspective that foregrounds contextual details which often are either deliberately neglected for journalistic and narrative purposes, or omitted due to lack of appreciation.

9.1.3 An ecological perspective on innofusion

Our ecological approach to the analysis of an innovation project provided in-depth insights into the interactions of users, producers and a range of other intermediaries. We shed light on recurring cycles of interaction at different locales as the artefact was developed and appropriated to fit particular social settings. Interactions were characterised by struggles of learning about user requirements and of configuring the artefact correspondingly to solve problems in the practice of strategic planning. This process of learning-by-struggling is at the core of the innofusion model (Fleck, 1988). It describes an evolutionary process of development

> "[...] in which environmental contingencies are explicitly built in at each stage of variation." (Fleck, 1988, p. 22)

Originally emerging from studies of robotics, varying instances of the innofusion process have recently been articulated in a number of studies. For example, the notion of dispersed-user innovation has been conceptualised to describe an innofusion process where conventional vehicle manufacturers fail to conquer a market that is dominated by user-made technologies (Hyysalo & Usenyuk, 2015). The extent of configurability of a technical artefact and a dynamic political environment has also been well documented by the analysis the development and implementation of an Indian health technology (Sahay et al., 2009). A study that is close to the remit of our work analysed shifting meanings of innovativeness, i.e. the perceived value of novelty, and technological potentials over multiple decades (Höyssä & Hyysalo, 2009). This study elaborates how a technological innovation, a 'liquid microprocessor', struggled to materialise its disruptive potential in the industrial context. Although its innovativeness was widely acknowledged by different players, otherwise the development would not have survived over such an extended period of time, no breakthrough moment occurred. Both the technology and its configuration with social contexts changed significantly in shape over time. The study concludes with coining the notion of 'the fog of innovation' to emphasise the limitedness of managing technological change when it comes to understanding innovativeness internally and presenting it externally to others. Similarly, our study analysed how a technological innovation came about and transformed over time as it crossed paths with a variety of players. However, our ecological perspective narrowed our attention to changing nature and shape of relationships among these different social entities. Our analysis draws on the combination of concepts on expectation dynamics and the configuration of ecologies. Thus, it allows us to articulate a contribution regarding an ecological perspective on the innofusion process.

The discussion chapter reflected how we distinguished the contents of technological development from its surrounding context which, in our study, is embodied by the wider ecology of ecologies contiguous to the organisation of the artefact concerned. This interpretation of an interactive social world enabled a focus on the promissory work at the fringes of social entities. There, actors entered arenas to engage in promise-requirement cycles with actors from other ecologies. In exchange for promises, enactors were granted mandates and resources to engage with exploratory or developmental activities. Our case study indicated how under particular circumstances this process can escape organisational and disciplinary boundaries to reach out to contiguous ecologies in social proximity to an ongoing enterprise. Each completion of a promise-requirement cycle, which is marked by an enactor delivering an acceptable outcome to the respective selector, brings the two ecologies closer together and opens the opportunity to utter new promises. This process of bringing together of social entities has been termed yoking in an institutional context (Abbott, 1995). Taking into account expectation dynamics, our re-interpretation of yoking emphasises the local and spatial specificity of this process. It allows a finer examination of interactions between actors of different ecologies. In particular, it points to how the innofusion process can be dispersed across multiple locales simultaneously. Because of the 'fog of innovation' (Höyssä & Hyysalo, 2009), enactors cannot not predict what variation of technology or what sociotechnical configuration will be successful. Therefore, they constantly search for opportunities to enter new promising arenas to anchor their artefact to another ecology in order to sustain their enterprise by gaining financial, political or other types of currencies. This temporal ecological anchoring, made possible by partial realisation of expectations, sustains the piecemeal building of the artefact. The ecological approach underscores the temporality of this strategy since political circumstances can shift both ways as our and other case studies indicate (e.g. Sahay et al., 2009).

Technological development is often presented as a linear achievement. At the launch event of the NetworkPlanner the audience was presented a linear account of a success story that transitioned linearly from research and development to practice. The analysis of our data sketched a different picture of the various biographies of the artefact. Innovation is not a linear process and neither was the development and implementation of the NetworkPlanner. It is a repetitive cycle of learning-by-struggling which oscillates between development and use (Fleck, 1988). However, it is not limited to a single user-producer configuration. Our contribution emphasises that the innofusion process transcends organisational and disciplinary boundaries as actors creatively plot diverse strategies depending on the opportunities patterned by the current ecological landscape. By yoking together ecologies, stronger relationships are built between users and producers as the artefact is configured to match specific requirements of the user setting. The notion of innofusion was conceptualised to counter the perception that technological development is a linear process (Fleck, 1988). It introduced the differentiated understanding of technology as being configurational to argue against the diffusion theoretical account that knowledge about an innovation moves only in one direction.

Rather, innofusion underlines the bi-directionality of technological development. The ecological approach continues this line of argument. We argue that innofusion can also go side-ways and thus accounts for moments of discontinuity along established paths.

9.2 A biographical perspective on an innovation project

The ecological framework was developed because the biographical perspective does not provide a strong programmatic guidance yet. The framework allowed us the accomplish our goal to tell the long and complex story of the NetworkPlanner. In this course we gained further insights into innofusion processes. We also gained further understanding about the biography perspective. In this section we reflect on these two accomplishments and outline the empirical and methodological contribution to knowledge that our study derived. In the first part of this section we will highlight how this study confronted us with a complex set of methodological and conceptual problems which eventually influenced our framework development and analysis. The second part will address in more detail how we applied a particular methodological perspective to support our approach and how our work contributes to generate further insights into that perspective.

9.2.1 Analysing and narrating a long and complex technological project

Our study unfolded to become an empirical investigation into the crystallisation process of a technological artefact. Therefore, we made decisions to privilege the examination of some phenomena over others. For example, constructing the analytical framework we chose to foreground how, as time moved on, changes in linkages between different organisational entities influenced qualitative interactions between individuals and, as a consequence, the shape of the technology concerned. Other choices about the research focus or configuration of the framework would have resulted in a different analytical approach. For instance, the viewpoint of this study might not have been on the technological project but on a different aspect or perhaps on a different level. Akera (2007) elaborated a layered representation of how knowledge can be connected across multiple levels and ecologies. Drawing on this representation, this study could have focused, for example, on how the application of OR influenced knowledge and skill sets of actors involved. This could have led to a study analysing how the increasing utilisation of OR methods in workplaces reshaped the role of strategic planners. Our data indicated that the job specification of strategic planners began to change due to the adoption of the artefact. The profession of industrial engineers appeared to get to upper hand in the strategic planning domain at the expense of the traditionally strong profession of mechanical engineers. There are various opportunities to change the configuration of the research design to examine different aspects of the same social phenomena.

However, we decided to examine the historically contingent and contextually shaped texture of the innovation project. In line with this objective, we identified a certain set of research problems and scoped this research project accordingly. Consequently, we faced analytical challenges as the research undertaking unfolded. The data collection resulted in a contextually and historically-rich set of data which was, we argue, inadequately accounted for by prevalent theories and frameworks of technology. We found that social analyses of comparably complex technological projects neglected influences of historical and contextual linkages in their analytical frameworks (e.g. Callon & Law, 1988; Latour, 1996). This prompted the development of a new analytical framework that better distinguished agential and structural influences in the social shaping process. The development of the framework proceeded in tandem with the analysis of the data. However, it was not a linear development process but an experimental process of innofusion where advances occurred iteratively. This study is the synthesis of an ecological analysis and the narration of empirical findings that covered a period of more than decade and that were patterned by historical dynamics dating back another two decades.

The final outcome of our research design is not only the thick description of the biography of a technological artefact – usually the primary objective of an actor-centric account – but also the broader explanation of its coming about. This narrative result marks the first contribution to knowledge of this study that we want to emphasise. Due to the prolonged shaping of the technology and the complete turnover of people involved in its development and implementation, no other single individual had an extensive overview of all relevant events and development else than the author of this thesis. Therefore, an important contribution to knowledge is the comprehensive report of the empirical data on the social shaping and social learning processes rendering the biography of the technology concerned. This contribution is valuable not only for other researchers but also for practitioners involved in processes of social shaping of technology. Especially practitioners in the operations research domain may be interested in learning about the details of the development process. Appreciating how context and history influence a technological development could help understanding better why local difficulties emerge in implementation stages of other operations research-based solutions. Equally, users of such technologies could learn to understand that difficulties during episodes of implementation and use can be rooted in a technological artefact's prior configuration to a different social setting.

To summarise, we argue that the consideration of an extended biographical and ecological account of technological development can help in improving our understanding about the general technology/society relationship. However, in order to advance a historically and contextually more nuanced perspective on technological change there are methodological challenges to be faced. A challenge that we addressed was to test and to extend methods that support nuanced examinations. The 'Biography of Artefacts and Practices' perspective proposes an integrated approach that incorporates those ecological principles that we found important. The next section will address how we made use of this perspective in our study and how this study contributes to its further development.

9.2.2 Extending the 'Biography of Artefact and Practices' perspective

The intention to conduct a longitudinal study of the development, implementation and use of a technology carries demanding methodological implications. A technology comes into existence through interactions and negotiations among a wider set of players. Innovation processes are characterised by disturbances and discontinuities that complicate any technological development. We adopted the 'Biography of Artefact and Practices' perspective to capture these contingencies and continuities of technology dynamics and their unfolding over time. This perspective outlines a methodological approach that does justice to the multiple dimensions of technological change. Its proponents argue for social analysts of technology to consider that events and developments take place in multiple locales and practices, and may advance in different speeds over varying timescales (Pollock & Williams, 2009; Hyysalo, 2004, 2010).

There are many studies available that deal with longitudinal analyses of organisations (e.g. Pettigrew, 1985) or technology (e.g. Latour, 1996). However, these did not provide an adequate methodological template or guide for our purposes. In light of this shortfall of methodological perspectives, the biography approach is yet an emerging perspective where there are not many studies available to turn to for guidance. Hyysalo (2004) largely paved the way for framing the biographical approach in scope of a doctoral thesis which serves as a guideline for this study. Our study, however, addressed some issues that we found required further attention and that posed interesting questions. Addressing these challenges enabled us to derive findings that could be helpful in guiding further biographical studies, especially PhD theses.

The most significant consequence of applying a biographical perspective in this study was the limitation of resources and, most of all, time. Since doing a PhD is an educational exercise to acquire an academic qualification, its scope to conduct research is limited to a few years only. Although this timeframe can be extended it usually does not last long enough to follow the entire lifecycle of a complex technology. The way how we designed and implemented a research strategy to accommodate the biographical approach within this limited time period is, therefore, a helpful template for other students to plan their research projects. In particular, this study is characterised by its longitudinal design that takes into account both multiple locales and multiple perspectives. Our broadly scoped data collection process entailed a certain level of redundancy in enquiry. This enabled a richer and more robust account that was better able to pick up unexpected influences. Exploring multiple locales and adopting multiple perspectives of different involved actors, not just those of elite actors, produced a rich understanding of a broad range of processes and events that contributed to sustaining the technological project.

A particular contribution to the biography of artefact perspective emerged from our explicit interest in exploring the themes of history and context. Especially the focus on historical dynamics of technological development pushed the perspective into a direction, i.e. further back in time, which has not been given extensive consideration by the authors developing the perspective. Although Pollock and Williams (2009) propose the use of historical methods within a set of mixed methods, it is not further conceptualised how this should be applied in reference to a technology concerned. Our approach framed the use of archival and other historical data in relation to relevant dynamics in the development of the technology studied. In particular, the development of our framework foregrounds the notion of relating findings of a historical analysis with findings derived from ethnographic data. In general, the conceptual framework designed to make sense of this rich but mixed set of data is the core contribution of this study. It enabled us to produce a narrative that pulls together a corporate historical analysis with an account of the prolonged development of a technological project.

As a result, we successfully developed a framework to support the application of the Biography of Artefacts and Practices perspective to a special form of innovation, a project within a single large organisation with a long historical track record. The first biographical study of a single technological artefact was the examination of the development and implementation of a health and social care technology (Hyysalo, 2004). This study was scoped around a single organisation that was lined up to produce this particular type of product. Thus, the historical record of that organisational context was relatively short. We do not aim to argue that other biographical studies neglect the historical perspective. In contrary, other authors of the biographical perspective pay extensive attention to preceding historical, organisational and technological developments that conditioned the shaping of artefacts and practices. The difference in our approach is that we do not only aim to pay attention to historical precursors but to take them actively into account in our conceptualisation of social processes of technological change. Our case study explored a technological project that was embedded within a single large organisation with a long and intricate history. Historical occurrences have given rise to a unique corporate topography of organisational and political gulfs which required the project's members to strategise carefully about what alliances to forge and which to avoid. Our interpretation of the biographical perspective therefore is distinguished by the inclusion of histories and contexts of not just the technological project but also that of the social organisation of actors and resources involved in the development and the partnering ecologies which made the success of the technology possible. This is why the title of our thesis highlights the multitude of biographies involved in an innovation project. We argue, it is only the application of an extended biographical perspective, which integrates a detailed understanding of micro-level developments with long-term dynamics, that enables us to comprehensively understand how the social shaping of a technology correlates with the continuous process of social learning about its identity and meaning in a historically-shaped and contextualised environment.

9.3 Reflection on the research journey

We continue with a reflection upon the research journey this study has taken over the course of five years, a path patterned by difficulties in its early episodes. Just as an innovation project is sensitive to dynamics in its surroundings and that are rooted in past events, this PhD enquiry has been shaping and was shaped by its context. By reflecting on these influences, we can shed light on how the conditions under which we designed the research strategy were constrained externally and how this affected the overall outcome of the study. The research design was emergent in the sense that we, like our research object, depended on opportunities to forge alliances with various players at different moments in time to advance the research. Particularly in the early stage of this PhD, unexpected events significantly influenced the range of options that were available in later episodes of the research project.

9.3.1 Complications in the early stages of the research journey

The lack of a strong and coherent research strategy from the outset is usually considered a considerable weakness in light of a temporally limited undertaking of a doctoral research project. In the first two years this research undertaking struggled to identify a clear research focus. Shifts in the configuration of the supervisory team and the transfer to a new research institution took its toll. Moving to another research environment involved a move between analytical traditions with implications for the research design. A consequence of the early lack of coherence in the research design was the somewhat extensive, broadly-scoped and open-ended approach to data collection. In respect of the final outcome this weakness turned out to be an empirical cornerstone of this thesis. As a result of taking a broad perspective on the technology, actors and dynamics involved, a rich set of data had been accumulated that documented events and developments in relation to both the contents and the context of the technological project.

The prolonged data collection stage and the researcher's intimate involvement in the project under study enabled us to gain a level of insights and understanding that would not have been achievable had the data collection stage been shorter. A shorter duration would have yielded a more limited perspective on the state of the project, but, arguably, would have resembled more of a snapshot study of a few episodes in the innofusion of the artefact. With the extended data collection period, it was possible to participate in a wider range of activities and to observe multiple instances of similar processes under different conditions. For example, about a year after starting the collaboration we were able to arrange for extended placements in the three user department thanks to strong interpersonal relations developed during the prolonged exposure to project participants.

In hindsight the early difficulties on defining a specific research focus unintentionally contributed to establishing a broad and in-depth understanding of the technological project. This encompassed both extended duration and multiple settings within the firm. A more specific framing of the research would most likely have resulted in a more selective focus and probably a shorter period of data collection. However, in the early episodes of the data analysis, this rich set of data was problematic as the lack of a precise research focus complicated the sense-making process. Identifying a clear research focus and articulating a set of research questions was a procedural achievement that stretched over a long period of time including later stages of the study. Hence, the research focus was reshaped in tandem with progress in analysing the data.

Arguably, a less ambitious project with a research strategy that was demarcated more precisely from the outset would have yielded a compacter thesis. However, we feel, a compacter thesis would not have done justice to the richness of the data collected. Although this extended thesis, probably to the dismay of the reader, is characterised by the level of detail and temporal and spatial breadth, it produced insightful and comprehensive contributions to knowledge that had unlikely been achieved had the research strategy worked out in an orderly manner. This thesis is the result of a long process of strategising in which opportunities were taken, if available, and in which risks were circumnavigated, if possible. The final outcome, thus, was unpredictable from the beginning. An interesting insight emerging from this, then, is to understand how the troublesome research journey shaped the contents of this research. We will look at this in the following section.

9.3.2 Emergent design of a project-level perspective

The shaping of our research agenda was conditioned by external events but also by deliberate choices we have made. In light of difficulties during early data collection efforts we found that the best opportunity to sustain the availability of resources to fund this study was to align our research agenda with the agenda of the industrial research team that we gained access to. This contextual circumstance, i.e. an opportunity to link up with a contiguous ecology in favour of our undertaking, was among the most significant reasons why the research focus diverged from initial research interests. As a result, the research focus and data collection strategy were patterned by the decision to scope this study in respect of a particular technological development within a certain organisational context. In more general terms, the design of any research project results in the construction a particular viewpoint (Pollock & Williams, 2009). The concept of agora, which is the Greek term for "market" or "marketplace", has been introduced to conceptualise broadly the social space where all producers and consumers of technology interact (Kaniadakis, 2006). A market player can be a producer and consumer at the same time: its role is determined by its interaction with other players. A viewpoint makes a slice of the agora and highlights a certain set of relationships between players. We acknowledge that this research delineates a particular viewpoint, a project-level perspective, from which we examine this case study and draw our conclusions.

When building the conceptual framework, the project-level approach influenced our preferences in selecting suitable concepts to make sense of data. The multi-sited character of this study, i.e. the examination of practices and dynamics across multiple locales, suggested pursuing theorisation that foregrounded both the diversity of local practices and commonality across locales. This led our research journey to implicitly adopt a research strategy that resulted in the conceptualisation of what can be characterised as the middle range of theory. Middle range theory reconciles between micro-theorisation of day-to-day observations and all-encompassing, systematic theories of global phenomena (Merton, 1967). Multi-sited ethnography has been described as a means to address the divide between micro-level analyses, such as single-sited laboratory studies, and social theories of the macro-scale (Hine, 2007). Applying methods of multi-sited ethnography we examined how local practices changed over time to adapt to shifting conditions in surrounding and linked ecologies. Equally, we examined how the innofusion process of the technological artefact provoked changes in the fabrics of alliances between ecologies.

To conclude, the orientation of theoretical and conceptual findings to contribute to the population of middle range theorisation is understood, admittedly, as a result of an initially unspecific research strategy. Had the research strategy been designed more rigidly and had it been backed by a consistent institutional setting and more secure funding conditions, the outcome would have likely been more compact and oriented towards a more specific goal. However, despite imponderables complicating the research journey, the outcome of this study offers a case to argue generally for more flexible and open-ended research strategies. Particularly in scope of a biographical study of technology, where in the beginning it can be unclear how far a technological development stretches spatially and temporally, such research strategies can be advantageous in avoiding methodological and epistemological pitfalls that are due to limiting assumptions about the boundaries of innovation processes. We intend not to propagate abandoning the design of clear research strategies but want to highlight that as much as innovation is an unpredictable endeavour, a research strategy should not strive to anticipate and solve all problems in advance but remain open and flexible to change in terms of unexpected findings or events.

9.4 Limitations of research

Facing practical and theoretical concerns in different episodes of our journey this research study emerged from applying a mix of strategies ranging from careful strategic planning to taking advantage of opportunities appearing along the path. Planfully applying techniques and methods of data collection and analysis helped in complying with generally accepted principles to uphold expectations of objectivity and critical thinking. However, we can identify influences that limited the outcomes of this research by design. These limitations are due to our particular circumstances and also decisions we had to make at different times to advance our work. Major limitations emanated from the decision to take a case study approach. However, another limitation we have identified results from the emergent nature of the development of the analytical framework. We begin with exploring the methodological limitations of this study.

Our study benefitted greatly from being intensively exposed to the case study organisation and the innovation process examined. We have been deeply involved in the technological project and innovation activities surrounding the development and implementation of the technological artefact. Interacting with industrial researchers and users involved over an extended period of time resulted in a social and cultural closeness that privileged us to gain insights and that would probably not have been possible had we undertaken a shorter data collection approach. However, while being among the strongest qualities of this study, it is at the same time potentially its most significant limitation. Weaknesses of ethnographic data collection instruments, such as biases and false accounts by interviewees, can be mitigated by the use of triangulation to generate a richer and more valid picture (Denzin, 1994). However, it does not avert the weaknesses entailed by being "native" (Alvesson, 2003). Having worked with the research department and some of the individuals involved prior to the study introduced a strong sense of familiarity and cultural bias. Emotional, cultural and professional attachment makes it more difficult for a researcher to break out from taken-for-granted assumptions and ideas which can prevent from addressing questions uncomfortable for both the interviewee as well as the interviewer. Alvesson (2003) introduced the term self-ethnography to circumscribe limitations of interview-based qualitative research and ethnographies. Much like some features of this study, a self-ethnography is characterised by ease of access to the research object and its participants who regard the researcher more or less on equal terms with other participants. As a consequence, our interpretation was necessarily biased in the sense of lacking liberation from taken-for-granted assumptions. However, no research can be fully liberated from biases of socially shared frameworks (Alvesson, 2003). Our awareness of this limitation was one way to address this general weakness in the process of analysing and writing up this research text. What contributed further to an increased awareness and consideration of cultural bias was the fact that this study has been conducted in a research institution based in a different country than the case study organisation. Discussions with supervisors from a different cultural background than myself helped in eliciting differences that might have gone unnoticed otherwise. Finally, the development of an analytical framework helped us examining the data from a stranger's point of view. Adhering to the framework during analysis allowed us to create some distance from our biased experience as participant observer in the project under investigation. Nonetheless, the narrative produced is an interpretative outcome of the author of this study. It is most likely that a researcher from another background would produce a narrative that would diverge in some details from our account.

Further concerns of methodological limitations could be raised by addressing the single case study methodology applied in this research. Although some aspects were covered that addressed external organisations, most activities examined in course of the thesis took place within the confines of a single German company. Thus, the study was geographically and culturally limited. These methodological features potentially raise the questions about the generalisability of theoretical and conceptual findings to other organisational and cultural settings. In general, the case study approach has been perceived sceptically in regards of its validity to making generalisations, mostly by critics who themselves operate in logics of statistical inference (Blaikie, 2009). However, other forms of logics have been proposed for case study methodology including analytic generalisation (Yin, 2003; Blaikie, 2009). Analytic generalisation allows to link between case studies and, thus, supports theory development and testing. Our approach followed and contributed to the tradition of theorisation of the social shaping of technology. Consequently, we have drawn on a robust set of theoretical principles which have been applied and tested in numerous other studies examining technological projects in a variety of national and cultural settings. In that sense, we have applied methods of logical inference to increase replicability and validity of our approach by emphasising linkages to other theoretical and conceptual accounts (Mitchell, 2006). In conclusion, we argue that our findings offer valid theoretical contributions that can be generalised to other cases of technological developments which have similar empirical features.

9.5 Future studies

Different technologies emerge under different social structures and circumstances. Organisations with a competitive work environment exert different structural and circumstantial influences than organisations with a collaborative work environment. The historically-extended biographical and ecological perspective attempted to capture the richness of such contextual and structural influences which play important roles in patterning the development of technological projects which often are beyond the control of the designers and users of the artefact. For example, the NetworkPlanner emerged in a context where the senior management of the research group attempted to implement conditions of a partial internal market to orient research activities more closely to meeting business needs. This had significant influences on the strategies that the researchers applied. Similar corporate initiatives to set up market-like behaviour within corporate research infrastructures have been made in other private organisations (Gallacher, 2004). Our empirical analysis foregrounded how such contextual dynamics interrelated with 'contentual' dynamics over an extended period of time.

In industrial contexts, although this is similar in other contexts, the large majority of studies on technology are concerned with investigating the process of technology development and adoption and, eventually, the unfolding of consequences to society or a narrower social space. The dominating quest for technologists and practitioners, therefore, is "How is technology made? That is the question!" as the title of Bijker's (2009) contribution to a research journal proclaimed. We agree to the relevance of the 'how' question but we go further by claiming that we equally require a better understanding of why technology is developed. Although 'why' questions generally pose interesting challenges for philosophical discussions on technology, we argue that understanding why technologies are developed has strong practical value as it is essential to increase the effectiveness and success rate of technological innovation. A technology can be developed by different players who are interlinked with different ecologies and thus motivated by different agendas. For example, a competitor of CarCo developed a similar information system to support its strategic network planning department (Fleischmann et al., 2006). Although Fleischmann et al. (2006) acknowledge the research by Jordan and Graves (1995), a contribution that strongly shaped the methodological approach taken by the developers of the NetworkPlanner, the authors rejected the method without providing the rationale for their decision. In this case, a different set of contextual and circumstantial influences produced a different decision. Therefore, an interesting direction for further studies would be to broaden the scope to other similar information systems. A comparative study of biographies of strategic network planning systems, for example, CarCo's NetworkPlanner and the information system reported in Fleischmann et al. (2006), poses an interesting research challenge which promises valuable insights into how different structural properties enable and constrain the development of the family of technology. A major challenge to this undertaking, however, would be the uncertainty of getting access and enough exposure to collect sufficient data to conduct a biographical study of another strategic network planning tool since this sort of privilege was probably the most relevant strategic advantage of this study.

Another direction of future studies can be identified in exploring how the evolution of the instrumentality package, which in our case study is the application of operations research (OR) methods in context of strategic network planning, continued to unfold to other locales. We see at least two opportunities where the development of instrumentalities, i.e. the development of methods to transform nature, branched into new research objects. First, the implementation of the generic version of the NetworkPlanner enabled users to engage with planning problems that conventional methods could not address adequately. For instance, a new doctoral researcher was recruited by a planning department to explore such a new research object. Her research undertaking applied the artefact to redefine an existing problem, in this case the analysis of implications of various free trade agreements on CarCo's production networks, according to the terms of the NetworkPlanner. The NetworkPlanner potentially becomes the boundary object for a new alliance of ecologies which deals with matters related to free trade agreements including, for example, planners and regulators who monitor that CarCo meets relevant regulatory requirements and regional production quotas. Tracing this branch allows learning about how the instance of a new but specific artefact informs the redefinition of previously anomalous phenomena into doable problems. Second, the interaction between the industrial researchers with their academic counterparts in course of the LICOPRO project also posed an episode where the work on instrumentalities opened an opportunity to carry on researching the utilisation of OR methods in other domains. Informed by insights gained from working with an industry partner, the academic research partners continued elaborating theories and methods that are applicable in other domains such as, for example, the domain of logistics. Basically, these two opportunities differ in the locales which lend themselves for further studies. While the first opportunity points to expand investigation into the industrial context, the second encourages broadening the investigation by exploring the academic setting of the instrumentality package concerned. Exploring these and other potential linkages promises to improve the understanding of how instrumentalities, the means and ends of science and technology, evolve by oscillating between episodes of concretisation and abstraction.

Finally, we address a potential conceptual opportunity to improve our framework. The development of the analytical framework was informed by a focused review of literature on technology and innovation studies. For this reason we found the Biography of Artefact and Practice perspective to be most applicable for our purposes. But we are aware of other perspectives that seem to do similar work. One such perspective is the social worlds framework (Clarke & Star, 2008). Similar to the Ecological Shaping of Technology framework, the social worlds framework is a theory/methods package comprising a set of analytical and methodological concepts of which some are represented in our framework. Inherent to the framework is the belief that social actions exist in a space populated by complex social actors with their own perspectives, commitments and agendas. Making sense of and finding social order in these complex interrelations is an objective that both the social worlds framework and the ecological shaping framework have in common. However, due to the former framework's roots in grounded theory and symbolic interactionism (Clarke & Star, 2008), these two frameworks diverge in their ontological and methodological assumptions. The social worlds framework foregrounds social action and seeks to map current concerns through situational analyses (Clarke, 2005). Articulating the differences and similarities between the Ecological Shaping of Technology framework and the social worlds framework could be a useful future direction.

Above we have pointed a few opportunities how to carry on ecological analyses of technological change. There are promising venues and good reasons to continue tracing the evolving development of social processes and instrumentalities in the domain of operations research. Methods of operations research co-evolve with the increasing computational capacities of information technologies. As this case study has reported, highly-skilled operations research analysts successfully claim new grounds in areas traditionally dominated by other professions. We expect that operations research researchers and practitioners will continue in forming strong alliances both in external and internal ecologies as well as across sectors. The thorough social study of the empirical data shed light on how these dynamics play out in a specific organisational context. It can be a helpful starting point for other empirical cases to draw on our insights. Building on Hyysalo's (2004) first doctoral venture into the biographical study of an innovation project, the methodological approach outlined in this study provides a promising framework to inform the design of follow-up studies.

9.6 Closing remarks

Much like an innovation project, this study was shaped by the topography of the landscape and timescape (Gaddis, 2002) that we passed through during our research journey. Reflecting on major influences along this path and highlighting that we attribute significance to specific moments in time retrospectively, much in line with a kairotic representation of our timeline (Czarniawska, 2004b), we understand that a few events were central in shaping the focus of this study. In the first chapter we introduced an anecdote about speaking to the individual who was pivotal in developing the first prototype of the NetworkPlanner. He challenged us with the statement that he could write up the biography of the artefact on a weekend. As a result of this conversation we decided to place the emphasis of our study on examining those influences that he was not aware of due to his limited viewpoint as an engineer of the artefact. Drawing on Gaddis' (2002) reductive interpretation of time, where structural residues are the only remaining witnesses of past processes, we set out to reconstruct past processes to explore the structures that gave life to the technological development. This study found that there was no single individual that can be attributed as the mother or father of the NetworkPlanner. We found that knowledge about the origins of contributing structures, the residues of past processes, was limited. As a result the attribution of due credits was skewed. Interestingly, accurate knowledge about historical and contextual facts was not a prerequisite to accomplish the technological development. We find it is this negligence or even ignorance over the relevance of ecological influences in past processes that contribute to misleading representations and narratives of technological change. It is understood that the ending, or rather the representative of a winning party, defines its own beginning (Czarniawaska, 2004b). Our study was a step towards giving a voice to those who are not immediately associated with the winning party, i.e. the wider collective of actors and players involved in the development, implementation and use of a technology that is embedded in a specific organisational setting. We strongly believe that the ecological and biographical approach can contribute to a more balanced perspective on how past processes continue to predetermine the choices available to us in the present. We hope that this case study will be soon only one among many that combine the historical method with social analyses to draw attention to structures that are easily overlooked otherwise. In that sense, we leave the final words to the historian Timothy Snyder (2015) who in his sociohistorical analysis of climate change remarks:

> "When we lack a sense of past and future, the present feels like a shaky platform, an uncertain basis for action." (Snyder, 2015)

10 Appendix A – Timeline spreadsheet

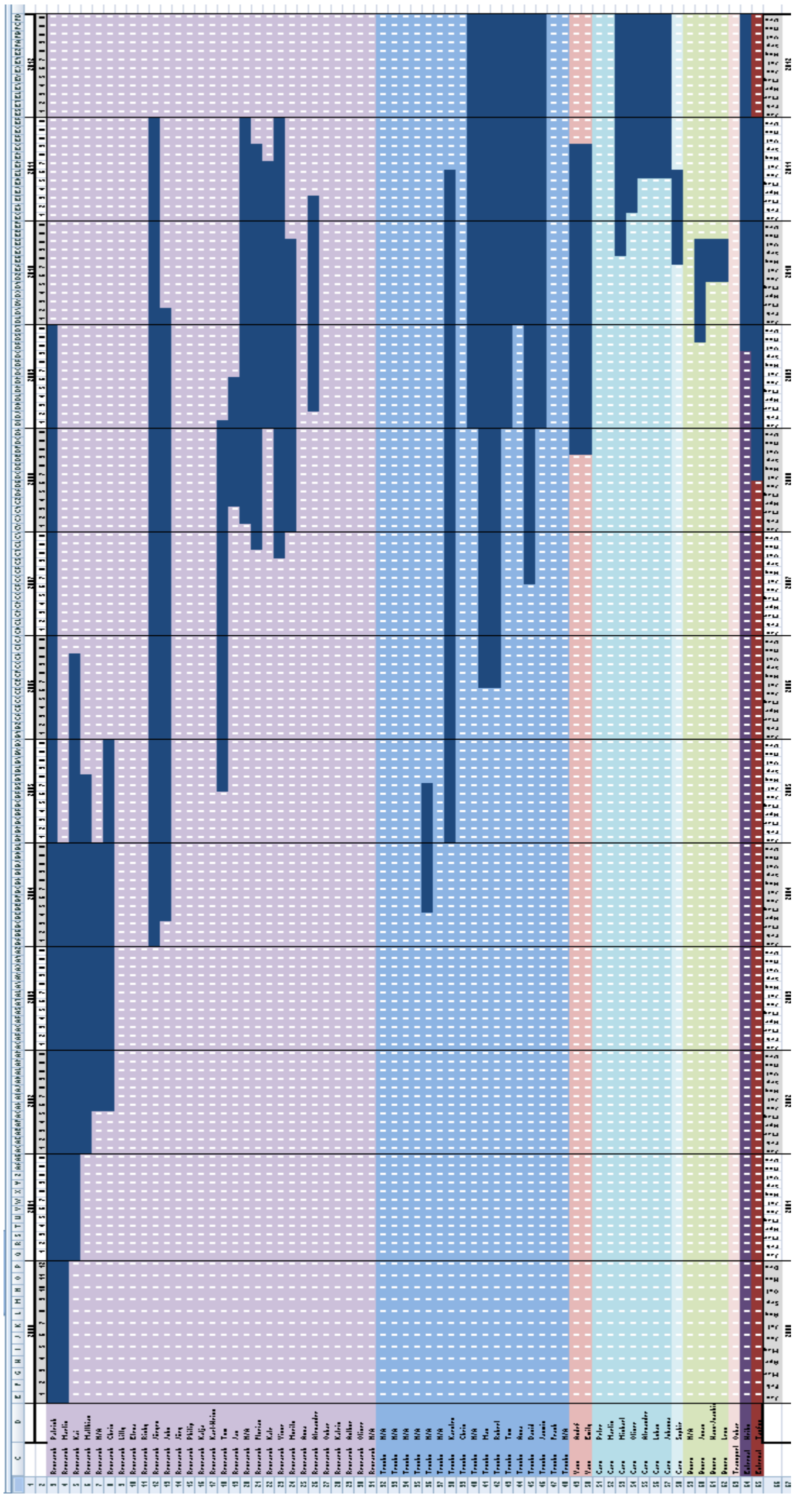

Figure 20 Timeline spreadsheet of people involved in the technological project

11 Appendix B – Quantitative analysis I

Figure 21 Visualisation of people involved in different years (Manual configuration of multiple screenshots, application used for visualisation: Gephi)

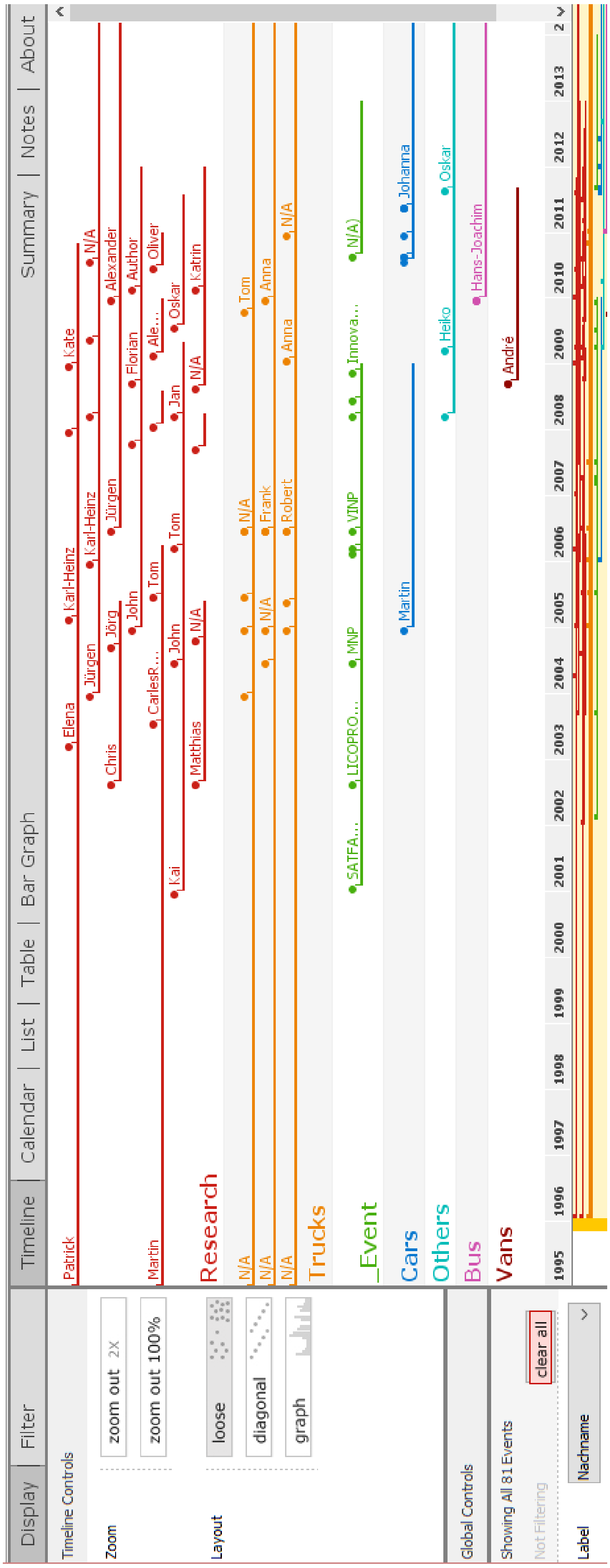

Figure 22 Visualisation of all people involved in the technological project (application used for visualisation: TimeFlow)

12 Appendix C – Quantitative analysis II

Table 3 Overview of individuals involved (in average, by year and division)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Research	2	3	5	6	8	6	5	4	9	9	7	5	0
Trucks	0	0	0	0	1	2	2	4	4	7	8	8	7
Vans	0	0	0	0	0	0	0	0	1	2	2	2	0
Cars	0	0	0	0	0	0	0	0	0	0	1	4	5
Buses	0	0	0	0	0	0	0	0	0	0	2	0	0

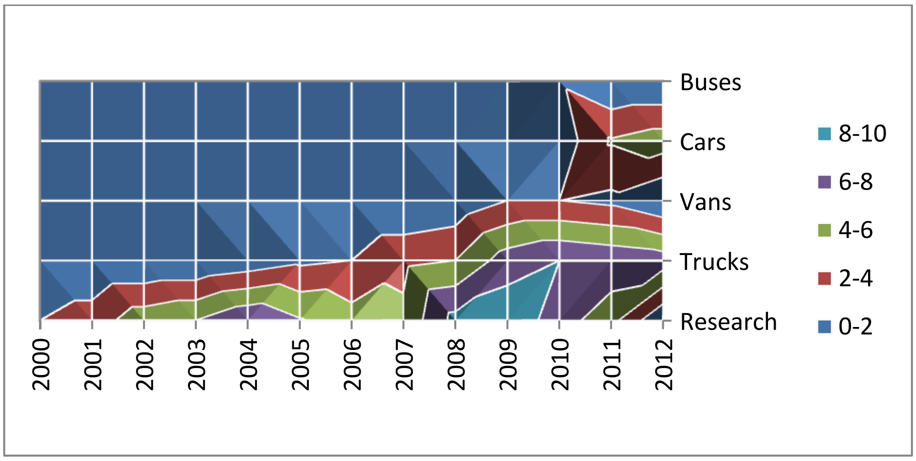

Figure 23 Mapping of people involved (per division)

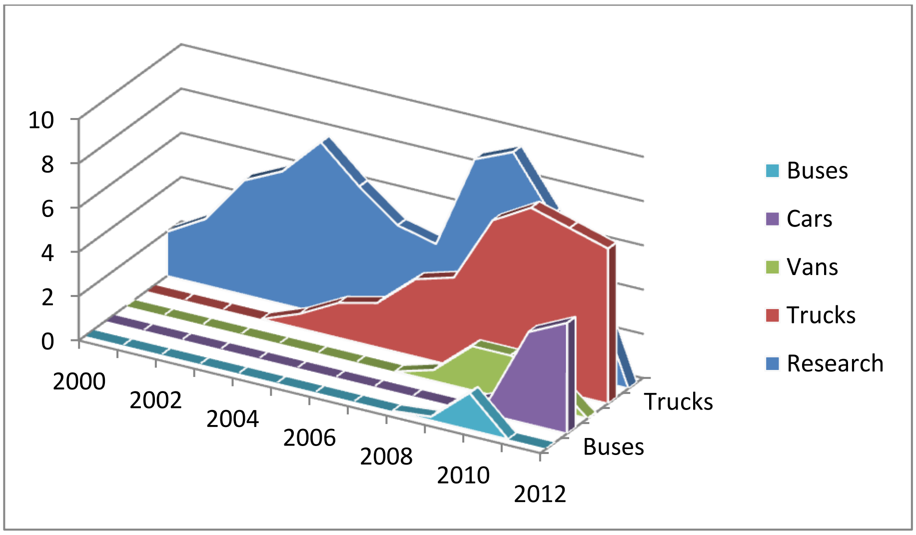

Figure 24 Alternative visualisation of people involved (per division)

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